NATURE AND SYSTEM 6 (1984), 195-215.

Wholes, Parts, and Laws of Motion

R. F. Hassing

PREFACE

There are deservedly well-known studies on the laws of motion in Newton and Descartes. The works of Boas, Jammer, Hall, Cohen, Koyre, Gabbey, and Westfall are among the most noteworthy.[1] All have provided carefully crafted and highly instructive accounts of the structure and development of the physical thought of Newton and Descartes. Each has proceeded within, and contributed to, the history of science or the philosophy of science. Yet none has addressed the question of the relation of living beings to the laws of motion, a concern more characteristic of what could be called philosophy of nature.[2] Now the meaning of 'living being' must involve at least this: a special relation of parts and whole, in which the former are what they are only in terms of, and are thus not neutral to, the latter.[3] This of course appears to be fundamentally incompatible with the tradition of physics deriving from Newton. Is it really incompatible? The present investigation seeks to clarify this issue by dispelling certain mistaken or incomplete conceptions of the philosophical implications of physics.

I. TWO LAWS OF INERTIA

1.1 *Introduction.* The aim of Part I of this paper is to show that, contrary to most current interpretations, there is no one law of inertia.[4] Rather, Newton's first law is distinct from Descartes' in its implications for our understanding of nature. The crux of the argument is this: The law of inertia forbids self-initiated motion; no body at rest can put itself in motion.[5] This stands in obvious contradiction with the phenomena of living beings initiating their own local motion. The law of inertia thus cannot stand on its own. To save it from the phenomena, it must be supplemented by other principles. It, therefore, becomes one element in a system of concepts forming an explanatory whole larger than the law of inertia by itself, and in light of which the law must be interpreted. This explanatory whole is different in Descartes' physics than in Newton's. Specifically, Newton's first law is linked to the other two universal laws of motion. We shall see that the third law, the law of action and reaction, removes the contradiction between living beings and the first law. Although they are compatible with a corpuscular account of matter, these three laws of motion do not logically entail such an account. By themselves, they are neutral with respect to the distinction, made within ordinary experience, between living and non-living. By themselves, they are thus compatible with substantial form or, more generally, with holism, in living beings.[6] In contrast, Descartes' law of inertia lacks an accompanying law of action and reaction, and is necessarily joined to corpuscularism. The contradiction with certain sensible wholes, i.e., animals, is thus removed by recourse to subsensible parts. The resulting theory is incompatible with any holistic principle. It follows that, concerning the relation of wholes and parts, the confrontation between the pre-modern understanding of nature and our own post-Newtonian, and not Cartesian, tradition of physics is more complex than is often thought to be the case. This is developed in Part II of this paper.

1.2 *The Animals versus the Laws of Inertia.* Descartes' first law of nature, as presented in *Le Monde,* is:

> . . . each particular part of matter continues always to be in the same state unless collision with others constrains it to change that state. This is to say, if the part has some size, it will never become smaller unless others divide it; if it is round or square, it will never change that figure without others constraining it to do so; if it is stopped in some place, it will never depart from that place unless others chase it away; and if it has once begun to move, it will always continue with an equal force until others stop or retard it.[7]

One "part of matter" is whatever contains no relative motion of sub-parts, or whatever may be so considered relative to certain problem contexts.[8] The "true form and . . . essence" of matter is, of course, extension.[9] The law is asserted not simply of motion, but of nature, which is here identical to matter.[10] The "state" in which a part of matter continues thus includes size, figure, and arrangement of parts, as well as local motion.[11] It is more general than Newton's first law: "Every body continues 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."[12] This law is only about the local motion of a body as a whole. As a consequence, we may abstract from its internal parts and their relative motions.[13] Thus the local motion of something extended may be represented by the local motion of an unextended point ("in a right line").[14]

A comprehensive analysis of the first laws of Newton and Descartes and their respective concepts of force and inertia is not our intention.[15] Essential for our purpose is the following obvious point, common to both laws of inertia: No body can begin to move by itself. Yet animals, beings that we call 'alive', *appear* to do so all the time. The animals *appear* to violate the laws of inertia. How is this issue resolved? Consider a cat at rest on the mat. When it gets up and goes, what agency external to the cat effects the change of state? Cartesian physics and Newtonian physics give different answers.

1.3 *The Corpuscularian Resolution of Descartes.* The Cartesian response to the phenomena of animals on behalf of the first law is given in Chapter 7 of *Le Monde:*

> Now, even though in most of the motions we see in the true world we cannot perceive that the bodies that begin or cease to move are pushed or stopped by some others, we do not thereby have reason to judge that these two rules [the first law and the law of conservation of motion] are not being observed exactly. For it is certain that those bodies can often receive their agitation from the two elements of air and fire, which are always found among them without being sensed. . .[16]

Sensible wholes must be understood in terms of the subsensible parts of matter. Thus, in terms of Descartes' law of inertia, the cat, as it accelerates from rest, may not be considered as one part of matter. The motion of this phenomenal whole is caused by the motions of unseen parts of matter present within and around it. The cat is an example of a *mixed* body, and such bodies contain "*in themselves* some qualities that are contrary" and "that tend to make [them] change."[17] Indeed "all the bodies that appear about us are mixed or composite and subject to corruption."[18] The first law, it seems, would not apply to such a body *as a whole*. This is, at least in part, the reason for the inclusion of the phrase "insofar as it is simple and undivided" in the later statement of the law in *Principles* II, 37.[19] This issue is important, and an adequate account of it would have to clarify the meaning and use of the term 'simple' in Cartesian science, and the type of concept formation deriving therefrom in subsequent science—not a simple task.[20] For the moment, however, the essential point is that no such phrase appears in Newton's first law, for the issue does not arise within the explanatory system composed of Newton's three laws of motion. How this is so will be shown in the following section.

The simple and subsensible parts of matter in terms of which corporeal phenomena are to be explained came to be called *corpuscles*.[21] Unlike Democritean atoms, they possess no ultimate determinacy.[22] Unlike Aristotelian matter, they are fully actual. Corpuscularism is incompatible with substantial form in living beings (indeed the term 'living' must now refer to *mere* appearance) or, more generally, with holism, the notion that there exist wholes in nature non-reducible to elementary parts, to parts which are neutral to the wholes which they compose. Descartes' resolution of the contradiction between animals and his first law thus contains fundamental implications concerning matter and causality. In particular, the motion of any whole must be a sum of the motions of simple parts, parts governed by fixed laws of "nature."[23] How does it stand in the physics deriving from Newton?

1.4 *Causal Neutrality and Newton's Laws of Motion*. We must begin with an important qualification. Phrases such as 'post-Newtonian physics' and 'the physics deriving from Newton' are used deliberately in place of 'Newton's physics'. For we shall not here attempt to interpret Newton, that is, to understand Newton as he understood himself. (This will be attempted briefly only in section 2.4 below, on the parallelogram rule.) Much recent work has been directed to this goal, without which no adequate comprehension of physics is possible.[24] Here, however, we are concerned to interpret that physics which, by its successful development (whether by Newton, Leibniz, Euler, D'Alembert, or Lagrange), claims to provide evidence in the argument against holism. This physics clearly begins from, and incorporates, Newton's laws of motion.

Newton's first law requires that, for any body undergoing a change of velocity, there be a force impressed upon the body. In order to be *impressed upon* the accelerating body, this force must be exerted by another body external to the former.[25] When the cat on the mat accelerates from rest, what body, external to the cat, impresses a force on it? If no such force and agent can be identified, the animal is in violation of Newton's first law. Now this force is specified, and the difficulty removed, by the third law of motion: the mat impresses a force on the cat. For "[t]o every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."[26]

It surely seems to us that the action of the cat on the mat is not of the same sort as the reaction of the mat on the cat. It is not clear in what sense the latter is action at all. This, however, is a problem for the philosophy of nature, not for the mathematical principles thereof.[27] In terms of Newton's three laws, actions and reactions are of equal status. Both are simply forces, each quantitatively related by the second law to a simultaneous change in velocity (assuming they are net forces). And a force in classical mechanics is just a push or a pull, that is, *whatever* effects, or tends to effect, a change in the velocity of a body.[28] There is no further specification of causes. Thus Newton's three laws of motion are neutral with respect to the question of how actions and reactions are initiated, whether in the moved or in another. In this regard, note that Newton's first law does not require that the cat's *pushing* on the mat be externally caused. It requires only that the cat's *change of velocity* be related (in accordance with the second law) to the simultaneous external push or pull. Unlike Descartes' first law, Newton's bears no obligation to account for a change of state in general, such as the cat's beginning to push, but only for a change of velocity.

If causal priority is given to the (living) cat's action over the (non-living) mat's reaction, it is not because of Newton's three laws of motion, but on grounds of ordinary experience. On the basis of the three laws of motion alone, 'the cat's alive, the mat's dead', 'the mat's alive, the cat's dead', 'everything's alive', 'everything's dead' are all acceptable statements. This is the meaning of the causal neutrality of Newton's universal laws of motion.

In sum, instead of joining his first law to corpuscularism and qualifying it in terms of the 'simple and undivided', Newton posits or discovers a mathematically representable reaction force which fulfills the requirement for an impressed force in the case of animals, but whose causality is left unspecified.[29] This guarantees the universality of his first law. Unlike Descartes', it applies to every body (*corpus omne*) taken as a whole, as it presents itself to our senses, living and non-living.[30] Within the system consisting of the three laws of motion, Newton's first law, unlike Descartes' corpuscularism, does not rule out the possibility of self-initiated motion. It is compatible with either holism or reductionism. Newton's three laws of motion are, by themselves, merely guidelines which the measurable aspects of all forces and accelerations must satisfy. They have no fundamental implications concerning matter and causality. Within the post-Newtonian development of physics, therefore, such implications can arise only on grounds of a larger argument, one that includes but goes beyond the three laws of motion.

This completes the account of two laws of inertia and their implications for our understanding of nature. Obviously, however, we cannot stop here. For our analysis has led to a larger question, one which bears crucially on the problem of the status of living beings in relation to physics. What precisely *is* the argument from post-Newtonian physics for reductionism and against holism?

II. The Reductionist Argument from Post-Newtonian Physics

2.1 *Introduction.* The goal of Part II of this paper is to set forth and evaluate the argument for reductionism based on post-Newtonian physics, or classical mechanics. Now classical mechanics is (especially, although not exclusively) the mathematical description of the local motion of bodies effected by forces. The argument thus turns on the relation between whole and parts in terms of motion and force. Can the force and motion of a whole always be derived from the forces and motions of its simple parts, and those of environing bodies? If so, reductionism is true and holism refuted. Needless to say, the phrase 'simple part' is crucial.

A final decision on this question will prove to lie beyond the reach of the present endeavor. For while it is not difficult to set forth the reductionist argument, the attempt to evaluate it, to assess its truth, will lead into a nexus of issues, at first submerged in the notes to Part I, concerning the meaning of 'simple part', and the concepts of matter and law. We shall circumscribe these issues and conclude (Sec. 2.5) with a summary of what has been clarified, and an unresolved question. Let us indicate how this occurs.

The question of the relation between wholes and parts in terms of motion and force leads easily to three items familiar in Newtonian physics. The first we have already discussed, namely, Newton's three universal laws of motion. The second is the idea of force law, exemplified above all by the law of universal gravitation, and without which no *trajectories* can be determined. The third is the rule by which the force exerted by a compound is related to the forces exerted by its constituent parts, forces and parts which, in some unclear yet crucial sense, must be simple or elementary. The best-known representation of this is the parallelogram rule for composition of forces. These are the three ingredients of the argument for reductionism from classical mechanics sometimes called Newtonian-Laplacian determinism.[31] The third ingredient will be found to involve a certain assumption of dynamical independence which goes to the core of the issue between holism and reductionism. Our evaluation of the reductionist argument will then turn into an attempt to clarify this assumption (Secs. 2.4 and 2.5).

2.2 *Force Laws and Trajectories.* Newton's three laws of motion are, by themselves, barren for the description of moving bodies. It is only when these laws, the second law in particular, are combined with force laws that *equations of motion* result. Equations of motion coupled with initial conditions yield trajectories.

A force law is a specification of the force on a body, under given conditions, as a mathematical function of time, and of the body's position and velocity. Thus, most generally, $\mathbf{F} = \mathbf{F}(\mathbf{r}, \mathbf{v}, t)$, where boldface letters denote vectors. It presupposes the concept of force present in the three laws of motion, but is not derivable from them. It also involves measurable properties, or *dimensions* of bodies, such as mass and charge.[32] The most famous example is the law of gravitational attraction.

The calculation of trajectories of comets and planets from the laws of motion and gravitation was the first great achievement of classical mechanics. It was seen as evidence against the pre-modern understanding of nature. For the motions of *these* bodies could be described to (almost) arbitrarily high accuracy without regard to formal causality, final causality, or divine agency.[33] On this basis the claim for reductionism was built. For our purposes, that claim can best be expressed as follows.

There is no essential difference between the motion of an animal, and that of planets in the solar system. All are determined by fixed and universal laws. The most basic principles by which we calculate the trajectories of planets are also those which must determine the motions of animals; biology is logically entailed by physics. The difference is one of calculational complexity, and this is without philosophical significance. For in neither case is there any need to speak of causes of motion other than those contained in the laws of attraction and repulsion, the paradigm of which is gravitation.

The core of this claim is the idea that any system whatsoever, thus any body, is composed of smaller parts which interact and move along trajectories determined by force laws, just as planets in the solar system by the force of gravitational attraction. Thus, according to Newton, "nature is exceedingly simple and conformable to herself. Whatever reasoning holds for greater motions should hold for lesser ones as well."[34] And so Laplace declared that "the regularity which astronomy shows us in the movements of the comets doubtless exists also in all phenomena."[35]

This is an account familiar to students of physics and the history of science. Implicit therein is the third ingredient of the reductionist argument, the rule for composition of forces. Without it, the argument cannot stand. In order to make it explicit, it is useful to present the reductionist argument in the mathematical terms of classical mechanics.

2.3 *Composition of Forces.* Consider any body, b, of constant mass m_b. We wish to investigate the local motion of b (in any inertial frame). The basis is the second law of motion:

$$m_b \mathbf{a}_b(t) = \mathbf{F}_b(t) \qquad [1]$$

where $\mathbf{F}_b(t)$ is the net force impressed on b at time t by external bodies acting or reacting on b, and $\mathbf{a}_b(t)$ is the acceleration of the center of mass of b. If $\mathbf{F}_b(t)$ can be shown to be in principle determined for all time t, then $\mathbf{a}_b(t)$ is determined as a function of time which can be integrated to yield the position and velocity, thus the trajectory, of b, for given initial conditions.

To illustrate most directly what is involved in the composition of forces, we consider first the paradigmatic example, the solar system. Thereafter, we turn to the case of an arbitrary system, or compound, and forces of attraction and repulsion in general.

Let b be a planet moving under the gravitational attraction of the sun and other planets. Then $\mathbf{F}_b(t)$ represents the total force on b at time t exerted by the sun and other planets. To prepare the most general discussion, we introduce a peculiar locution: $\mathbf{F}_b(t)$ represents the force or action on b of a *compound* consisting of parts, namely, the sun and other planets, which parts also act upon each other. What, now, is the form, fixed in time and expressed in terms of algebraic symbols, of $\mathbf{F}_b(t)$? We know from the law of universal gravitation that any one part of this compound, say planet j, of mass m_j, taken by itself, i.e., as if it were isolated from all others, exerts a force on b of magnitude

$$f_{jb} = G(m_j m_b / R_{jb}^2) \qquad [2]$$

where R_{jb} is the (time-dependent) distance between j and b, and G is the universal gravitational constant. But when many interacting parts, namely, the sun and other planets, together act on b, what is the one resultant force which affects the motion of b? In the case of gravitation, the answer is simple: just assume that each part acts independently of all the others. Then we can add up forces using the parallelogram rule introduced for this purpose by Newton immediately following the three laws of motion.[36] For example, the resultant force on b by the sun, of mass m_s, and planet j is shown in Fig. 1, and written out in Eq. 3:

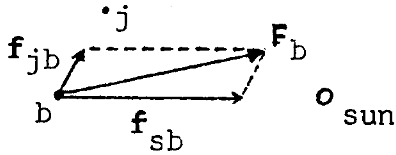


FIG. 1

$$\mathbf{F}_b(t) = G(m_j m_b / R_{jb}^2)\mathbf{r}_{jb} + G(m_s m_b / R_{sb}^2)\mathbf{r}_{sb} = m_b \mathbf{a}_b(t) \quad [3]$$

where $\mathbf{r}_{jb}$ and $\mathbf{r}_{sb}$ are unit vectors appropriately directed. The distances R_{jb} and R_{sb} are time-dependent since all three bodies are in motion relative to each other. The solution for the motion of b, therefore, requires that the trajectories of j and s be calculated as well. Thus Eq. 3 must be supplemented by similar equations for the motions of the sun and planet j. Although the resulting system of coupled differential equations is, in general, too complicated for solution in closed, analytic form, the motion of b is, in principle, determined.[37] 'In principle' means according to the physics used to constitute these equations of motion.

The point, now, is to make clear the crucial step, represented by Eq. 3, in which the force exerted by the gravitational compound is composed of the elementary forces of its parts. In this step we discover the assumption that each part acts independently of the others, independently of the relations in which it stands in composing the whole. Let us call this the assumption of the dynamical independence of the parts of a gravitational system. Given this assumption, the parallelogram rule may be applied to the elementary forces $\mathbf{r}_{jb}Gm_jm_b/R_{jb}^2$ and $\mathbf{r}_{sb}Gm_sm_b/R_{sb}^2$, in order to determine the conjoint action of the sun and planet j on planet b. Consider the alternative. If it were the case that the force of attraction exerted by the sun on b ceased to be given by Gm_sm_b/R_{sb}^2 and became something else, that is, if the form of the force law changed due to the presence of planet j, then we could not use this law in determining the resultant gravitational force exerted by a compound of many gravitating bodies.[38] *Some* force would be exerted on a given test body, producing acceleration, yet the form of that force would not be determined by composition of elementary forces of the form Gm_im_k/R_{ik}^2. In addition, difficulties could arise in the definition of mass.[39] But this alternative does not occur. *For gravitation,* the assumption of dynamical independence, and the consequent applicability of the parallelogram rule to elementary gravitational forces, is warranted by the success of the resulting calculations, and entailed by the concept of gravitational mass, about which we shall have more to say. Our fundamental concern is with the universality of these notions. Do they apply to *all* the actions of *all* the wholes in nature? Let us complete the exposition of the role played by composition of forces in the reductionist argument.

Let b in Eq. 1 be an arbitrary compound body, subject to the action or reaction of an arbitrary force $\mathbf{F}_b(t)$. We can then imagine that b is what we call an 'animal', which appears to move itself by pushing or pulling on environing bodies. For our purpose here, the latter bodies may be assumed to be composed of dynamically independent parts. Our purpose is to present the demonstration that $\mathbf{F}_b(t)$ is completely determined by classical mechanics, so that there can be no essential difference between living and non-living. Both have no other causes and principles of motion than those contained in Newton's laws of motion and force.

To probe the force $\mathbf{F}_b(t)$ impressed on b, it suffices to introduce a test particle, a, of mass m_a, on which b acts by exerting a force $\mathbf{F}_{ba}(t)$, as represented in Fig. 2. If $\mathbf{F}_{ba}(t)$ can be determined, then the motion of b is

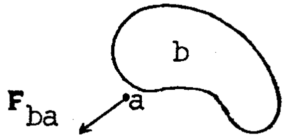


FIGURE 2

determined. For, by Newton's third law, the force $\mathbf{F}_{ba}$ exerted by b on a is equal and opposite to the force $\mathbf{F}_{ab}$ exterted by a on b: $\mathbf{F}_{ba}(t) = -\mathbf{F}_{ab}(t)$. The motion of b in the presence of a is then, by the second law:

$$m_b \mathbf{a}_b(t) = -\mathbf{F}_{ba}(t).$$

If $\mathbf{F}_{ba}(t)$ is in principle determined, then the net force impressed on b by (the actions or reactions of) *any* set of environing bodies can be obtained as the vector sum, i.e., parallelogram composition, of forces exerted by an appropriate set of test bodies.[40]

Now the program for specifying $\mathbf{F}_{ba}(t)$ is straightforward. $\mathbf{F}_{ba}(t)$ is given by the vector sum, i.e., parallelogram composition, of forces $\mathbf{f}_{ia}$ exerted by the i-th particle of b on a. *These particles are understood to be elementary or simple in that they interact by an elementary force law,* $\mathbf{f}_{ia}$, analogous to the gravitational interaction, Eq. 2, in possessing a fixed form, expressed in terms of position, velocity, and measurable properties. This conceptual reduction of b to parts which are 'simple' in relation to a force law is represented by Fig. 3:

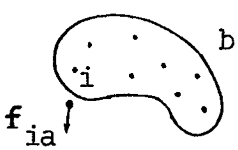


FIGURE 3

and by the equation

$$\mathbf{F}_{ba}(t) = \sum_i \mathbf{f}_{ia} \qquad [4]$$

The values of the forces $\mathbf{f}_{ij}$ depend on time through the positions and (in general) velocities of particles i and j:

$$\mathbf{f}_{ij} = \mathbf{f}_{ij}(\mathbf{r}_i, \mathbf{r}_j, \mathbf{v}_i, \mathbf{v}_j) \qquad [5]$$

The index j runs over a and all the particles of b other than the i-th. Finally, the motions of the particles of b are determined by

$$m_i\mathbf{a}_i = \sum_{j\neq 1} \mathbf{f}_{ji} + \mathbf{f}_{ai} \qquad [6]$$

together with initial conditions $\mathbf{r}_i(t_0)$, $\mathbf{v}_i(t_0)$ for all i. The system of equations 4, 5, and 6 expresses the argument for universal determinism by reduction of any body to its sufficiently simple parts.

The parallelogram rule (more precisely, polygon rule, since here we are adding many forces, not just two) for composition of forces, and the associated concepts of simple part and elementary force law, are explicit in the three sentences preceding Eq. 4, in Eq. 4 itself, and again in Eq. 6. The parallelogram rule forms the crucial link *from* elementary or simple forces and particles *to* the force exerted by the compound. Without this link, Eqs. 4 and 6 must be withdrawn, and therewith the reductionist argument from classical mechanics.

As in the case of gravitation, the conjoint employment of the parallelogram composition rule and the concept of elementary force law necessarily entails the assumption that a part of the compound in no way modifies its active character in function of its relation to other parts. The parts are dynamically independent, and neutral to the wholes which they compose. They are what they are, and act as they do, independently of the whole. Thus no whole acts *as such*, but only as a sum of neutral parts. This is the refutation of holism.

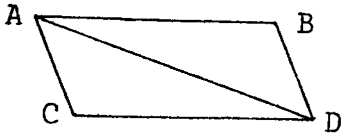
The parallelogram rule for composition of forces forms the doorway to a series of questions crucial for the interpretation of physics. As Newton said, upon "this Corollary . . . depends the whole doctrine of mechanics . . . ."[41]

What, then, is the status of this rule? In its role as link from sufficiently simple parts to the force or action of the whole, is it applicable to all the wholes in nature? Are all wholes in nature composed of dynamically independent parts? Are all forces or actions in nature either elementary, or composed of elementary forces, forces governed by fixed force laws? Any attempt to answer these questions must, at some point, undertake a thorough review of the opinions of others, beginning with Newton and his contemporaries. Here we can make only the barest beginning.

2.4 *Preliminary Historical Inquiry*. How does the parallelogram rule for composition of forces stand in Newton's *Principia?* It is introduced by way of two "corollaries" following the three laws of motion.[42] Is it, therefore, logically entailed by those laws? If the rule is denied, that is, asserted to be inapplicable to certain compounds in nature, is there a contradiction with the laws of motion? Is there a contradiction with the law of universal gravitation? We shall argue here that the existence in nature of forces and compounds to which the parallelogram rule is not applicable leads to no contradiction with the laws of motion. On the other hand, we shall see in the following section (as implied in the previous one) that denial of the rule *for gravitational forces* would indeed contradict the law of universal gravitation. Let us then examine Newton's account. In so doing, we are fortunate to have at hand the work of Max Jammer, a scholar noteworthy for his attention to an issue generally neglected in the secondary literature.[43]

Corollary I is the parallelogram rule for composition of velocities, not forces, resulting from two simultaneously acting impulsive forces.[44] We quote the statement of the corollary and the first sentence of the explanation:

A body, acted on by two forces simultaneously, will describe the diagonal of a parallelogram in the same time as it would describe the sides by those forces separately.



If a body in a given time, by the force M impressed apart in the place A, should with an uniform motion be carried from A to B, and by the force N impressed apart in the same place, should be carried from A to C, let the parallelogram $ABCD$ be completed, and by both forces acting together, it will in the same time be carried in the diagonal from A to D.[45]

The remaining five explanatory sentences involve the directional part of the second law, as well as the first law (for the constancy of the resultant velocity along AD). The essential point is this: Newton assumes that, although acting simultaneously, each force, M and N, acts independently of the other.[46] The independence of effects (traversal of distances AB and AC in a given time) follows from the independence of the agencies producing those effects. In this, the compound agent, acting by the two component forces M and N, is like the gravitational compound. Its parts are dynamically independent. Corollary II then draws the conclusion for composition (and resolution) of dynamically independent forces:

And hence is explained the composition of any one direct force AD, out of any two oblique forces AC and CD; and, on the contrary, the resolution of any one direct force AD into two oblique forces AC and CD: which composition and resolution are abundantly confirmed from mechanics.[47]

This is not further proven, but rather illustrated by means of its application to a typical mechanics problem. The dynamical independence of component forces is assumed. It is not entailed by the laws of motion, or by the concept of force as whatever effects, or tends to effect, acceleration.[48] Validation of this assumption, and thus confirmation of Corollaries I and II, consist in the success of the resulting description in each particular case: "... the usc of this Corollary spreads far and wide, and by that diffusive extent the truth thereof is further confirmed."[49]

Is there here any basis for asserting that all compounds in nature are composed of dynamically independent parts? We believe the answer is no. Consider the opinion of Jammer: "Newton's derivation of the parallelogram theorem of forces tacitly assumes that the action of one force on a body is independent of the action of another force, an assumption that is far from self-evident."[50] Indeed, the assumption can be withdrawn without contradicting the laws of motion. In the language of Corollary I, we would then have the following situation: The agents acting by forces M and N when apart modify each other when acting together so that the resultant force, P, is not given by the parallelogram rule applied to *M* and *N*. The accelerations produced by *M*, *N*, and *P* all satisfy the second law. Furthermore, each force can be resolved into calculationally convenient components. Yet *P* is not the parallelogram sum of *M* and *N*, *since these three forces do not act simultaneously*. For concreteness, we can think of *P* as the force exerted by a live animal; *M* and *N*, the forces exerted by the two parts obtained by cutting the animal in half. Here (1) the whole has a mode of action, a specific activity, $P(t)$, which is not fully reducible to the actions, $M(t)$, $N(t)$, of its parts;[51] and (2) this is not inconsistent with the three laws of motion.

On this interpretation—and Newton's own language supports it—the parallelogram rule for composition of forces stands in Newton's *Principia* as an hypothesis to be tested in each case. This claim cannot, however, be understood apart from the notion of dynamical independence. Specifically, whenever a whole consists of dynamically independent parts, then the forces exerted by the parts are related to the force exerted by the whole according to the parallelogram (polygon) rule. A reductionist description, deterministic in the sense of Laplace, is possible when, in turn, the dynamically independent parts are sufficiently simple to interact by elementary force laws analogous to the law of gravitation. It is not, however, an *a priori* or necessary truth that all wholes in nature consist of dynamically independent simple parts in the sense described.

The possibility of forces and compounds to which the parallelogram rule would not apply was known to 19th Century physics. The French elastician Barre Saint-Venant described the possibility that, at the molecular level,

> . . . the total force impressed on a particle is not exactly the geometric resultant composed by the static rule of the parallelogram or polygon, which we know, of all the forces impressed [on the particle] separately by the other particles if each of them existed alone with it, as was believed until our day; this rule will not be more true than for actions at perceptible distances, whose strength is that of universal gravitation, inversely as the square of the distance, and always negligible compared to actions at imperceptible distances which produce elasticity, capillarity, collisions, pressure and vibration; and these last and energetic actions are not subject to the static rule under discussion.[52]

At the time of writing his well-known memoir, "On the Conservation of Force" in 1847, Hermann Helmholtz adhered to what he called the principle of the "complete comprehensibility of nature":

> . . . natural phenomena are to be reduced to the motions of matters possessing unchanging forces of motion, which forces depend only on spatial relations. . . . The force, however, which two whole masses exert on each other must be resolved into the forces of all their parts on one another; thereby mechanics goes back to the forces of material points, that is, to the points of space filled with matter. . . .
>
> Finally, then, the task of the physical natural sciences is specified thus: to reduce natural phenomena to unchanging attractive and repulsive forces, whose strength depends on the distance. The realizability of this task is, at the same time, the condition of the complete comprehensibility of nature.[53]

In his appendices of 1881, however, Helmholtz retreated from his earlier position. His revised opinion included the following statement:

. . . That the forces of motion are, as they are defined in Newton, resultants of all the individual forces constructed according to the parallelogram law, that they emanate from all the individual mass elements present—this I can still only acknowledge as a natural law found by experience. . . . I can no longer acknowledge the principle of comprehensibility as sufficient for the consequence that the effect arising from the conjoint action of two or more causes of motion must necessarily be found through the (geometrical) summation of those effects of the individual causes.[54]

Perhaps these opinions and our assessment of the parallelogram rule in Newton's *Principia* suffice to resolve the issue between holism and reductionism. Holistic systems in nature are compatible with, and not reducible to, physics. This is possible because, from the beginning, the reductionist argument against the possibility of holism was false. It erred by its overhasty universalization of the parallelogram rule and the associated concept of dynamical independence.

Where, then, would things stand? We know by the successes of physics that compounds exist (clocks, cars, the solar system) which admit reductionist and thus deterministic descriptions. If these systems are terrestrial, so that we can get at them, they can be disassembled and reassembled, precisely because their parts are neutral to the whole. The crucial question, however, concerns the comprehensiveness that can in principle be claimed for the reductionist theory. For there remain systems in nature—animals, for example—for which any attempt to lay bare their parts to the extent required to specify force laws irreversibly destroys the character of the whole. According to the account of the composition of forces given so far, the post-Newtonian development of physics validly provides (1) three *universal* laws of motion which are, however, neutral to the issue between holism and reductionism, and (2) a deterministic description but only at a *particular* level of nature. As to the further specification of holistic principles, it is a goal lying beyond the scope of the present endeavor. Our intention here is simply to consider how such principles might be possible. As to the precise relation between holistic principles and the content of physics, it must suffice for the present to remark that Niels Bohr suggested a principle of complementarity for organisms analogous to that for wave-particle duality in quantum mechanics. In the words of Werner Heisenberg:

. . . Bohr has suggested, that our knowledge of a cell being alive may be complementary to the complete knowledge of its molecular structure. Since a complete knowledge of this structure could possibly be achieved only by operations that destroy the life of the cell, it is logically possible that life precludes the complete determination of its underlying physico-chemical structure.[55]

We have here suggested the logical possibility of a principle of complementarity in the realm of classical physics.[56] Specifically, in the case of an organism, the parallelogram rule for composition of elementary forces cannot be applied. For the force we perceive exerted by the whole as such, and the elementary forces we reveal by our experimental intervention do not act simultaneously and cannot be compared. Knowledge of the compound *as one whole* and knowledge of *parts acting according to simple force laws* are 'complementary'. Knowledge of the one precludes knowledge of the other.

The preceding paragraph could serve as the conclusion of this paper were it not for certain further considerations, previously advertised, involving the concepts of simple part, matter, and law.

2.5 *Conclusion.* Descartes' first law of motion governs things insofar as they are simple and undivided, thus governs the individual parts of matter of which all things corporeal are constituted. The elaboration of the terms 'part' and 'matter' requires an immediate turn to corpuscularism, in which parts are defined neither in terms of ultimate parts, nor in terms of the wholes which they compose. They are defined rather in terms of the Cartesian simples, figure, extension, and motion. The resulting account rules out a type of whole-part relation which we have called holism, and which includes substantial form in living beings. In this sense, the Cartesian account is not causally neutral.

Newton's first law governs all bodies as we know them in the ordinary course of nature, yet does so as one element in the system of the three laws of motion. These three laws require no supporting account of whole, part, or matter. Entailing no commitment concerning whole-part relations, they can accommodate cases in which the action of the whole is irreducible to the actions of the parts. They are compatible with both holism and reductionism, and, in this sense, they are causally neutral.

Yet, Newton's three laws of motion are, for the most part, only the stage on which the real players must appear. Principal among them are the laws of Newtonian action at a distance (and, later, of propagating force fields). Let us again consider the premier force law, that of universal gravitation, for we must make it clear that it is not causally neutral in the sense here employed.[57] We have made two distinct claims about it. First, in Sec. 2.3 it was asserted that the dynamical independence of the parts of a gravitational system (and resulting validity of the parallelogram rule) is entailed by the concept of mass. Second, in Sec. 2.4 it was asserted that the denial of the parallelogram rule for gravitational forces would contradict the law of universal gravitation. Thus, *in the case of gravitation,* a reductionist relation of whole and part is intimately involved with (1) the concept of matter as (gravitational) mass, and (2) the concept of force law associated with mass. Let us try to clarify this.

The mundane fact that the weight of a body is the sum of the weights of its parts provides the simplest introduction to the issue in question.[58] The weight of a body is the gravitational force of the earth on it. By the third law of motion, it in turn attracts the earth toward it with an equal force; whatever else it does, this is the gravitational portion of the body's activity.[59] It follows (from the additivity of weight and the third law of motion) that the gravitational portion of any body's action is the sum of the gravitational actions of its parts. This sum can only be the composition of forces (here, the attractions of the parts of the body on the earth) by the parallelogram rule. In the language of present-day physics, the gravitational attraction of a distribution of mass is correctly given by the vector sum of the gravitational attractions of its mass elements. This is the calculation which Newton had to carry out in order to establish that, for bodies on the surface of the earth, gravitational force is proportional to the inverse square of the distance to the *center* of the earth:

After I found that the force of gravity towards a whole planet did arise from and was compounded of the forces of gravity towards all its parts, and towards every one part was in the inverse proportion of the squares of the distance from the part, I was yet in doubt whether that proportion inversely as the square of the distance did accurately hold, or but nearly so, in the total force compounded of so many partial ones; for it might be that the proportion which accurately enough took place in greater distances should be wide of the truth near the surface of the planet, where the distances of the particles are unequal, and their situation dissimilar.[60]

Indeed, for bodies of arbitrary shape in proximity to each other, it is not clear what distance, R, should be used in the Newtonian formula Gm_1m_2/R^2; R is the distance between *which* two points of the bodies? The possibility of finding an answer to this question consists, as Newton indicates, in the reducibility of any body to parts, of masses m_1, m_2, which act "accurately enough" according to the law Gm_1m_2/R^2.[61] Such a mass element is the "one part" to which Newton refers in the passage above. Here we find the presence of Descartes. 'Part' means part, not *of a whole,* but *of matter*, matter conceived as an algebraically representable measurable property, or dimension, of all the wholes in nature. Yet, in contrast to Descartes, the dimension is quantity of matter, or mass, not extension, and a part thereof is *one* not in terms of motion, but in relation to a law of action specific to mass.[62] When two pieces of mass, m_1, m_2, are situated such that their sizes are small compared to the distance, R, between them, then Gm_1m_2/R^2 describes their attraction.[63] Each is then *one part* or, as Newton says, "one single corpuscle" of mass.[64] Newton's *gravitational* physics is a corpuscularism of mass and law. Any body, *insofar as gravitationally acting,* is merely an aggregate of corpuscles of mass, each of which acts by the law of attraction. Accordingly, the simple parts of mass add up arithmetically to the mass of the whole, and the correlative elementary forces add up vectorially, by the parallelogram rule, to the force of the whole.

To the extent that this way of thinking is adequate to nature, reductionism is true and holism refuted. To what extent, then, can we generalize the gravitational account of body and action to the following universal principle: All wholes in nature, insofar as active and thus knowable, are sums of simple parts of algebraic dimensions, which are, and act, by simple force laws?[65] The answer to this question would, in turn, contribute to the resolution of a large issue: Can the tradition of physics since Newton claim to be the comprehensive account of nature?

In arriving at our present vantage point we have established the following three points, to our knowledge not previously made explicit: (1) Newton's laws of motion differ fundamentally from Descartes' in their implications concerning matter and causality. The former are compatible with holism and thus with the possibility of an essential distinction between living and non-living; the latter are not. (2) The argument for reductionism from post-Newtonian physics depends crucially on the parallelogram rule for composition of elementary forces. (3) The universal employment of the parallelogram rule in reducing the action of a whole to the elementary forces of deterministic parts presupposes a way of conceiving matter, simple part, and law, first exemplified in Newton's theory of gravitation.

Center for Naval Analyses

ACKNOWLEDGEMENT: No acknowledgement could be as generous as the instruction of Richard Kennington which informs this work, and without which it could not have been written. For the guidance and encouragement of William A. Wallace I am most grateful.

NOTES

1. M. Boas, "The Establishment of the Mechanical Philosophy," *Osiris* 10 (1952): 412-541; Max Jammer, *Concepts of Force: A Study in the Foundations of Dynamics* (Cambridge: Harvard University Press, 1957); A. R. Hall, *From Galileo to Newton* (New York: Dover, 1963 and 1981); Alexandre Koyre, "Newton and Descartes," *Newtonian Studies* (Chicago: University of Chicago Press, 1965), pp. 53-114; R. S. Westfall, *Force in Newton's Physics* (New York: American Elsevier, 1971); Alan Gabbey, "Force and Inertia in the Seventeenth Century: Descartes and Newton," *Descartes Philosophy, Mathematics and Physics,* S. Gaukroger, ed. (Totowa, N.J.: Barnes and Noble, 1980), pp. 230-320, a revised and expanded version of "Force and Inertia in Seventeenth Century Dynamics," *Studies in History and Philosophy of Science* 2 (1971): 1-67; I. B. Cohen, *The Newtonian Revolution* (Cambridge: Cambridge University Press, 1980).

2. The terms 'living being', 'organism', and 'animal' appear rarely, if at all, in these studies. An exception is Hall, *op. cit.,* in which Ch. 7 is titled "Problems of Living Things." Although Hall seems to favor mechanism in the dispute with vitalism (p. 196), there is no detailed examination of the arguments.

3. This can, of course, be denied, so that there is no essential distinction between living and non-living. The former becomes a mere appearance or epiphenomenon of the latter. Since it is the purpose of this paper to examine the reductionist position, that position will not be presupposed. We thus begin in the common experience of living beings as possessed of a *unity* different in kind from that of the non-living.

4. Since the concepts of mass and inertia as we know and use them are not found in Descartes, one should suspect at first glance that differences must exist between the laws of inertia in Newton and Descartes. "It is in fact anachronistic to ascribe a 'principle of *inertia*' to Descartes, or indeed to anyone prior to . . . Newtonian dynamical researches." (Gabbey, p. 288.) The in-depth study of the meaning of this surface distinction forms a large part of Gabbey's expert account; see especially Part 4, where it is shown that the function and context of the law of inertia differ in Newton and Descartes.

N. R. Hanson has described some of the logical problems involved in Newton's first law in "Newton's First Law: A Philosopher's Door into Natural Philosophy," *Beyond the Edge of Certainty,* R. Colodny, ed. (New Jersey: Prentice Hall, 1965), pp. 6-28. This is an expanded version of the earlier "The Law of Inertia: A Philosopher's Touchstone," *Philosophy of Science* 30 (1963): 107-21. Hanson shows, in particular, that different choices of the logically primitive and derivative among the terms 'force free', 'uniform', and 'rectilinear' lead to "different semantic platforms" within the same mechanical theory (p. 12). Hanson's analysis thus reveals a logical or semantic sense in which there is no one law of inertia. Our account is distinct from, and generally compatible with, both Gabbey's and Hanson's. See, however, note 48 below.

5. This is in no way at variance with the canonical interpretation of the law of inertia, namely, that uniform rectilinear motion requires no cause or mover, and is a *state* rather than a *change* or process: "It is precisely the institution of the concept of *status* of motion for actual motion that enables Descartes—and will enable Newton—to assert the validity of his first law. . ." (Koyre, *op. cit.,* p. 69. We shall argue that more is involved in validating the law.

6. This is not to say that post-Newtonian physics supports no argument against holism and for universal reductionism. The determinism proclaimed by Laplace is well known. The point is that the three laws of motion in Newton are not the sufficient basis for that argument, which argument will be discussed in Part II of this paper.

By 'holism' we shall mean the idea, partially stated in the Preface, that whole and part determine each other, so that the whole is and acts not as a sum of neutral parts; and the parts are what they are, and act as they do, only in terms of the relation through which they constitute the whole. Thus, although their necessary conditions may be understood in terms of parts, a sufficient description of these beings would require principles specific to the whole, principles of the whole as such.

The best known proponents of holism are Aristotle and the medieval commentators, for whom substantial form is the holistic principle. For example, Aristotle states that "the continuous and limited is a whole when it is a unity composed of many parts, *especially when the parts are potentially present in it*.... And of these things themselves, those which are so naturally are more truly wholes than those which are so artificially...." (Emphasis added.) *Metaphysics*, Bk. V, Ch. 26, 1023b33-36; Loeb Classical Library, H. Tredennick, trans. (Cambridge: Harvard University Press, 1975), p. 281. And Thomas Aquinas: "all parts are related to the whole as the imperfect to the perfect, which is, indeed, the relation of matter to form.... flour is called the matter of bread but not insofar as it stands under the form of flour." *Commentary on Aristotle's Physics*, Bk. II, Lectio 5, Sec. 184; Blackwell, Spath, and Thirlkel, trans. (New Haven: Yale University Press, 1963), p. 90. And in Bk. IV, Lectio 4, Sec. 436, Blackwell et al., p. 200: "the whole has the nature of a form in respect to the parts...."

Clearly, in Aristotle and the commentatorial development, substantial form is a principle of *all* natural (as opposed to artificial) beings, both living and non-living, i.e., the elements. William A. Wallace has shown that the issue of substantial form as a principle of motion in the non-living carried over into the formative period of early modern science. See, for example, "Causes and Forces at the Collegio Romano," William A. Wallace, *Prelude to Galileo* (Dordrecht: Reidel, 1981), pp. 110-26, especially pp. 113 and 122. The present investigation, however, will not enter into the question of substantial form as a principle of motion in the non-living. Rather, substantial form will be taken as one example of a holistic principle, and it will suffice for our purposes to focus on living beings as the source of strongest evidence for holism.

The argument between holism and reductionism remains alive within contemporary science: "Most biologists are in general agreement that vital processes, like non-living ones, occur only under determinate physico-chemical conditions and form no exceptions to physico-chemical laws. Some of them nevertheless maintain that the mode of analysis required for understanding living phenomena is fundamentally different from that which obtains in the physical sciences. Opposition to the systematic absorption of biology into physics and chemistry is sometimes based on the practical ground that it does not conform to the correct strategy of biological research. However, such opposition is often also supported by theoretical arguments which aim to show that the reduction of biology to physico-chemistry is inherently impossible." Ernest Nagel, *The Structure of Science* (New York: Harcourt, Brace, 1961), pp. 398-99.

As for contemporary evidence in support of holism, it is of two kinds: (1) ordinary experience of living beings and our inability to take them apart and put them together as we can machines—it remains the case that living organisms have never been artificially produced out of non-living material; (2) scientific evidence, as presented for example by James A. Shapiro, "Variation as a Genetic Engineering Process," *Evolution from Molecules to Man*, D. S. Bendall, ed. (Cambridge: Cambridge University Press, 1983), pp. 253-70. Shapiro finds that "a detailed investigation of the variational process [in cells] reveals the coordinated action of biochemical systems whose specificities and regulation are beyond simple chemical explanations" (p. 254). He then details three examples "relevant to the formulation of evolutionary theories" (p. 254).

Among the most incisive post-Newtonian formulations of holism are Hegel's: "The notion of the whole is to contain parts: but if the whole is taken and made what its notion implies, i.e., if it is divided, it at once ceases to be a whole. Things there are, no doubt, which correspond to this relation: but for that very reason they are low... existences.... The relation of whole and parts ... comes very easy to reflective understanding; and for that reason it often satisfies when the question really turns on profounder ties. The limbs and organs, for instance, of an organic body are not merely parts of it: it is only in their unity that they are what they are, and they are unquestionably affected by that unity, as they also in turn affect it. These limbs and organs become parts, only when they pass under the hands of the anatomist, whose occupation, be it remembered, is not with the living body but with the corpse. Not that such analysis is illegitimate: we only mean that the external and mechanical relation of whole and parts is not sufficient for us, if we want to study organic life in its truth." *Encyclopedia Logic*, Sec. 135, Note, in *Hegel's Logic*, William Wallace, trans. (Oxford: Oxford University Press, 1975), p. 191. See also Sec. 38, Note (p. 63) and Sec. 126, Note, (p. 183).

7. Descartes, *Le Monde*, Ch. 7. M. S. Mahoney, trans. (New York: Abaris, 1979), p. 60; hereafter cited as *Le Monde*. I have changed Mahoney's translation slightly for greater literalness. Descartes' statement of the first law in *Principles of Philosophy*, Part II (hereafter *Principles* II), 37, is: "the first [law of nature] is: every thing, insofar as it is simple and undivided,

remains, so far as in it lies, always in the same state, and never changes except by external causes." *Oeuvres de Descartes,* Adam and Tannery, eds. (Paris, 1897-1913), Vol. 8 (i), p. 62. Hereafter this edition will be referred to as AT. The latest English translation is Descartes, *Principles of Philosophy,* V. R. Miller and R. P. Miller, trans. (Dordrecht: Reidel, 1983); the first law is on p. 59. Hereafter this edition will be referred to as MM. Our translation will not always coincide with theirs. The later formulation of the first law differs in several ways from that of *Le Monde.* Most important for our purposes is the addition of the two phrases "Quantum in se est," and "quatenus est simplex et indivisa." The first joins Descartes to Newton and is discussed by I. B. Cohen, " 'Quantum in se est': Newton's Concept of Inertia in Relation to Descartes and Lucretius," *Notes and Records of the Royal Society of London,* 19 (1964): 131-55. The second distinguishes him from Newton and will be discussed further in sections 1.3 and 1.4. For the moment, let us note that the phrase "insofar as it is simple and undivided" makes explicit a significant point present in *Le Monde,* as we shall see, but not there contained within the statement of the law.

8. *Le Monde,* pp. 20-22. See also *Principles* II, 25; AT, Vol. 8 (i), p. 54; MM, p. 51. The definition contains well-known circularity.

9. *Le Monde,* p. 56. Also *Principles* II, 4; AT, Vol. 8 (i), p. 42; MM, p. 40. As used by Descartes, the phrase 'part of matter' is possessed of fundamental significance. To begin to see why, consider what is said in *Principles* II, 8: "Thus . . . we may consider the whole nature of corporeal substance which is in a space of ten feet, although we do not attend to this measure of ten feet; because it is clear that *the thing understood is the same in any part of this space as in the whole"* (emphasis added). AT, Vol. 8 (i), p. 44; MM, p. 43. To grasp the nature of matter—here identical to extension—in any part is to grasp its nature in any whole, in fact, to grasp its nature simply. Within this understanding, parts are not parts *of wholes,* just parts *of matter.* Such parts are obviously neutral to, and not determined by, the wholes which they constitute. This way of conceiving body-as-matter differs fundamentally from that of the preceding tradition. It is involved with the notion of simplicity in Descartes (see note 20, below) and will figure in our discussion of the argument for reductionism in sect. 2.5.

10. *Le Monde,* p. 58.

11. *Le Monde,* p. 40.

12. Newton, *Mathematical Principles of Natural Philosophy,* A. Motte and F. Cajori, trans. (New York: Greewood Press, 1962), p. 13. All references will be taken from this edition, hereafter cited as *Mathematical Principles.* The Latin formulation (p. 644) is preferable since it contains the important word *perseverare* which is not adequately translated by 'continues': *Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare." I. B. Cohen, op. cit.,* (1980), p. 187, remarks the more restricted character of Newton's *Mathematical Principles* compared to Descartes' *Principles.*

13. This is perfectly compatible with Descartes, *Principles* II, 25, regarding abstraction from internal relative motions.

14. This is compatible with, but does not entail, the view that the ultimate sources of activity are actually unextended beings in empty space, a notion apparently first proposed by Boscovich, *Theory of Natural Philosophy,* J. M. Child, trans. (Cambridge: MIT Press, 1966), p. 45.

15. The excellent studies of Gabbey, Westfall, and Cohen cited in note 1, above, are of especial relevance.

16. *Le Monde,* pp. 66-68. The parallel account in *Principles* II will be discussed momentarily; see note 19, below.

17. *Le Monde,* pp. 40 and 42, emphasis added.

18. *Le Monde,* p. 42.

19. For the statement of the law, see note 7. Following the statement is an explanation of how *phenomena* of self-terminated motions do not *in reality* violate the law: "However, because we inhabit the earth, which is so constituted that all motions which occur near to it cease in a short while, and frequently from causes which are concealed from our senses, we often judged, from the beginning of our life, that those motions which thus ceased by causes unknown to us, did so spontaneously. And we tend to hold in all cases what we think we have observed in many cases, namely, that motion ceases by its own nature, or tends toward rest. Now this is most opposed to the laws of nature." AT, Vol. 8 (i), pp. 62-63; MM, p. 59. The case for phenomena of self-initiated motions must be the same. In both cases, what appears to be the case "is most opposed to the laws of nature," and the resolution is in terms of the strictly lawful behavior of unobservable parts.

20. The concept of simplicity arises in Descartes, *Regulae ad Directionem Ingenii,* Crapulli, ed.

(The Hague: Martinus Nijhoff, 1966). Rule VI introduces the simple natures as intuitively immediate beginning points of knowledge (pp. 18-19). Indeed, in Rule VIII it is asserted that we "can have certain experience only of the entirely simple and absolute" (p. 27, lines 22-23). In Rule XII we learn that the simple is known completely or not at all, that is, the least knowledge thereof suffices to know the whole (p. 47, lines 20-23). Extension, as described in *Principles* II, 8 (see note 9, above) is thus, for Descartes, simple. Rule XII states that "in the order of our knowledge, each simple thing should be viewed differently than when considered as it really exists" (p. 45, lines 17-19). Simplicity is thus a property more of concepts than of real things. Indeed, in *Principles* II, 41, motion is asserted to be simple; AT, Vol. 8 (i), p. 65; MM, p.62. Yet a mere concept cannot be acted upon, collide, accelerate and decelerate. Simplicity must then refer to bodies as well as to concepts. (The possibility of such reference is the possibility of Cartesian mathematical physics.) The passage cited in *Le Monde*, notes 17 and 18, above, indicate that in applying the notion of simplicity within physics, certain bodies cannot be considered as "simple and undivided" in respect to certain of their changes. These bodies and changes must then be reduced to motions of parts of matter which can be so considered.

21. The term 'corpuscle' is Boyle's. See, for example, *Origin of Forms and Qualities (The Theoretical Part),* (Manhattan Beach: The Sheffield Press, 1976), p. vi.

22. The parts of matter are not of infinite but of *indeterminate divisibility; Le Monde,* p. 16; *Principles*, I, 26; AT, Vol. 8 (i), pp. 14-15; MM, p. 13. For Descartes, any one part of any of the three elements can be transformed into a part of another element through modification of size and speed; *Le Monde*, pp. 34-48. There is no essential heterogeneity of elements as there was in ancient atomism. There are always three elements, due, not to the being of the elements, but to laws and processes which facilitate a "dynamical equilibrium." Thus, for Descartes, it is more accurate to say that there are three conditions of matter, rather than three elements. The same absence of ultimate determinacy in the corpuscularism of Boyle has been clearly discerned by Thomas Kuhn, "Robert Boyle and Structural Chemistry in the Seventeenth Century," *Isis* 43 (1952), 17, 19, 22, 32, and 33. It is difficult to see, however, how this could be Aristotelian, since both Descartes and Boyle reject the Aristotelian principle of potency.

23. As we shall see, this assertion can apply as well to post-Newtonian physics. It is, in fact, a concise statement of reductionist determinism. To repeat (note 6, above), the point is that Newton's three universal laws of motion are not a sufficient basis for it. This will be discussed in Part II..

24. See the studies listed in note 1, above. J. E. McGuire has argued persuasively that there is more to Newton's thought about nature than the rational mechanics of the *Mathematical Principles;* see McGuire, "Force, Active Principles, and Newton's Invisible Realm," *Ambix* XV (1968), 154-208. Gabbey agrees: *op cit.,* p. 240.

25. Newton's second law is then the basis for the quantitative relation between impressed force and acceleration. Assuming constant mass, and in its present formulation, $F(t) = ma(t)$. Indeed, "force as we understand it is the logical correlate of the principle of inertia, an external action that alters the state of a body unable to initiate such a change of itself." R. S. Westfall, *op. cit.*, p. 301. We would modify Westfall's statement in two ways: (1) the word 'state' should be changed to the more narrow 'velocity'; (2) whether a body is able or unable *of itself* to initiate a change in velocity is something about which Newton's three laws of motion are, by themselves, silent. The second is the point of the present section.

26. *Mathematical Principles,* pp. 13 and 644. The mat is, of course, stuck to the floor of the house, and the house to the earth.

27. Concerning forces, "[i]n *Principia* [Newton] is not concerned with investigations of anything other than their mathematical description. . ." Gabbey, *op. cit.*, p. 239. See also the author's "The Use and Non-Use of Physics in Spinoza's *Ethics," Southwestern Journal of Philosophy,* 11 (1980), p. 50.

28. Gabbey: "Newton's *reactio* is at the same time an *actio*, the *'re'* expressing both the fact of dynamical opposition and the fact that one of the bodies can always be taken as that which resists," *op. cit.*, p. 271.

Newton's generalization of the force concept to include both impulsive and continuously acting forces is described in I. B. Cohen, *op. cit.* (1980), sect. 4.4. That Newton's concept of force, as it first appears in the *Mathematical Principles,* is really impulse, which we represent as *Fdt,* is also shown by Brian Ellis, "The Origin and Nature of Newton's Laws of Motion," Colodny, ed., *op. cit.*, pp. 29-68.

29. The reaction force is not simply a fiction. It is supported by certain experiences. If you walk

inadvertantly into a wall, as I have done, it feels exactly as if someone shoved you. (This can only be an experience, not an experiment.)

30. This is the sense in which Newtonian physics can rightly be said to be common sense sharpened up, a remark often made by teachers of the subject. The tendency in recent scholarship to analyze each of Newton's laws singly, in terms of its historical development, leads to an emphasis on Newton's relation to Descartes and obscures a view of the three laws of motion as a completed interlocking whole. See, for example, Koyre, *op. cit.,* p. 65, and I. B. Cohen, *op. cit.,* (1980), p. 185; also J. Herivel, *The Background to Newton's Principia: A Study of Newton's Dynamical Researches in the Years 1664-1684* (Oxford: Oxford University Press, 1965). These studies accordingly suggest that Newton owed more to Descartes than he acknowledged. Yet, to the extent that Newton understood his final product in the manner here described, he owed rather less to Descartes since he arrived at a basically different physics.

31. It is Newtonian in that it incorporates the three items listed, all of which appear in the *Mathematical Principles.* It is Laplacian in that Laplace seems to have been the first to proclaim it publicly in *A Philosophical Essay on Probabilities,* F. W. Truscott and F. L. Emory, trans., (New York: Dover, 1951), p. 4. Newton did not proclaim it, and we must pass over the intriguing question whether his caution was prudential or theoretical.

32. Descartes, *Regulae,* Rule XIV; Crapulli, p. 67.

33. Approximations are necessary due to the many-body problem, and general relativistic corrections to Newtonian theory are well established. The question of final causality cannot be so easily dispensed with. While trajectories can be obtained without reference to final causes, they cannot be obtained without a choice of initial conditions. What then are the particular initial conditions that led to a solar system stable over a human time scale? The laws of motion and gravitation (Newtonian and Einsteinian) are necessary but not sufficient to account for the way the world is.

34. Newton, "Unpublished Conclusion of the *Principia," Unpublished Scientific Papers of Issac Newton,* A. R. and M. B. Hall, eds. (Cambridge: Cambridge University Press, 1962), p. 333. See also Newton's preface to the first edition of *Mathematical Principles,* p. xviii.

35. Laplace, *op. cit.,* p. 6.

36. *Mathematical Principles,* Corollaries I and II, pp. 14-15.

37. It is well known that such solutions can be found only for the 2-body and restricted 3-body central force problems. As indicated, the complexity of the many-body problem is of no philosophical significance.

38. In the language of physics, gravitation would then be a 'many-body force' rather than a 'two-body force'. Many-body force effects in the known forces are virtually always assumed away. The assumption is obviously justified by, and to the extent of, the success of the resulting calculations. It is equally obvious that this does not mean the assumption is universally true.

39. See, for example, Isaac Todhunter, *A History of the Theory of Elasticity,* K. Pearson, ed. (Cambridge: Cambridge University Press, 1893), Vol. 2, pt. 1, p. 183, note 2.

40. This makes use of the assumption that the bodies *on which b* acts are composed of dynamically independent parts, and thus subject to the parallelogram rule. The crucial application will be the reduction of the force exerted *by b* as a whole to the forces exerted by the parts of *b*.

41. *Mathematical Principles,* p. 17.

42. Ibid., Corollaries I and II, pp. 14-17.

43. Jammer, *op. cit.,* Ch. 7. Gabbey's excellent study will also be cited, *op. cit.,* pp. 281-86. Jammer, however, covers the history of the composition of forces more extensively, and, we believe, more correctly.

44. That the forces are impulsive and not continuously acting is implied by the constancy of the resulting component velocities. See also note 28, above. Corollary I is reported in Jammer, *op. cit.,* pp. 130-31, and Gabbey, *op. cit.,* pp. 281-82. Westfall, *op. cit.,* Ch. 8, cites the early versions of the parallelogram rule appearing in Newton's researches leading up to the *Mathematical Principles.*

45. *Mathematical Principles,* Corollary I, p. 14.

46. Newton, *Add. MS.* 3965.6, f. 86, quoted by Westfall, *op. cit.,* pp. 479 and 523, makes it clear that Newton presupposed the dynamical independence of forces *M* and *N:* "if the forces *M* and *N* be impressed . . . as though they were separately generating motions . . ."

47. *Mathematical Principles,* Corollary II, p. 15.

48. Jammer asserts, concerning the parallelogram rule, that "Newton . . . was convinced that its validity can be derived from the very concept of force, as is shown by his demonstration following Corollary I." *Op. cit.*, p. 128. We do not see the reason for the last phrase of this sentence, and suggest that the concept of force need not entail the dynamical independence of all agents in nature.

Gabbey states that "the respective actions of *M* and *N* . . . are independent *by definiton. M* and *N* are *vires impressae*, and so in the corollary are geometrically conceived component forces which cannot influence each other when acting simultaneously. If they did, this would contradict that part of the Second Law which refers to direction." *Op. cit.*, p. 286. We suggest that *M* and *N* are independent *by hypothesis* and will explain momentarily why we do not agree that the directional part of the second law is incompatible with a notion of modified action.

Westfall, *op. cit.*, Ch. 8, refers frequently to the parallelogram rule, but dynamical independence is assumed throughout without comment. Westfall, indeed, recounts Newton's struggle with a more immediate problem, namely, how to sort out inherent force (*vis insita*) from impressed force (*vis impressa*), both called 'force' by Newton, yet possessing different relations to motion.

49. *Mathematical Principles*, p. 17.

50. Jammer, *op. cit.*, p. 132.

51. The action of the whole is *partially* reducible to the actions of parts. For example, the gravitational portion of the animal's action is so reducible. Suppose that the live animal's weight is 15 lbs., so that its gravitational activity is to attract the earth toward it with a force of 15 lbs. Obviously, the sum of the weights of the parts of the dead animal is 15lbs. Clearly, then, the sum of the gravitational actions of the parts equals the gravitational action of the whole. The further investigation of this case forms the content of the concluding section of this paper.

52. Barre Saint-Venant, "De La Constitution des Atomes," (1878), quoted in Todhunter, *op. cit.*, p. 185; and Jammer, *op. cit.*, p. 133; translation by Anca Hassing.

53. Hermann Helmholtz, "Ueber die Erhaltung der Kraft," *Wissenschaftliche Abhandlungen* (Leipzig, 1882), Vol. I, pp. 15-16, my translation.

54. Ibid., pp. 68-69, my translation.

55. Werner Heisenberg, reporting Bohr's opinion in Heisenberg, *Physics and Philosophy* (New York: Harper & Row, 1958), pp. 104-105. For Bohr's description of the notion of complementarity in quantum physics, see, for example, "Discussion with Einstein on Epistemological Problems in Atomic Physics," *Albert Einstein Philosopher-Scientist*, P. A. Schilpp, ed., (LaSalle: Open Court, 1969), pp. 210 and 236.

56. What about quantum mechanics—has it not made the whole issue of determinism obsolete? Not in a way that would make clear the status of holistic principles in nature. The real question then is, what is the relation between holism and quantum theory? To answer this large question requires clarity about quantum mechanics. Yet the interpretation thereof remains open despite the ascendancy of the Copenhagen (Bohr-Heisenberg) school. See, for example, L. E. Ballentine, "The Statistical Interpretation of Quantum Mechanics," *Reviews of Modern Physics* 42 (1970): 358-81. See also the works of David Bohm. Furthermore, it is well known that quantum physics remains dependent on classical physics in a way that seems not to be removable by further changes of interpretation. "A more general theory can usually be formulated in a logically complete manner, independently of a less general theory which forms a limiting case of it. Thus relativistic mechanics can be constructed on the basis of its own fundamental principles, without any reference to Newtonian mechanics. It is in principle impossible, however, to formulate the basic concepts of quantum mechanics without using classical mechanics. The fact that an electron has no definite path means that it has also, in itself, no other quantitative dynamical characteristics. Hence it is clear that, for a system composed only of quantum objects, it would be entirely impossible to construct any logically independent mechanics. The possibility of a quantitative description of the motion of an electron requires the presence also of physical objects which obey classical mechanics to a sufficient degree of accuracy . . . . Thus quantum mechanics occupies a very unusual place among physical theories: it contains classical mechanics as a limiting case, yet at the same time it requires this limiting case for its own formulation." L. D. Landau and E. M. Lifshitz, *Quantum Mechanics*, J. B. Sykes and J. S. Bell, trans., (London: Pergamon Press, 1958), pp. 2-3. The attempt to understand classical physics is a necessary first step.

57. Both Newton and post-Newtonian physics refrain from specifying a cause of gravitation, and stay with the law of its effect. In this sense, Newtonian gravitational theory is not a causal

theory. The sense of causal neutrality used in this paper, however, gives special emphasis to the whole-part relation.

58. See note 51, above.

59. It attracts all the other bodies in the universe, but we can neglect this here.

60. *Mathematical Principles,* Bk. III, Prop. VIII, p. 415. See also Hall, *op. cit.,* p. 295.

61. Newton used Props. 75 and 76 of *Mathematical Principles,* Bk. I, and their corollaries to carry out the needed calculation. Using modern vector integration, the procedure is standard in mechanics and field theory: "The law of gravitation as formulated [Gm_1m_2/R^2] is applicable only to particles or to bodies whose dimensions are negligible compared with the distance between them; otherwise the distance [R] is not precisely defined, nor is it immediately clear at what points and in what directions the forces act. For extended bodies, we must imagine each body divided into pieces or elements, small compared with the distances between the bodies, and compute the forces on each of the elements of one body due to each of the elements of the other bodies." K. R. Symon, *Mechanics* (Reading: Addison-Wesley, 1960), p. 257.

62. Is this not the presence of Bacon? ". . . in nature nothing really exists besides individual bodies, performing pure individual acts according to a fixed law. . ." *New Organon,* Spedding, Ellis, and Heath, trans., F. H. Anderson, ed., (Indianapolis: Bobbs-Merrill, 1960), p. 122.

63. How small should the ratio of their sizes to their separation be? As small as required to yield the accuracy needed for the calculation in question. The law seems to be intimately related to practice.

64. *Mathematical Principles,* Bk. I, Prop. 75, p. 197.

65. A completely passive being could not act on our sense organs (or on any sensing instrument) and would thus not be perceptible.

The mental production of algebraic magnitudes, and the implications of their employment in the science of nature are treated by Jacob Klein, *Greek Mathematical Thought and the Origin of Algebra,* E. Brann, trans., (Cambridge: MIT Press, 1968), a work as important as it is difficult to understand. The meaning of 'law'—the fundamental intelligible in the modern understanding of nature—remains to be fully explicated.