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THE LEIBNIZIAN-NEWTONIAN DEBATES: NATURAL PHILOSOPHY AND SOCIAL PSYCHOLOGY

By Carolyn Iltis*

By the time of the Leibniz-Clarke correspondence of 1716 the Newtonian and Leibnizian systems of natural philosophy had reached maturity. Each system consisted of different physical as well as metaphysical principles which, taken together, formed a world view. At the time of their famous debates, Leibniz at 70 and Newton at 74, the founders of two highly developed scientific philosophies, were struggling to establish and defend the ontological and mechanical bases of differing bodies of organized knowledge.

One aspect of this clash of philosophies was the famous *vis viva* controversy which revealed metaphysical as well as physical disagreements.[1] In this paper I shall discuss the mechanical arguments between the Leibnizians and Newtonians, showing how these arguments were related to the scientific metaphysics of the two systems. The positions of the two great thinkers, Leibniz and Newton, were set forth in the Leibniz-Clarke correspondence of 1716 with Samuel Clarke representing Newton.[2] The followers of the two men carried on debates in mechanics during the 1720s through the communication channels of the Royal Society and certain continental journals.

In the following analysis, I shall make three main points:

1. The Leibnizian-Newtonian controversy was fundamentally a clash of philosophical world views on the nature of God, matter, and force. The two systems of natural philosophy were very different organizations of knowledge based on metaphysical and mechanical principles.

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[1] This paper forms one of a series of discussions by myself and others concerning various aspects of the *vis viva* (living force) controversy over the measure of the 'force' of a body in motion. Carolyn Iltis, 'Leibniz and the *vis viva* controversy', *Isis*, lxii (1971), 21–35; 'The decline of Cartesianism in mechanics', *Isis*, lxiv (1973); 'D'Alembert and the *vis viva* controversy', *Studies in history and philosophy of science*, i (1970), 135–44. Thomas Hankins, 'Eighteenth century attempts to resolve the *vis viva* controversy', *Isis*, lvi (1965), 281–97. L. L. Laudan, 'The *vis viva* controversy, a post-mortem', *Isis*, lix (1968), 131–43.

[2] Samuel Clarke, *A collection of papers which passed between the late learned Mr. Leibniz and Dr. Clarke* (London, 1717).

2. The adherents to a scientific system also function as a social system. The Newtonian and Leibnizian groups of the 1720s developed a commitment to the mother scheme and took on the task of defending that system against the perceived threats of outside attacks. These attacks were implicit in the mechanical problems and experiments posed by adherents to the opposing system, challenging fundamental presuppositions and principles.
3. The followers defended their respective world views by reinterpreting the challenging experiments so that they supported their own mechanical philosophy. They were unwilling and *unable* to see that the other side had valid arguments. The early *vis viva* controversy of the 1720s was therefore the result of a problem in communication brought about by the inability of the participants to cross the boundary lines of their particular natural philosophies. The recognition that both viewpoints could be valid began to take place by the 1740s, when integrations between the two schemes began to occur.

In attempting to substantiate these claims I shall discuss first the social psychology of the Newtonian and Leibnizian groups, then the Newtonian and Leibnizian natural philosophies, and finally the mechanics of the *vis viva* debates of the 1720s. In these arguments the challenging Leibnizian experiments were performed by William 'sGravesande, a convert from the Newtonian camp, and Giovanni Poleni. The Newtonian case was defended by Henry Pemberton, John Theophilus Desaguliers, John Eames, and Samuel Clarke.

1. *Social psychology of the Newtonian and Leibnizian groups*

It has often been stated that the *vis viva* controversy was the result of a communication problem. Contemporary participants as well as historians have considered it 'a mere question of words'.[3] However, the communication barriers were more than matters of definition; they were the results of social and psychological considerations.

It has been thought that the controversy was a result of inadequate communication over the meaning of words, that if the participants had been better able to define their terms, the controversy would not have arisen, or at least would have been quickly resolved. Although an abundance of information was repeatedly stated by many individuals, constant

[3] William Whewell, *A history of the inductive sciences* (3rd edn., New York, 1872), i. 361: 'Finally d'Alembert in 1743 declared it to be, as it truly was, a mere question of words'. Jean d'Alembert, *Traité de dynamique* (1st edn., Paris, 1743), p. xxi: 'The entire question cannot consist in more than a very futile metaphysical discussion or in a dispute of words unworthy of still occupying philosophers'. William 'sGravesande, 'Remarques sur la force des corps', *Journal littéraire de La Haye*, xiii (1729), pt. 1, 196: 'I will pass to impact where it will be seen that what was at first a dispute over words becomes a dispute on the thing itself'. Max Jammer, *Concepts of force* (Cambridge, Mass., 1957), p. 165: 'Without going into details and discussing the various arguments of the participants in this discussion, it may be stated that it was a mere battle of words, since the disputants discussed different concepts under the same name'.

repetitions continually failed to resolve the controversy. With the recognition that the adherents to a scientific system also function as a social system, the course that the controversy took can be explained better. The transmission of ideas and the production of results depend upon communication among people working within a given system of natural philosophy and between systems.

Although a scientific system is a structure of knowledge, it always has associated with it an informal organization of scientists. The Newtonian group concerned with the *vis viva* controversy in the 1720s consisted of Samuel Clarke, Henry Pemberton, John Theophilus Desaguliers, and John Eames.[4] These men were involved in the task of expounding Newton's ideas, translating them into popular language, devising demonstrations and experiments for explicating Newtonian principles, and teaching Newtonian concepts to the general public through lecture demonstrations and textbooks. They were in close physical proximity to Newton, now in old age, relating to him by direct communication or through correspondence. Intellectually they related directly through the implications and applications of the Newtonian metaphysics and concept of force. Because they functioned in this close satellite relationship to Newton, they formed a scientific bureaucracy devoted to the exposition and explanation of Newtonian principles.

We may argue that the followers of a particular scientific system identify with the central ideas of the system, developing a loyalty to it and its originator. The metaphysical and theoretical presuppositions of the system become imprinted on them. The scientists become functioning members of an informal group, perceiving and communicating from within the assumptions, objectives, and principles of the system. As a cohesive group they feel a strong sense of responsibility to the ideals of the conceptual scheme and their leader. There may also be a tendency to exclude outsiders.

The Newtonian and Leibnizian followers developed a commitment to the systems of natural philosophy developed by Newton and Leibniz. As a result of this commitment, they became wedded to the goals, methods, concepts, and analysis of nature afforded by each of these scientific schemes. Theology, metaphysics, and mechanics formed aspects of the systems to which they adhered.

Newtonian followers, operating under this commitment, viewed problems and competing theories with a different perception from those operating outside the group. The writings and experiments of adherents to other systems were perceived by them as a threat to the legitimacy of Newtonian natural philosophy. Their psychological reaction to these

[4] On the concept of a Newtonian group see Frank Manuel, *A portrait of Sir Isaac Newton* (Cambridge, Mass., 1958), ch. 13, and W. G. Hiscock, *David Gregory, Isaac Newton, and their circle* (Oxford, 1937).

outside disruptive factors was to try to restore the Newtonian scheme to its original validity, by explaining the threatening data in their own terms. This prevented them from seeing the validity of supposedly 'objective' 'factual' experimental results from another equally legitimate perspective.[5]

This analysis can serve to explain the violent reactions of both the Newtonians and Leibnizians to outside attacks on the systems of the masters. It also helps to undermine the notion of objectivity in the sciences, by showing how social factors can influence a scientist's perception.

One of the challenges to the Newtonian scheme took the form of mechanical free-fall experiments conducted by the Leibnizians, William 'sGravesande and Giovanni Poleni, supporting the measure of force, mv^2. The Newtonian group in explaining the experiments from within the Newtonian framework attempted to restore the system to its established state by demonstrating the successful handling of mechanical problems using momentum (mv) considerations. In regard to these free-fall experiments, they adequately demonstrated their ability to apply and translate the concept of Newtonian force so as to explain the externally imposed Leibnizian problem. They also discussed the previously established problems of the lever and impact from the point of view of momentum conservation. But in the early years of the controversy they were unable to perceive any validity in the arguments of the opposition.

The Leibnizians responded to these defences by further explicating the mv^2 interpretation of the free-fall experiments from their own particular perspective. 'sGravesande, who had crossed the boundaries between the two schemes through his conversion to the Leibnizian concept of force, was now unable to accept the adequacy of the Newtonian arguments.

Theological and metaphysical commitments on the part of these experimenters caused them to interpret the mechanical experiments in a manner consistent with their natural philosophies. I shall show that although their experimental results were unconvincing and fraught with experimental error, their positions were unchanged and their loyalties were not undermined.

2. *The Newtonian and Leibnizian world views*

The Newtonian and Leibnizian views of nature were radically different. Concepts of God, matter, force, and causality formed fundamental metaphysical dichotomies. It is insufficient to argue that Newton and Leibniz both added differently defined concepts of force to the mechanical philosophy's ontology of matter in motion.[6] The metaphysics

[5] For an account of the psychological dynamics of social groups see Daniel Katz and Robert L. Kahn, *The social psychology of organizations* (New York, 1966), especially pp. 223–8.

[6] Richard S. Westfall, *Force in Newton's physics* (London, 1971), p. 283.

behind these concepts of force had developed from widely differing intellectual traditions.

(a) Theology

Newton's and Leibniz's opinions on the nature of God may be examined against the background of the intellectualist-voluntarist debates of the medieval period.[7] The intellectualist tradition with which Leibniz can be associated assigned primary importance to God's intellect, logic, and rationality. The voluntarists, who included Newton, made the divine will prior to divine intelligence.

Aquinas had considered the essence of God to be identical with his infinite intellect. The logical consistency of his properties was primary; from these followed his power to act. Intellect gave rise to the will and from this proceeded God's love. The *potentia anima* was uppermost in man and likewise in God. If the will was stressed too much, God became unintelligible. For the Thomists, omniscience regulates omnipotence.

The Augustinian voluntarist tradition emphasized the will, power, and love of God in his active creation and intervention in the world. God could create everything immediately, spontaneously, and directly, out of nothing. This manifestation of infinite power and will guarded God's freedom. The divine will was prior to and motivated the intellect's interests. Following in the voluntarist philosophy were the Franciscans and nominalists, Duns Scotus and William of Ockham.

The intellectualist-voluntarist argument was of primary importance in initiating the Leibniz-Clarke correspondence. Leibniz considered the necessity of God's intervention in the Newtonian machine of the universe to be a limitation on his wisdom and foresight.[8] Newton and Clarke argued that God's glory and power were manifested in his providential care and interposition.[9] The world as Newton and Clarke viewed it could have been otherwise, for it depended on the free exercise of God's will and its continued sustenance.

For Leibniz, the actual world was the best of all possible worlds since God operated rationally within the laws of logic to create it. The possibility for the existence of the natural world must be consistent with the principle of non-contradiction; its beings must exhibit nothing mutually destructive or incompatible.[10] However, such a possible world may not actually exist; the principle of sufficient reason explains the existence of this world and no other.[11] This principle is necessary in proceeding from the laws of

[7] On the voluntarist background to Boyle's philosophy, see J. E. McGuire, 'Boyle's conception of nature', *Journal of the history of ideas*, xxxiii (1972), 523–42.

[8] Gottfried Wilhelm Leibniz, *Philosophical papers and letters*, ed. Leroy E. Loemker (Chicago, 1956), ii. 1096.

[9] Ibid., 1098. See also David Kubrin, 'Newton and the cyclical cosmos; providence and the mechanical philosophy', *Journal of the history of ideas*, xxviii (1967), 326–46.

[10] Loemker, ibid., 1099.

[11] Ibid., 1100.

logic to those of natural philosophy. God's sufficient reason unites his logic with his power.[12] The creation of the world by will alone might result in an ill-constructed, inferior world.

At the root of the intellectualist-voluntarist debate was the fear that God's nature would be limited. The Newtonians feared that Leibniz's concept of God would lead to atheism, for if God could not intervene in his creation, it was only one more step to say that the concept of a creator was unnecessary. The Leibnizians held that the necessity of God's intervention implied a limitation on his intelligence and foresight. These anxieties helped to programme the positions which individual 'scientists' took in the *vis viva* controversy over the concept of 'force'.

(b) Philosophy of Matter

A related but equally fundamental difference between the two philosophies of nature was the issue of a mechanistic versus a vitalistic view of the relationship between matter and force. The mechanical philosophy expressed in Newton's Queries to the *Optics* presupposed dead, static, unchanging, extended particles of matter.[13] From his correspondence and private papers it is clear that he considered the ultimate source of force and motion to be God himself, externally superimposed upon bodies.[14] Matter itself was lifeless; the machine of the world inert without its operator.

On the other hand, Leibniz viewed the world as an organic whole in which all parts were interconnected and interrelated. Matter was alive and contained a force or a principle of change within it. Nothing in nature was fixed or static, but was in constant dynamic change. In 'The monadology' of 1714, Leibniz had explained that natural changes in the lives of the simple unextended substances called monads came from an internal principle.[15]

External causes could not influence the interior actions of these windowless monads. Each monad mirrored the universe in its own way, its life unfolding simultaneously with the lives of all other monads in an organically related, pre-established harmony. As Leibniz put it,

> There is a world of creatures, living beings, animals, entelechies, souls in the smallest particle of matter. Each part of matter can be thought of as a garden full of plants or as a pond full of fish. But each branch of the

[12] Ibid., 1102.

[13] Isaac Newton, *Opticks* (based on the 4th edn., London, 1730; New York: Dover Publications, 1952), p. 400.

[14] J. E. McGuire, 'Force, active principles, and Newton's invisible realm', *Ambix*, xv (1968), 154–208. P. M. Heimann, 'Nature is a perpetual worker', *Ambix*, xx (1973), 1–25.

[15] Loemker, op. cit. (8), ii. 1045. The first published version of the 'Monadology' appeared in German translation in 1720.

plant, each member of the animal, each drop of its humors, is also such a garden or such a pond.[16]

It is important to explore briefly the intellectual traditions that gave rise to these dichotomous views of matter. Frances Yates and Allen Debus have discussed the increased interest in Renaissance Hermeticism and neoplatonism which paralleled the rise of the mechanical philosophy.[17] Walter Pagel has shown that Leibniz's monadology stemmed from the Helmontian aspect of this tradition and has suggested that Leibnizian vitalism can be pushed back to Paracelsus, who was an important influence on van Helmont.[18] Newton, however, was influenced by another strand of Renaissance neoplatonism, as has been demonstrated by McGuire, Rattansi, and Westfall.[19]

Leibniz's theory of matter may be analysed in the light of a Paracelsian dynamism, emphasizing the interconnectedness of all things. Paracelsus, in his 'Hermetic philosophy', held a vitalistic view of matter.[20] All created things consisted of the four elements.[21] 'An element', he said, 'is really neither more nor less than a soul'. 'An element is spirit and lives and flourishes in those things as the soul in the body . . . For the first matter of the elements is nothing else than life which all created things possess.'[22] Like Leibniz's monads, the four elements contain a principle of change within them. The monads, like the elements, are souls in their simplest state.[23]

The Paracelsian elements exist independently of one another. Things are not compounded of several elements in conjunction, but four worlds

[16] Ibid., 1056. This passage bears striking resemblance to Far Eastern views of the universe as an organic whole whose parts are interrelated. Although the purpose of this paper is to place Leibniz's view of nature within a Western intellectual tradition, it should be pointed out that Leibniz was in close contact with Jesuit missionaries bringing back ideas and texts from China to Western Europe (see Loemker, ibid., i. II). Joseph Needham in *Science and civilisation in China* (Cambridge, 1956), ii. 291–2, 498–500, has suggested a strong influence of Chinese philosophical thought on Leibniz: 'Against the Cartesian view of the world as a vast machine, Leibniz proposed the alternative view of it as a vast living organism, every part of which was also an organism. This picture was finally presented (in 1714 at the very end of his life) in the short but brilliant treatise posthumously published, the *Monadology*. The hierarchy or monads and their "pre-established harmony" resembled the innumerable individual manifestations of the Neo-Confucian Li in every pattern and organism. Each monad mirrored the universe like the nodes of Indra's Net' (499).

[17] Frances A. Yates, 'The Hermetic tradition in renaissance science', in *Art, science, and history in the renaissance*, ed. Charles S. Singleton (Baltimore: Johns Hopkins Press, 1968); *Giordano Bruno and the Hermetic tradition* (New York, 1964). Allen Debus, *The English Paracelsians* (London, 1965).

[18] Walter Pagel, 'The religious and philosophical aspects of van Helmont's science and medicine', *Bulletin of the history of medicine*, supp. no. 2 (1944), 1–43; *Paracelsus* (New York, 1958), pp. 36, 108.

[19] J. E. McGuire and P. M. Rattansi, 'Newton and the "Pipes of Pan"', *Notes and records of the Royal Society of London*, xxi (1966), 108–43. P. M. Rattansi, 'Newton's alchemical studies', in *Science, medicine and society: essays to honor Walter Pagel*, ed. Allen G. Debus (New York, 1972), pp. 167–82. Richard S. Westfall, 'Newton and the Hermetic Tradition', ibid., pp. 183–98.

[20] Paracelsus, *Hermetic and alchemical writings*, ed. A. E. Waite (London, 1894), ii. 249–81.

[21] Ibid., 263.

[22] Ibid., 266.

[23] Loemker, op. cit. (8), ii. 1047.

develop separately from each element: 'The doctrine of the elements does not lay it down that the world must be sustained by the four elements but rather that everything is conserved by one element, namely that from which it sprang . . . Neither is the world going to perish by itself but suffices for its own sustentation . . . Nothing decays, nothing perishes', Paracelsus stated.[25] Leibniz's monads are likewise simple substances, whose lives unfold separately, conserving within them the total 'force' of the universe. They cannot be destroyed naturally nor can they have a natural beginning; instead all are created or annihilated at once. The monads are 'the elements of things'.[26]

From the four elements of Paracelsus flow four worlds, each separate and self-contained, yet co-existing. Each element puts forth its own different species and essences.[27] For example, the element of fire gives forth the firmament, the sun and stars. The fire which burns is not the element fire, but its soul, the life of which can be present in all things.[28] So as roots, stems, filaments and flowers emerge from a single seed, the elements produce their own worlds. 'Every element nourishes itself.'[29] 'So in water a special world is to be recognized together with its mystery, even to the end of the world. There is no beginning in these save that which is in the other elements; nor is there any other end than is found in the other elements . . . Thus we must understand the four worlds according to the four elements'.[30] The flowing out of four worlds from the four elements of Paracelsus became the unfolding of a plurality of worlds in the philosophy of Leibniz. Each monad, its life unfolding from within, contains a world within itself. It reflects the larger world from its own point of view.[31]

Paracelsus, like Leibniz, emphasized the relations between the concurrent processes in the four worlds:

> One element . . . gives sign of its course and its advent which are easily recognized by the stars, not because these rule or influence us but only because they run concurrently with us and imitate the inner movement of our body . . . If anything suffers from the error of the elements, other things grow uncertain too. All ought to proceed with a perfect and unimpeded motion . . . And the defects and errors of the firmament can be observed by us, no less than the firmament observes our defects.[32]

Leibniz expressed a similar idea of the interconnectedness of all things when he wrote:

[24] Paracelsus, op. cit. (20), ii. 270.
[25] Ibid., 264.
[26] Loemker, op. cit. (8), ii. 1044.
[27] Paracelsus, op. cit. (20), ii. 267.
[28] Ibid., 266.
[29] Ibid., 271.
[30] Ibid., 268.
[31] Loemker, op. cit. (8), ii. 1053.
[32] Paracelsus, op. cit. (20), ii. 268.

> This mutual connection or accomodation of all created things to each other and of each to all the rest causes each simple substance to have relations which express all the others and consequently to be a perpetual living mirror of the universe.[33]

'Every body responds to everything which happens in the universe so that he who sees all could read in each everything that happens everywhere . . .'[34]
Pagel has pointed out that the repercussions of particular changes on the rest of the world implied a 'consensus' of individual actions in the philsophies of both Paracelsus and Leibniz.[35]

Leibniz carefully dissociated himself from the philosophy of Robert Fludd, which denied 'a proper activity to created things' and Henry More whose doctrine of a universal spirit external to matter negated an activity of particular souls within it.[36]

Pagel has demonstrated further important connexions between van Helmont (who was influenced by Paracelsus) and Leibniz's 'Monadology'. Van Helmont created a vitalistic pluralism of seeds, unifying spirit and matter. His dynamic principles like those of Leibniz were immanent in matter. The dynamic principle in matter, or the *archeus* of van Helmont, 'acts by its own spontaneity according to its own innate schedule, which runs down to its destined end', unalterable from without.[37]

Newton, in sharp contrast with Leibniz, was concerned with demonstrating the passivity and non-activity of matter. The active principles which provide the source of motion in bodies were external to matter. He held that matter depended ultimately on the will of God for its existence and motion.[38] The conception of matter as self-active led to atheism.

Newton's belief in the passivity of matter with its external source of activity developed from another strand of the Hermetic tradition. This conception emphasized the idea of spirit as the source of activity infusing matter with life and vital processes. The *spirtus* notion played an important role in the natural magic of Ficino, and the 'philosopher's mercury' of alchemists such as Elias Ashmole and Robert Fludd. Ashmole held that

> The power and vertue is not in Plants, Stones, Minerals, etc. . . . but 'tis that universal and all-piercing Spirit, the One operative vertue and immortal Seede of Worldly things that God in the beginning infused into the Chaos, which is everywhere active and still flows through the world in all kindes of things by universal extension.[39]

33 Loemker, op. cit. (8), ii. 1053.
34 Ibid., 1054–55.
35 Pagel, *Paracelsus*, op. cit. (18), p. 38.
36 Loemker, op. cit. (8), ii. 816, 901.
37 Pagel, 'Religious aspects', op. cit. (18), 34.
38 McGuire and Rattansi, op. cit. (19), 119.
39 Quoted in Rattansi, 'Newton's alchemical studies', op. cit. (19), p. 174.

For Fludd, matter was never the first cause but was transformed by the action of winds and ultimately influenced by the angels whose activity was an instrument of God's eternal wisdom.[40]

The chemist Stahl believed motion to be an immaterial substance which was superimposed on a body from the outside, an active external influence of the *anima* or soul on matter.[41]

Henry More, an early influence on Newton, stated that 'The Notion and Idea of a Spirit . . . is plainly distinguished from a Body whose parts cannot penetrate one another, is not Self-moveable, nor can contract nor dilate itself, is divisble, and separable one part from another.'[42] The active properties of spirit were thus opposed to the attributes of dead matter.

In the natural philosophies of Descartes and Boyle, the active-passive polarities of the alchemists and Hermetic philosophers became a dualism of mind and matter. Descartes reduced nature to passive, inert, extended matter, and translated the *spiritus* into a fine, subtle æther which provided the external source of the motion of bodies.[43]

Newton's mechanical æther of the 1670s, his belief in an immaterial cause of gravity of the 1690s, his active principles and repulsive æther of the 1706–17 *Optics* all reflect this tendency toward external sources of activity in nature. We can see therefore that Renaissance Hermeticism and neoplatonism were important influences on the philosophies of both Newton and Leibniz, but diverging trends led to their differing mechanistic and vitalistic philosophies of matter.

(c) Causality

A third but also logically related difference between the Newtonian and Leibnizian philosophies of nature brought out by the Leibniz-Clarke correspondence was the problem of causality. It related directly to the above theological positions and views of matter. For Leibniz the equality of cause and effect relationships in nature was synonymous with a general metaphysical principle of conservation. The 'same force and vigor' was always present in the world passing from one particle of matter to another.[44] In contrast, Newton held to no such principle of strict causality. In his philosophy, the world could decay and run down owing to loss of motion between colliding hard atoms.[45] God's power and providential care could be manifested in supplying new motion to the unwinding clockwork mechanism. His intervention in the universe was therefore guaranteed.

[40] Walter Pagel, 'Religious motives in the medical biology of the XVIIth century', *Bulletin of the Institute of the History of Medicine*, iii (1935), 270.
[41] Pagel, 'Religious attitudes', op. cit. (18), 33.
[42] Alexandre Koyré, *From the closed world to the infinite universe* (New York, 1958), p. 128.
[43] Westfall, op. cit. (19), pp. 186–7.
[44] Loemker, op. cit. (8), ii. 1096.
[45] Newton, *Opticks*, op. cit. (13), pp. 397–9.

Leibniz's principle that total cause equals total effect in mechanical interactions was consistent with his view of the primacy of God's rational omniscience and a manifestation of the principles of identity, and non-contradiction: A is A and cannot be non-A.[46] Since matter was held to be elastic, force could be stored in the small parts and released, conserving 'force', mv^2, between the macroscopic and microscopic realms.

Newton's concern with the ontology of causation was directed towards the relationship between the hidden forces and invisible atoms of the microscopic world and the manifest quantifiable forces and laws of the macrocosm.[47] By the 'analogy of nature' similar laws could by hypothesized to operate in both realms. But since the underlying hard atoms of the invisible realm could dissipate macroscopic motion one could not assume causal conservation relationships between the two levels of reality.

In the Leibniz-Clarke correspondence Clarke, speaking for Newton, discussed the question of conservation of motion between hard colliding atoms. In his fourth reply he stated that two inelastic bodies colliding with equal forces lost all their motion, implying that this was an example of the diminution as opposed to the conservation of force in the universe.[48] Leibniz had answered that in the collision of two soft or inelastic bodies, the 'forces' (meaning mv^2) were lost only in appearance. For 'the wholes lose it with respect to their total motion, but their parts receive it, being shaken internally by the force of the concourse . . . The bodies do not lose their forces, but the case here is the same as when men change great money into small'.[49]

To this Clarke had replied that the problem lay not with *soft* inelastic bodies but with *hard* inelastic bodies, as were Newton's atoms:

> But the question is: when two perfectly HARD unelastic bodies lose their whole motion by meeting together, what then becomes of the motion or active impulsive force. It cannot be dispersed among the parts, because the parts are capable of no tremulous motion for want of elasticity.[50]

Although the death of Leibniz in 1716 cut short the correspondence before he had answered Clarke's fifth reply, his approach would have been to deny the existence of absolutely hard bodies in nature. Leibniz had argued often on the basis of the law of continuity that the diminution of motion cannot take place in leaps.

In his 'Fifth reply' Clarke elaborated on the diminution of motion and the role of God in preventing blind mechanism:

> And if God, or Man, or Any Living or Active Power, ever influences any thing in the material world; and everything be not absolute mechanism;

46 Loemker, op. cit. (8), ii. 1099.

47 McGuire and Rattansi, op. cit. (19), 125. J. E. McGuire, op. cit. (14), 194–7; 'Atoms and the "analogy of nature"', *Studies in history and philosophy of science*, i (1970), 4–6.

48 Loemker, op. cit. (8), ii. 1131.

49 Ibid., 1161–2.

50 Clarke, op. cit. (2), p. 111, sec. 99.

there must be a continual Increase and decrease of the whole Quantity of Motion in the Universe. Which this Learned Man frequently denies.[51]

The argument between Clarke and Leibniz emphasized fundamental differences for the role of force, F, and causality in hard and elastic matter mechanics. Motion in the mechanics of Newton and Clarke was inertial, a state of being. A body, mass m, continued its constant velocity, v, because of its inertia or resistance to change of motion. This was expressed as a quantity of motion, or momentum, mv. If the momentum changed, the action of an impressed external force was indicated. If the total motion in the universe decreased, owing to head-on hard-body collisions between equal atoms, the universe could run down. New motion must be supplied by God, an instance of his providential care. In Leibniz's energy mechanics the action was internal. Force was measured by mv^2, the mass multiplied by the square of the velocity. Activity and the tendency toward motion were inherent within matter. These tendencies and motions stored in the small parts of matter could be changed to the motions of the entire body when dead force changed to living force. The energy of matter was thus fundamental to Leibniz's view. The elastic parts of matter were a storehouse where energy and motion were conserved. For Newton the infinite storehouse of new motion was God, because matter itself was composed of hard unchanging inelastic atoms.

In section 2 I have tried to characterize certain aspects of the fundamentally dichotomous views of nature held by Leibniz and Newton. These radically different systems of natural philosophy were related to intellectual traditions and placed within an historical framework. That these deep differences existed is important in understanding the psychology of the emotional ties and loyalties developed by the followers of the two systems. The heated arguments over mechanics to which we now turn are better comprehended within such an intellectual and socio-psychological framework.

3. *Mechanics and the free-fall debates: 1718–28*

Adherents to the Newtonian and Leibnizian systems of natural philosophy devised mechanical arguments in support of the extremely different concepts of force, mv and mv^2. In the period 1718 to 1728 a lively debate occurred concerning the problem of the 'force' acquired by freely falling bodies. The debate was triggered by free-fall experiments performed by Giovanni Poleni and William 'sGravesande in support of the *vis viva* principle. Counterarguments and experiments were presented by the Newtonians Henry Pemberton, John T. Desaguliers, John Eames, and Samuel Clarke.

In my discussion of these mechanical problems I wish to show that the two groups reacted to the externally imposed threats by strengthening

[51] Ibid., footnote to sec. 99, pp. 111–12.

their own analyses of force and by reinterpreting the experiments to fit their respective conceptual schemes. Secondly, I hope to demonstrate that the experiments in themselves were unconvincing and hence that the insistence of the practitioners that these experiments supported concepts of either mv or mv^2 were coloured by loyalties and preconditioned adherence to the mother philosophies. Thirdly, wherever possible I shall indicate the extent to which the various participants adhered to the systems of natural philosophy outlined in section 2.

(a) The Leibnizian free-fall experiments

In the 'Brevis demonstratio' of 1686 Leibniz had presented logical arguments concerning the force of two unequal bodies (of weights or masses 1 and 4) falling from heights inversely proportional to their masses.[52] 'Force', he said, should be measured by its effect, i.e. by the height to which a given force can elevate a body of a given magnitude. The mathematical measure of force was later expressed by Leibniz as *vis viva*, mv^2, or the body's mass multiplied by the square of its velocity. (If bodies having masses, m, (or weights) in the ratio 1 to 4, fall from heights, s, of 4 and 1, their 'forces' or *vires vivae*, mv^2, will be equal, because $s \propto v^2$. See Figure 1.)

It was not until after Leibniz's death in 1716 that the thought experiment described in the 'Brevis demonstratio' was empirically tested. A work by Giovanni Poleni of Padua, *De castellis per quae derivantur fluxiomru latera convergentia* (1718), summarized the arguments for *vis viva* which had appeared prior to 1718 and described experimental support for the principle.[53] In this treatise Poleni discussed the forces produced by water pressures in several vessels resembling castles, hence the title, *De castellis*. In the concluding pages of his book he presented a theory for the 'force' of bodies in motion based upon his work on the flow of water in which he distinguished between the momentum and *vis viva*.

He described the loss of motion of a body in impact, in which a body experienced a pressure (*pressio*) brought about by the thrust (*impressio*) of another body.[54] The change brought about by the completion of the pressure was the *momentum pressionis*. If a body used up all its motion in the interaction, the cause of this complete effect could be measured as *vis viva* or living force. He described free-fall experiments in which a moving body lost all motion in impact with a soft medium. His experiments were designed to show that this concept of 'force' should be measured by the 'body' multiplied by the square of the velocity:

[52] Gottfried Wilhelm Leibniz, 'Brevis demonstratio erroris memorabilis Cartesii et aliorum circa legem naturalem, secundum quam volunt a Deo eandem semper quantitatem motus conservari; qua et in re mechanica abutuntur', *Acta eruditorum* (1686), pp. 161–3. Translation in Loemker, op. cit. (8), ii. 445–63.

[53] Johannis Marchionis Poleni, *De castellis per quae derivantur fluviorum latera convergentia* (Padua, 1718), pp. 47–54. The title was also a play on the name of Benedetto Castelli,

[54] Ibid., pp. 45–6.

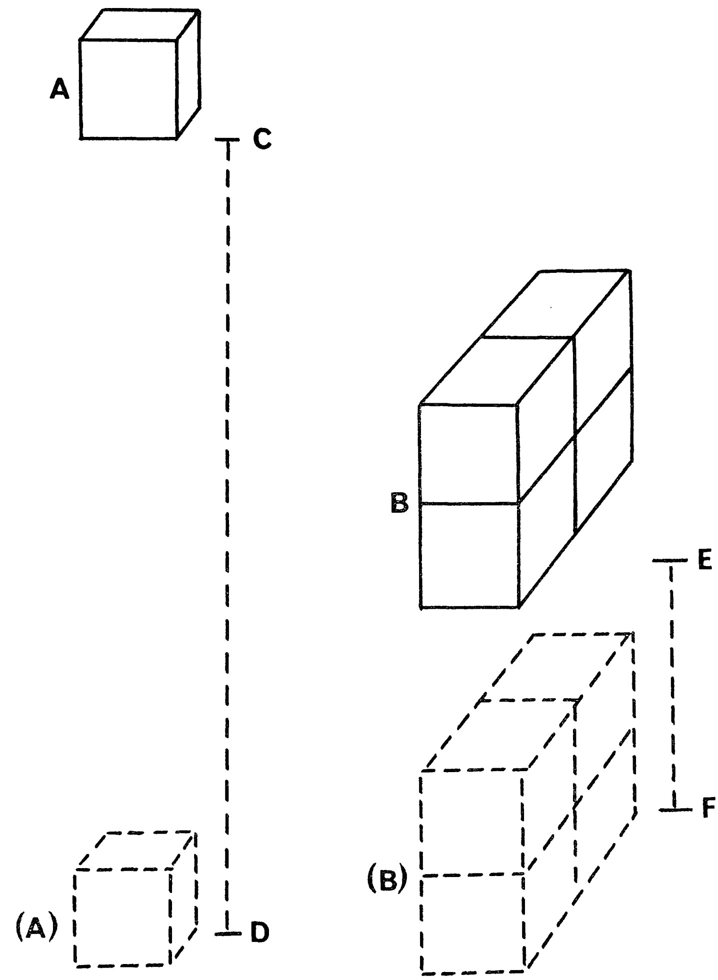

FIG. 1
From Leibniz, 'Brevis demonstratio . . .', *Acta eruditorum* (1686).

I took a Vessel, that had in it congeal'd Tallow six Inches deep, and fix'd it to a level floor, in such manner that the surface of the Tallow, which was flat, should every where be equally distant from the Floor. I had caused to be made two Balls of equal Bigness, the one of Lead, the other of Brass, the last of which was a little hollow in the middle, that it might weigh but one Pound, whilst the other weigh'd two. Suspending these Balls from the Ceiling by Threads, in such manner, that the lighter Ball hung over the Surface of the Tallow, from twice the Height that the Heavier Ball did, I cut the Threads, and the Balls falling perpendicularly upon the Tallow, by their Fall made Pits in the Tallow, that were precisely equal; the Ball of one Pound, from the Beginning of its Fall, till it came to rest, going through a Space express'd by the Number two, produced an effect equal to that which the two Pound Ball did produce, in falling thro' a Space express'd by the Number one. It follows therefore that we may look upon it as a settled truth, That the active Forces (*vires vivae*) of falling Bodies are in a reciprocal Ratio of the Spaces which the said Bodies describe by their Fall. And because these Spaces are in the same Ratio, as the Squares of the Numbers expressing the Velocities; it appears by the Experiment that the active Force (*vis viva*) of the Falling Body, is that which is made up of the Body itself, multiplied into the Space described in the Fall, or into the Square of the Number that expresses the Velocity of the Body, at the end of the Motion. This Experiment I did not only make once, but several times, changing the Balls, the Distances, and the Body on which they fell; as for example making use of Clay, or of soft Wax: and notwithstanding these various ways of trying the Experiments, the Effects were constantly the same; which made me easily conclude, that there was always the same Reason in Nature for this Phenomenon.

$$\left[\frac{ws}{w's'}=\frac{mv^2}{m'v'^2}=\frac{1\,(2)}{2\,(1)}\right].$$ [55]

In attempting to repeat and evaluate the procedure of this eighteenth-century experiment today, several experimental difficulties should be noted. The falling objects must be uniformly round so that, after falling, the impressions formed will be uniform. An increase in the volume of the balls results in a shallower impression. The balls must be made of a dense substance such as lead in order to make impressions of a measurable depth in a substance such as clay or fat, from heights of the order of 6 to 12 feet, presumably the height of Poleni's ceiling. The clay into which the objects fall must be homogeneous and as soft as possible to produce the deepest impressions, but not so soft as to stick to the balls after falling. If a fatty medium is used, it must be kept cold to prevent the fat from sticking and heaping up. Care must be taken to achieve a level surface for the medium. The balls must be rigid so that the energy will not be dissipated upon striking the surface. With lead balls falling from a few feet, air resistance, which depends on v, is not an important contribution to the errors. With lead balls of 1 and 2 lb (446·0 g and 892·3 g) falling from heights of 6 feet and 3 feet, I found that rather shallow impressions of the order of $\frac{7}{8}'' \pm \frac{1}{16}''$ were obtained in soft clay, and $1\frac{5}{8}'' \pm \frac{1}{8}''$ in vegetable shortening. Considering the difficulties in maintaining a level surface and the shallowness of the impression, errors of about 8 per cent are inherent in the experiment. Whereas Newton, in the percussion experiments described in the *Principia*, is careful to discuss and estimate the errors involved, the free-fall experimenters do not do so.[56]

Poleni concluded that regard should be paid to the *effects* of the 'forces' of the bodies in motion. These 'forces' are seen to be composed of the

[55] Ibid., pp. 56–7. The above translation of Poleni's experiment made from the Latin by J. T. Desaguliers appeared in the *Philosophical transactions of the Royal Society*, xxxii (1723), 285–6.

[56] Isaac Newton, *Mathematical principles of natural philosophy*, trans. A. Motte and F. Cajori (Berkeley, 1960), pp. 22–3.

ratio of the simple power of the body and the square of its speed.[57] The 'forces' are of the same nature, irrespective of the causes which produced the motions.

Poleni's experiment is an actual physical experiment set up to demonstrate empirically the logic of Leibniz's 'Brevis demonstratio'. The results seemed to Poleni to confirm the theory that mv^2 is the measure of a force acting through a distance. The shallow, seemingly equal, impressions caused him to conclude that the 'forces' with which the two bodies hit the ground were equal. Poleni thus accepted Leibniz's measure of 'force'. However, he did not indicate adherence to the metaphysics of monads, the philosophical basis of the Leibnizian 'force' concept.

In 1729 Poleni published a rebuttal of his critics, among whom were the Newtonians Pemberton and Desaguliers.[58] He analysed their objections and attempted to refute the theoretical basis of their arguments. He reinforced his own viewpoint, while pointing to errors in his opponents' assumptions.

William 'sGravesande, who had presented a Newtonian analysis of collision problems in his *Mathematical elements of natural philosophy* (1719), became converted to the Leibnizian camp after performing some experiments similar to those of Poleni. It is interesting to note the ways in which his intellectual framework changed after he declared allegiance to the Leibnizian concept of 'force'.

In the preface to his 1719 Newtonian textbook he had adhered to certain theological views shared by Newton:[59]

> That the world was created by God is a position wherein Reason so perfectly agrees with Scripture, that the least Examination of Nature will show plain footsteps of Supreme Wisdom. It is confounding and oversetting all our clearest notions to assert that the World may have taken its Rise from some general laws of motion . . . This assertion . . . overthrows all our clearest Notions as has been fully proved by many learned Men; and is indeed so unreasonable and so injurious to the Deity that it will seem unworthy of an answer to anyone who does not know that it has been maintained by many ancient and modern philosophers and some of them of the first rank and far removed from any suspicion of atheism.

He held that the properties of matter depended on the free power of God and that there were many 'reasonings' other than mathematical ones which followed from the predetermined will of God.[60]

Following his conversion to Leibniz's concept of force, 'sGravesande took on other philosophical notions consistent with the new framework.

[57] Poleni, op. cit. (53), p. 57, sec. 119.

[58] Giovanni Poleni, *Epistolarum mathematicarum fasciculus* (Padua, 1729), 114 pp. Excerpts in Poleni, 'Recueil de lettres sur divers sujets de mathématique, second extrait', *Journal historique de la république des lettres*, (March, April, 1933), pp. 220–9.

[59] William 'sGravesande, *Mathematical elements of natural philosophy*, trans. J. T. Desaguliers (5th edn., London, 1737), pp. ix–x.

[60] Ibid., pp. xi, xiv.

According to his biographer Jean Allemand, this conversion occurred at the time when he became interested in the possibility of using experimental methods to refute Leibniz's measure of the 'force' of bodies in motion, having already convinced himself that Leibniz was in error on rational grounds.[61] His prior conviction that the experiment would successfully refute Leibniz's theory guided the experimental work. His brother-in-law Sacrelaire, who happened to be present when the first experiments were performed, reported his astonished cry, 'It is I who am wrong'. His subsequent experiments repeatedly convinced him of the truth of the Leibnizian position. He then proceeded to redevelop the mathematics of his percussion theory using the mv^2 principle. He discussed his conversion in 'A new theory on the collision of bodies', published in 1722.[62] There he wrote:

> The experiments I have made on collision have made me see demonstratively that the opinion of M. Leibniz is true, that is to say that the forces of different bodies are in a ratio of the masses multiplied by the squares of the velocities; it appears to me that *to determine the effects of collision one should never as has been done up to the present, consider the products of the masses by the velocities*, as if these products were proportional to the quantities of motion in the bodies. Quantity of motion and force are not things that one can distinguish. This consideration involved me in pushing my experiments further and I have arrived at a completely new theory of collision which, as regards the collision of two bodies and the direct collision of several non-elastic bodies, does not lead to different rules from those already known, and which experience confirms; but here one will find these rules demonstrated in a manner different from that which they have been up to the present; and one will see how from a principle contrary to experience, philosophers have arrived at these rules, by an argument in which they have neglected to pay attention to all they should have considered; without which it is impossible to arrive at the truth by the path they have taken . . . This new theory regards only collision and does not change anything which has been demonstrated regarding the projection of weights, central forces, centers of oscillation, the resistance of fluids, etc. The effects which in all these cases change the motion of bodies, are of a different nature from collision.[63]

In a supplement to this essay he wrote that, after his 'New Theory' was printed, he saw the book, *De castellis*, of Poleni. The experiments of Poleni, he said, differed from his own only in insignificant details. These experiments were performed prior to his, but his own method of demonstrating the rules of collision was new.[64]

In this same supplement he stated that, after the 'New theory' had been printed, many objections were raised concerning his reasoning and

[61] Jean Allemand, 'Histoire de la vie et des ouvrages de M 'sGravesande', in William 'sGravesande, *Oeuvres philosophiques et mathématiques* (Amsterdam, 1774), i. xiv–xv.

[62] William 'sGravesande, 'Essai d'une nouvelle théorie sur le choc des corps', *Journal litteraire, de La Haye*, xii (1722), 1–54, and supplement, 190–7.

[63] Ibid., 2, 3. Italics added.

[64] Ibid., 190.

proofs of *vis viva*. In answering them he had not entered directly into dispute with those raising them as was inevitable if one replied directly to each objection. His method, he said, was to clarify the truth to the extent to which he was capable, and, for this, ordinary disputes were not proper.[65] 'sGravesande performed both collision and free fall experiments in order to verify the *vis viva* principle.

In the free fall experiment he took balls of copper, all $1\frac{1}{2}$ inches in diameter.[66] One was solid, the other two were hollow and composed of two hemispheres joined together. Their masses were in ratio of 1, 2, and 3, with the heaviest referred to as ball 3, and the lightest as ball 1. A tray, 1 inch in depth, was filled with soft homogeneous potter's clay. The balls were allowed to fall into this clay from different heights. Precautions were taken so that the balls would fall from rest, receiving no motion from the hands of the experimenter. Since the balls he used were smaller than Poleni's, they would make deeper impressions and could be dropped from lower heights. The experimental difficulties were similar to those in Poleni's experiment. In my repetitions of this experiment, I used balls weighing 892·3 g for ball 3, 595·0 g for ball 2, and 297·0 g for ball 1. Since the balls measured $2\frac{1}{2}$ inches instead of $1\frac{1}{2}$ inches in diameter, I doubled the heights in order to obtain measurable impressions.

'sGravesande allowed ball 3 to fall from 9 inches and ball 1 from 27 inches. The impressions in the clay, he said, were equal. $[mv^2 = (3)(9) = 1(27)]$. I obtained impressions of $\frac{5}{8}'' \pm \frac{1}{16}''$.

Ball 2 was allowed to fall from 9 inches and ball 1 from 36 inches. $[2(9) \neq 1(36)]$. The impressions in the clay were different. I obtained impressions of $\frac{5}{8}'' \pm \frac{1}{16}''$ for ball 2 and $\frac{7}{16}'' \pm \frac{1}{16}''$ for ball 1.

When ball 3 fell from a height of 18 inches and ball 2 from a height of 27 inches, the impressions were exactly equal. $[3(18) = 54 = 2(27)]$. I obtained impressions of $\frac{7}{8}'' \pm \frac{1}{16}''$. The error range of 7–10 per cent for the experiment was quite high.

The cavities which the balls make in falling in the clay, said 'sGravesande, represent the entire actions of the 'forces' which the bodies have at the end of their falls.[67] The 'forces', mv^2, which would be acquired by balls 1 and 3 in falling from a height of one inch would be 1 to 3; hence the action of ball 1 in falling from the height of 27 inches is triple that which it has in falling from a height of 9 inches. It therefore appears that the 'force' of a ball is proportional to the height from which it falls. But this height is as the square of the velocity acquired in falling and with which the body strikes the clay. *Vis viva* could be measured only through its effects or the total action which consumed it. This measure was mv^2.

It is significant that 'sGravesande's expectations had been determined

[65] Ibid.
[66] Ibid., 21–2.
[67] Ibid., 408–11.

by rational considerations. Furthermore, the results of the experiment did not suggest to him that both viewpoints could be valid. An 'objective' evaluation leading to the legitimacy of both interpretations was not open to him. The only option was to choose one system or the other. Following his conversion, he spent much effort strengthening his Leibnizian position with mathematical and metaphysical arguments.

He now felt compelled to alter his mathematical solution to impact problems in order to remain consistent with his new Leibnizian interpretation. Inelastic collisions, however, presented a great difficulty since *vis viva* was not conserved. For these cases he derived an expression for the 'force', mv^2, lost in the collision and subtracted it from the total initial 'force' in order to find the common velocity of the two bodies together. This gave the 'force' remaining after the collision which, when divided by the sum of the masses, yielded the final velocity.[68] For the elastic case the change in the velocity of each body was twice that for the inelastic case, and relative velocities were conserved.[69]

'sGravesande's concept of 'force' was also altered to make it consistent with the Leibnizian interpretation. He now defined 'force' as inherent within a moving body by means of which it was transported from place to place, something altogether different from inertia.[70] A pressure or Leibnizian 'dead force' was a continuous 'effort' acting over a time without causing motion. If not destroyed by a contrary pressure it would produce 'living force'. When a body hit a mass of soft clay, part of the pressure was destroyed by the contrary pressure of the clay but the impression was formed by that part of the pressure due to the 'living force' acquired in falling. There were therefore two possible effects of pressure. In the first case the effect was destroyed in each instant as in dead force; in the second the effect of pressure produced *vis viva*.

In reaction to criticism made by the Newtonian Samuel Clarke, 'sGravesande in 1729 further strengthened his metaphysics of 'force' by developing it along the lines of Leibniz's 1695 'Specimen dynamicum'. He pointed out that the mere transportation of a body from place to place was often confused with the ability to act. A body in motion can act only because it has a force. *Vis viva* is the measure of a body's inherent power to act.[72]

In a motion carried out over a period of time two things must be considered: first, the instantaneous action or pressure exerted by acting

[68] Ibid., 31–8. For inelastic collisions 'sGravesande derived an expression which said that the lost force was proportional to the square of the relative velocity multiplied by the product of the masses, divided by the sum of the masses: $F \propto \frac{ABdd}{A+B}$ (p. 38).

[69] Ibid., 47–52.

[70] Ibid., 4–5, 19–20.

[71] William 'sGravesande, 'Remarques sur la force des corps en mouvement et sur choc; précédées de quelques réflexions sur la maniere d'écrire, de Monsieur le docteur Samuel Clarke', *Journal litteraire, de La Haye*, xiii (1729), 189–97 and 407–30.

[72] Ibid., 407–9.

bodies and, second, the total action or sum of all the small actions.[73] Following Leibniz, he appealed to causality arguments, as already discussed in section 2. The total action is proportional to the total effect. If the definition of force is taken as the 'total capacity to act' or to produce an effect, then the capacity to produce a certain effect is proportional to that effect and thus to mv^2.[74]

He attempted to resolve the controversy by arguing that the momentum proponents were really talking about instanteous action, *mvdt.* If the instantaneous action is summed up over a time interval the sum represents the total action or force, mv^2

$$[\text{i.e. } m \int_0^t v\mathrm{d}t = m \int_0^s \frac{\mathrm{d}s}{\mathrm{d}t}.\ \mathrm{d}t = ms = mv^2].$$ [75]

s'Gravesande did not use the concept of an integral, but it seems clear that he was following Leibniz's analysis of the integral of momentaneous impetuses, *mv*, over an interval of time, as presented in 'Specimen dynamicum'.

'sGravesande developed his ideas on causality more completely in his *Introduction to philosophy* in 1736–7.[76] He argued that there was a necessary chain of causes and effects in nature.[77] It is necessary that a wise Deity acts wisely and a contradiction that He should not do so. Moral necessity is comprehended within physical necessity.[78] In spite of a chain of necessary connexions, that which exists does not exist in and of itself, because nothing cannot be the cause of an effect. Hence created things could not have come from nothing and religion is therefore not a mere chimera.[79] In this way 'sGravesande sought to dispel the arguments that a necessary order in the physical world could lead to atheism. In addition, he held that any system in which the essences of things depended on the volition of God confined the divine power within limits too narrow.[80] This represented a change from his earlier supposition that the properties of matter depended upon the free power of God. 'sGravesande's natural philosophy therefore changed as his intellectual development gradually assumed more aspects of the Leibnizian system of philosophy and concept of force.

(b) The Newtonian reaction

'sGravesande's 'New theory of collision' with his new opinion concerning *vis viva* caused a great stir in the intellectual world of the

73 Ibid., 413.
74 Ibid., 413–14.
75 Ibid., 417.
76 'sGravesande, 'Introduction à la philosophie', in *Oeuvres*, op. cit. (61), ii. 179.
77 Ibid., 178.
78 Ibid., 179.
79 Ibid.
80 Ibid., ii. 2, 3.

1720s. His conversion was greeted with astonishment and disbelief. Desaguliers, translater of 'sGravesande's Newtonian textbook, considered him to be an ingenious professor who had been wholly overcome and led into error by his experiments.[81] Needless to say, the new experimental evidence of 'sGravesande and Poleni was not sufficient to convince the adversaries that *vis viva* had anything of value to offer to physics. Their discussions sparked a series of counter experiments and arguments by British Newtonians in the years 1722–8. Their response was to analyse and refute the validity of the experiments in terms of Newtonian mechanics. A counter-experiment of questionable adequacy was offered by Desaguliers.

The free-fall problem interpreted in terms of Newtonian mechanics required the use of either Newton's third law, stating that action and reaction are equal and opposite, or his definition that the accelerative quantity of the centripetal force is proportional to the velocity generated in a given time.[82] The second law of motion, as stated by Newton, concerned impulses or instantaneous changes of motion applicable to billiard ball collisions: $F \propto \triangle mv$.[83] For the case of gravitational free-fall involving continuous constant accelerative forces, the rate of change of momentum was the appropriate modification of Newton's statement of his second law. Whereas Newton concerned himself with its application to planetary motions, his followers in the *vis viva* controversy used rates of change to determine the increased momentum of falling bodies over a time interval.

The first of these Newtonian contributions, by Henry Pemberton dating from 1722, gained for its author recognition and association with Isaac Newton. Pemberton, who was well versed in the mathematical details of Newton's *Principia*, made Newton's acquaintance when his refutation of Poleni's experiment was shown to Newton by Dr. Mead.[84] It was said that Newton was so pleased with it that he condescended to visit Pemberton at his 'lodgings bringing along a confutation of his own based on other principles'.[85] Both Pemberton's paper and Newton's anonymous postscript were published in the *Philosophical transactions of the Royal Society* for 1722.[86] Pemberton's association with the Newtonian group and the friendship that arose between Pemberton and Newton resulted in his superintendence of the third edition of the *Principia*, which

[81] John Theophilus Desaguliers, 'An account of some experiments made to prove that the force of moving bodies is proportionable to their velocities', *Philosophical transactions*, xxxii (1723), 269–70.

[82] Isaac Newton, *Mathematical principles*, op. cit. (56), p. 4.

[83] J. Bernard Cohen, 'Newton's second law and the concept of force in the Principia', *Texas quarterly* x, (1967), pp. 127–57.

[84] James Wilson, *A course of chemistry, formerly given by the late and learned Dr. Henry Pemberton* (London, 1771), preface, a biographical sketch of Pemberton's life, pp. iii–xxv.

[85] Ibid., p. xiii. Evidence for Newton's anonymous postscript was first given in Henry Pemberton, *A view of Sir Isaac Newton's philosophy* (London, 1728), preface.

[86] Henry Pemberton, 'A letter to Dr. Mead . . . concerning an experiment, whereby it has been attempted to shew the falsity of the common opinion in relation to the force of bodies in motion', *Philosophical transactions*, xxxii (1722), 57–66.

appeared in 1726. In preparing this edition, he showed his support for Newton's theological belief in God's Providence, as outlined in section 2 of this paper, and his opposition to the eternity of the world. Like Bentley, who had edited the second edition, he altered and struck from Halley's 'Ode to Newton' the word eternal in the lines:

> . . . until, the origin of things
> He established, the omnipresent Creator, unwilling the laws
> To violate, he fixed the eternal foundations of His work.[87]

In 1728 he published one of the well known popular introductions to Newtonian science, a non-technical *View of Sir Isaac Newton's philosophy*. Although published after Newton's death (1727), this account, written during his close association with Newton in old age, was authorized by Newton himself. In this work he again mentioned 'a very strong philosophical argument against the eternity of the world'. He implied that the Leibnizian position cast 'a reflection upon the wisdom of the author of nature for framing a perishable work'.[88] In addition he repudiated the Leibnizian view of matter as self-active:

> For suppose a body by the structure or disposition of its part, or by any circumstance in its make was imbued with a power of moving itself, the self-moving principle which should be thus inherent in the body and not depend on anything external must change the direction wherein it would act, as often as the position of the body was changed.[89]

Pemberton's 1722 contribution to the *vis viva* controversy reflected his commitment to the Newtonian system. Pemberton stated to Dr Mead his contention that Poleni's conclusions were wrong and that Leibniz's opinion concerning force was unreasonable. If Newton's third law was applied to the experiment, it was consistent with the concept of force, *mv*.

> Perusing the Learned Polenus' Tract, *De Castellis* you were pleased to send me, I have found in it several curious experiments among which I reckon that of letting globes of equal Magnitude but of different weights fall upon a yielding substance as Tallow, Wax, Clay or the like from . . . heights reciprocally proportional to the weights of the globes. This experiment engaged in particular my attention as it is brought with design to overturn one of the First Principles established in Natural Philosophy . . . I cannot by any means admit of the Deduction that is drawn from thence, that because the globes make in this experiment equal impressions in the yielding substance, therefore they strike upon it with equal force . . . On the contrary I think this very experiment proves the great unreasonableness of Mr. Leibniz's notion.[90]

The experiment of Poleni, he wrote, 'better informs us of the law by which these yielding substances resist the motion of bodies striking them,

[87] Quoted in Kubrin, op. cit. (9), 328.
[88] Ibid., 329.
[89] Pemberton, op. cit. (85), p. 34.
[90] Pemberton, op. cit. (86), 57.

than to shew the forces with which Bodies strike'.[91] Using the Newtonian law that action equals reaction, Pemberton changed the problem of free fall from a *vis viva* problem to a momentum problem. He treated Poleni's experiment in terms of the action-reaction forces between the falling globe and the tallow rather than measuring the distance the globe travels in the tallow. Since the impact was inelastic, it could not be considered instantaneous, and the time for the action to occur had to be considered. Pemberton thus used Newtonian force as a rate of change of motion in the yielding material.

He argued that the opposition of the yielding substance to the globes of different weight entering equal distances into the substances was reciprocally proportional to the time it took them to move through the substance. (In modern terms $mv = Ft$, where F is the Newtonian force of the globe on the yielding substance as well as the reaction of that substance to the globe. The force, F, must be assumed constant in Pemberton's analysis. The distance to which the globe penetrates the tallow would be given by $s = \frac{1}{2}\, vt$.) The resistance of the tallow, $(-F)$, is therefore proportional to the velocity of each globe (since $F = mv/t$). The 'force' of motion of the falling globe, mv, is likewise proportional to the velocity of each globe. The globes while penetrating equal distances into the substance lost parts of their force, $(\triangle\, mv)$, which bear the same proportion to the whole force, mv. Hence, even if the velocities are proportional to the square root of the weights (masses), as in the case of living forces (mv^2), they are still proportional to the 'forces' (mv) with which they press into the substance and will make equal indentations in it. 'And therefore upon the Theory of Resistance here supposed, when the whole Force and Motion of both these Globes is entirely lost, they will be plunged into the substance at equal depths.'[92] Pemberton concluded:

> But as I have asserted in the beginning of this letter that the very experiment of Polenus is not only reconcileable to the common Doctrine of Motion, as I have now demonstrated; but even that it does itself make manifest the great unreasonableness if not the absolute absurdity of Mr. Leibniz's opinion.[93]

Although Pemberton considered himself to have disproven the Leibnizian analysis of the experiment, he had merely shown another way to explain the result by using momentum considerations. He was unable to see the validity in the *vis viva* interpretation.

In Newton's anonymous postscript to the article there appeared an argument that soon became the basis for an experiment devised by another of Newton's followers, John Theophilus Desaguliers.[94] Newton

[91] Ibid.
[92] Ibid., 60.
[93] Ibid., 62.
[94] Ibid., 66.

supposed that fine pieces of silk or other thin substance could be stretched in parallel planes at small intervals. If a globe could strike the middle of the outermost silk sheet perpendicularly, it would lose some of its motion in breaking through it. If the resistances of the pieces of silk are all equal, then equal forces (F) will be required to break each one. But the faster the ball is moving when it hits the silk, the shorter the time required to break through it. The loss of motion ($\triangle\, mv$) of the globe is therefore proportional to the time during which the silk opposes itself to the globe. Again force, F, is being used as a rate of change of motion, rather than an instantaneous change.

Desaguliers, known for his translation of 'sGravesande's work on physics, entered the discussion in 1723 with a paper entitled 'An account of some experiments made to prove that the force of moving bodies is proportionable to their velocities: (Or rather that the momentum of moving bodies is to be found by multiplying the masses into the velocities.) In answer to such who have sometime ago affirmed that force is proportionable to the square of the velocity and to those who still defend the same opinion.'[95] His work reflected the Newtonian natural philosophy.

Upon the revocation of the Edict of Nantes in 1685, Desaguliers, who had been born in France, fled with his Protestant father to England.[96] He succeeded John Keill as lecturer on experimental philosophy at Oxford's Hart Hall in 1710, and eventually became intimately acquainted with Isaac Newton and the group surrounding him. Appointed curator of experiments at the Royal Society in 1713, he attained a reputation for skilful demonstration experiments which he used in public lectures and courses on Newtonian science.

Desaguliers's commitment to a natural religion in which God as creator was the 'Great Architect of the Universe' and his rejection of the tendency towards atheism which could be implied as a consequence of the Leibnizian position were expressed in *The constitutions of the Freemasons.* This work was revised by James Anderson in the years 1717–22, under the influence of Desaguliers as Grand Master (c. 1720–1) of the Westminster Lodge. It stated:

> A Mason is oblig'd by his Tenure to obey the Moral law; and if he rightly understands the Art, he will never be a stupid Atheist nor an irreligious Libertine . . . .[97]

Anderson and Desaguliers's changes conceived of a natural religion, apprehended by human reason and binding all men who rejected atheists and agnostics.

[95] Desaguliers, op. cit. (81).

[96] W. R. Hurst, *An outline of the career of John Theophilus Desaguliers* (London: Edson Bros., 1928).

[97] 'Freemasonry', *Encyclopedia Britannica* (Chicago, 1954), ix. 735.

As a result of Desaguliers's influence, other members of the Royal Society joined the fraternity of Freemasons. Through him 'Freemasonry emerged from its original lowly station and became a fashionable cult'.[98]

Corroboration of his commitment to the Newtonian world view can be obtained from the second edition (1719) of the initially unauthorized transcription of Desaguliers's *Lectures of experimental philosophy*, prepared by Paul Dawson.[99] In the preface Desaguliers stated that he had looked over the whole book and corrected every error because he was unwilling that those who bought it should find it in any way imperfect. The transcription of the first lecture stated:[100]

> And tho' it is manifest to sense that there is a local Motion in Matter; yet Motion is not included in the Nature of Matter or Coeval with it . . . And though it be wholly disputed, how Matter came by that Motion, by those who acknowledge not an Author of the Universe; yet since a Man is not the worse Naturalist for not being an Atheist; we allow that the origin of Motion in Matter, as well as of Matter itself, is from God.

Although Desaguliers, in the second volume of his *Course of experimental philosophy* (1744), finally came to the conclusion that both measures of 'force' were correct, in the 1723 paper, as a committed Newtonian, he was very opposed to the Leibnizian opinion. He based his analysis in this paper on the Newtonian accelerative force of a falling body and used the term momentum to designate the *mv* of the falling body, a term that had been introduced by his predecessor John Keill in 1700. Keill had used the term momentum to mean the same thing as quantity of motion: 'A momentum (which is often called the quantity of motion, and also simply motion) is that Power or Force incident to moving Bodies whereby they continually tend to change their present places.'[101] If a body is in motion, it has a moving force, hence a momentum; the force to stop the body or change its motion is an impressed force.

By the time Desaguliers wrote the first volume of his *Course of experimental philosophy* in 1734, he stated Newton's second law, as had Keill, in the form: 'the change of motion is proportional to the moving force impressed', but deemed it necessary in defining quantity of motion to refer to Newton's definitions 2 and 8.[102] 'The Quantity of motion may be increased by applying more force; for here Force and Motion mean the same thing. (See Sir Isaac Newton in the first book of his *Principia*. Def. 2 and 8).'[103] Force is thus quantity of motion by definition 2, and by definition 8 is proportional to the motion generated in a given time. Hence

[98] A. Rupert Hall, 'Desaguliers', in *Dictionary of scientific biography* (New York, 1971), iv. 43.
[99] John Theophilus Desaguliers, *Lectures of experimental philosophy* (2nd edn., London, 1719).
[100] Ibid., pp. 7, 8.
[101] John Keill, *An introduction to natural philosophy* (4th edn., trans. from 3rd Latin edn., London, 1745), p. 84.
[102] John Theophilus Desaguliers, *A course of experimental philosophy* (London, 1734), i. 317, 63.
[103] Ibid., 43, 63.

Desaguliers took a step in the direction of defining force as a rate of change of motion. He used the concept of the motion generated in a given time implicitly in his analysis of Poleni's experiment (1723).

He began this 'Account of some experiments' which were to answer the Leibnizian argument with a summary of his view of the controversy:

> As far as I can learn Monsieur Leibniz was the first that opposed the received opinion concerning the Quantity of the Force of moving Bodies by saying that it was to be estimated by multiplying the Mass of the Bodies not by their velocity but by the square of it. But instead of shewing any Paralogism in the mathematical Demonstrations which are made up to Prove the Proposition of any mistakes in the Reasonings from the Experiment made to confirm it, he uses other Mediums to prove his assertions; and without any Regard to what others had said on that subject brings new Arguments which the Reverend and Learned Dr. Clarke has fully answered in his fifth letter to him. Messieurs John Bernoulli, Wolfius, Hermannus and others have followed and defended Mr. Leibniz's opinion and in the same manner so that what is answer to him is so to them. Polenus (Prof. at Padua) has acted after the same manner in the experimental way making some experiments to defend Mr. Leibniz's Opinion, without having shown those to be false which are made use of to prove the contrary . . .[104]

Desaguliers argued, as had Catalan and Papin, that the time of descent and the momenta rather than the spaces should be considered. But in this case the argument was drawn from Newtonian rather than Cartesian physics. 'As the Time of the fall through a space of four Foot [s_2] is twice the Time of a fall through one Foot [s_1 where $s \propto t^2$], the Velocity in the latter Case [i.e. the four foot space] is double that of the first and consequently the Blow, [$Ft = mv$] that the Body will give, will be double.'[105]

[If $\frac{s_1}{s_2} = \frac{1}{4}$, then $\frac{t_1}{t_2} = \frac{v_1}{v_2} = \frac{1}{2}$].

This defines the 'Blow' as the body's momentum, *mv*. Desaguliers, in attempting to refute Leibniz by referring to the times of fall rather than the distances, altered the problem by describing the momentum acquired by a falling body. Leibniz's 'Brevis demonstratio' had analysed the *vis viva*, mv^2, acquired in falling, an equally valid concept.

A second paper by Desaguliers in the succeeding issue of the *Philosophical transactions* criticized Poleni's experiment using bodies falling from different heights into soft clay.[106] According to Desaguliers, the mistake

[104] Desaguliers, 'An account of some experiments . . .', op. cit. (81), 269–71.

[105] Ibid., 272. In this paper Desaguliers also described his repetition of 'sGravesande's initial collision experiments from the *Mathematical Elements of Natural Philosophy* as confirmation that the 'Congress of elastic bodies' shows that the 'momentum of bodies is in proportion to the mass multiplied into the velocity . . . as demonstrated by Isaac Newton in his *Principia*' (ibid., 275–8).

[106] John Theophilus Desaguliers, 'Animadversions upon some experiments relating to the force of moving bodies; with two new experiments on the same subject', *Philosophical transactions*, xxxii (1723), 285–90.

made by Poleni was in estimating the force of the stroke of the falling balls by the depth of the impression in the yielding substance. Instead one must consider 'That when two Bodies (of different weights) move with equal Forces [*mv*] but different velocities, that which moves the swiftest must make the deepest Impression . . .'.[107]

He designed an experiment along the same lines as Newton's postscript to Pemberton's paper, in which the depth of the Impression could be 'stretched out' and presumably measured more precisely (Figure 2). An apparatus was constructed which consisted of a horizontal base on which stood two vertical parallel boards four inches apart. Between these boards, placed as horizontal shelves, were six evenly spaced wooden frames across each of which a paper diaphragm (C) was extended. The papers were similar to the pieces of fine silk suggested by Newton in his postscript and served the same function as the soft clay of Poleni. Like Leibniz, Desaguliers used heights in the ratio 4 : 1, but, unlike Leibniz, used weights in the ratio 1 : 2, rather than 1 : 4. Thus the momenta rather than *vires vivae* were equal. From a support (F) a hollow ivory ball weighing $1\frac{1}{2}$ ounces was suspended by a thread four feet above the first diaphragm. When the thread was cut the falling ball broke through four of the paper diaphragms. [$ws = (1\frac{1}{2})\ (4) = 6$]. The hollow ball was then filled with lead such that it weighed twice as much as before and was allowed to fall from a height of 1 foot. This time it broke only two diaphragms. [$ws = 3\ (1) = 3$]. Since the velocities are in the ratio 2 : 1, the forces, or *mv*'s are equal:

$$\frac{m_1 v_1}{m_2 v_2} = \frac{(1\frac{1}{2})\ (2)}{(3)\ (1)} = \frac{3}{3}$$

Upon repetition of the experiment using different heights whose proportion was always 4 to 1, it was found that whenever the weight of the balls was in the ratio 1 : 2, the heavier, slower ball broke through but half the number of papers.

Although Desaguliers' language indicated no variation in the number of diaphragms broken in these trials, this was not the case when the actual experiment was reconstructed and repeated. I found that when balls of $1\frac{1}{2}$ ounces and 3 ounces were allowed to fall from heights of four feet and one foot the ratio of tissue paper diaphragms broken was not always 4 : 2. In approximately one out of three trials the ball falling from four feet went through either three or five diaphragms. In this experiment much depends upon achieving a uniform tension in the diaphragms as well as the thickness of the tissue. The proper thickness of tissue must be found such that the falling ball does not stop at the first tissue or plunge through all the tissues. In my experiments this turned out to be two thickness of ordinary tissue paper. Hence if the ball falls through 4 ± 1

[107] Ibid., 286.

diaphragms, the number of papers per frame can themselves introduce an error.

Desaguliers interpreted the experiment on the basis of Newtonian mechanics. Both balls, of weights in the ratio 1 : 2 falling through heights in the ratio of 4 : 1, with velocities in the ratio of 2 : 1, hit the diaphragms

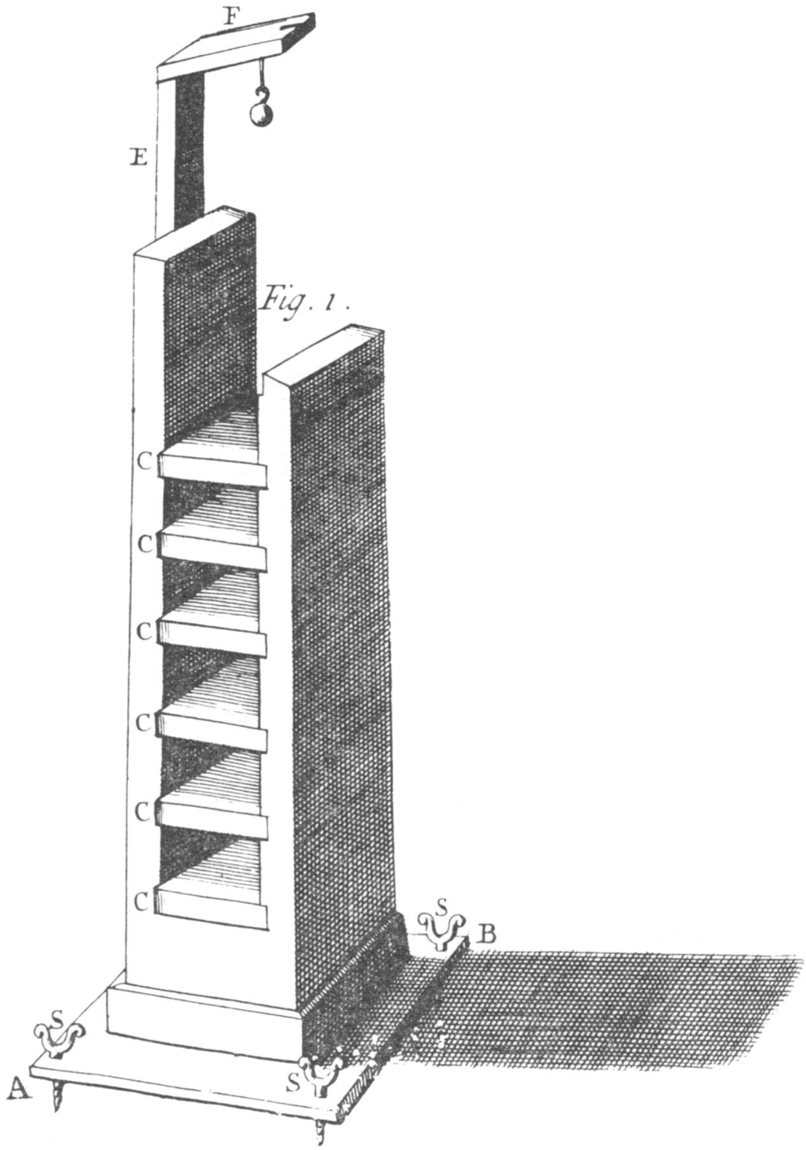

FIG. 2
From Desaguliers, 'Animadversions upon some experiments relating to the force of moving bodies', *Philosophical transactions*, xxxii (1723).

with equal momenta [$mv = (1)(2) = (2)(1)$]. The *vis viva* of the lighter [$w = 1$; $mv^2 = 1(2)^2 = 4$] is twice that of the heavier [$w = 2$; $mv^2 = 2(1)^2 = 2$] and it breaks twice as many diaphragms, which would seem to confirm the predictions of Leibniz. However, Desaguliers argued that the time of fall ($s \propto t^2$) of the lighter, falling through $s = 4$ is double that of the heavier falling through $s = 1$. The faster-falling ball moves through the papers faster, each diaphragm having half the time to offer resistance to the faster ball. Since the force of resistance, F, varies with the time, each diaphragm offers half the resistance to the ball with the greater velocity. The faster ball will therefore break more diaphragms.

Desaguliers concluded as follows:

> Now tho' this Experiment does at first seem to confirm Polenus' Theory; yet; when duly weigh'd, it proves no such thing. For the lighter Ball does not break thro' more Papers, because it has more Force, or a greater Quantity of Motion, but because each Diaphragm has but half the time to resist the Ball that falls with a double Velocity, and therefore their Resistance being as the time, as many more of them must be broken by the swift Ball as by the slow one.[108]

Although the ball having the greater *vis viva* breaks more diaphragms and thus seems to confirm Poleni's conclusion that it will make a deeper impression, Desaguliers interpreted the experiment on the basis of momentum: if mv is the correct measure, and if the mv of two falling bodies are equal, the depth of the impressions or the number of diaphragms broken are unequal. Therefore the depth of the impression cannot be used as a measure of the body's force.

Here, then, the problem is one of definition. If force is defined as mv^2 (Leibniz) then the depth of the impressions are equal for equal forces because mv^2 depends on the height. But if mv is the measure of motion (Desaguliers) then for equal mv the impressions are not equal.

A third member of the Newtonian group, John Eames, tutor in theology, science, and classics, contributed to the controversy in 1726. Through the friendship and influence of Newton, he had been elected to the Royal Society and was engaged in preparing an abridgement of its *Philosophical transactions*. His theological writings have all been lost, but we know that he was trained for the dissenting ministry in 1696, though never ordained.[109] He was the only layman who held a theological chair in the nonconformist Fund Academy in Moorfields.

In 1735 he joined the liberal divines Jeremiah Hunt and Samuel Chandler in a debate with Roman Catholic priests. Both Hunt and Chandler were non-conformist moderate Calvinist dissenters.[110] These facts would indicate that the three men held theological positions supporting the primacy of God's will and the manifestation of his providential

[108] Ibid., 288.
[109] 'John Eames', in *Dictionary of national biography* (London, 1917), vi. 313.
[110] 'Samuel Chandler', ibid., iv. 42, and 'Jeremiah Hunt', ibid., x. 274.

care in the world. There would be a strong tendency to reject any intellectualist position which reduced God's role to that of a mere creator.

In his 'Remark upon the new opinion relating to the force of moving bodies', Eames reiterated the conclusions of Pemberton (1722) and Desaguliers (1723) that the proper use of an experiment such as Poleni's was to discover the laws of resistance which soft or yielding substances make to bodies moving in them and not to discover the 'force' itself of the moving bodies.[111] Here the resistance was equivalent to the Newtonian impressed force, *F*. The latest experiments made on soft and yielding substances, said Eames, are 'a little complicated and improper for (their) purpose.' To discover the 'forces' by which bodies move, some simple experiments are 'more fit to determine the matter.' Eames's statement was an attempt to use Newton's third law to interpret the free-fall experiment as an action-reaction problem in which the resistance of the substance is the reaction to the Newtonian force, *F*, impressed on the clay by the falling body. Hence 'force' means *mv*, and resistance is equivalent to *F*. His paper thus represented another attempt to strengthen the Newtonian scheme by showing that its concepts could adequately explain problems or experiments offered by competing systems of natural philosophy.

Samuel Clarke formed a fourth member of the group of intimate and devoted acquaintances surrounding Isaac Newton in old age, who were determined to apply the Newtonian conceptual scheme to all possible physical problems. In comparison to the foregoing men, we see in Clarke's contributions the most intense loyalty and the strongest imprinting of the Newtonian world view. It was said that Clarke as a young university student of 22 in 1697 knew 'so much about those sublime discoveries (of Sir Isaac Newton) which then were almost a secret to all but a few mathematicians' that it was most amazing.[112] He was then engaged in a translation of the Cartesian Rohault's *System of natural philosophy* which he used as a vehicle to explain Newtonian ideas.[113]

His contribution of 1728 to the controversy appearing after the death of both Newton and Leibniz was one of the bitterest attacks the controversy produced.[114] His fanatical devotion to Newton led him to make outrageous insults to those who opposed Newtonian ideas. An interesting illustration of

[111] John Eames, 'A remark upon the new opinion relating to the forces of moving bodies, in the case of the collision of non-elastic bodies', *Philosophical transactions*, xxxiv (1726), 183–7. In this paper Eames also showed the *vires vivae* of non-elastic colliding bodies were not the same before and after the collision. A second paper by Eames in the same issue was a discussion of a proof by John Bernoulli based on the composition and resolution of forces showing that forces are as the squares of the velocities; see John Eames, 'Remarks upon a supposed demonstration, that the moving forces of the same body are not as the velocities, but as the squares of the velocities', *Philosophical transactions*, xxxiv (1726), 188–91.

[112] William Whiston, *Historical memoirs of the life of Dr Samuel Clarke* (London, 1730), pp. 5–7.

[113] Jacques Rohault, *System of natural philosophy, illustrated with Dr Samuel Clarke's notes taken mostly out of Sir Isaac Newton's philosophy* (London, 1733).

[114] Samuel Clarke, 'A letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly, F.S.R. occasion'd by the present controversy among mathematicians, concerning the proportion of velocity and force in bodies in motion', *Philosophical transactions*, xxxv (1728), 381–9.

this purely polemical aspect of the controversy is provided by the following statement from the pen of Dr Clarke (1728):[115]

> It has often been observed *in general* that Learning does not give men *Understanding*; and that the absurdest things in the world have been asserted and maintained by persons whose education and studies should seem to have furnished them with the greatest extent of Science.
> That knowledge in many *languages* and *Terms* of *Art* and in the History of *Opinions* and *Romantick* Hypotheses of Philosophers, should sometimes be of no effect in correcting Man's *Judgment*, is not so much to be wondered at. But that in *Mathematicks* themselves, which are a *real Science*, and founded in the *Necessary Nature* of *Things*; men of very great abilities in abstract computations, when they come to *apply* those computations to the *Nature* of *Things*, should persist in maintaing the most *palpable absurdities*, and in refusing to see some of the most *evident and obvious truths*; is very strange.
> An extraordinary instance of this, we have had of late years in very eminent Mathematicians, Mr. *Leibniz*, Mr. *Herman*, Mr. *'sGravesande*, and Mr. *Bernoulli*; (who in order to raise a *Dust* of Opposition against Sir *Isaac Newton's* philosophy, the glory of which is the *application* of *abstract Mathematics* to the real *phenomena* of *Nature*,) have for some years insisted with great Eagerness, upon a principle which subverts all Science, and which may easily be made to appear . . . to be contrary to the *necessary and essential Nature of Things*.
> What they contend for is, That the *Force* of a *Body in Motion* is proportional, not to its Velocity, but to the Square of its Velocity.
> The Absurdity of which Notion I shall first make appear and then shew what it is that had led these gentlemen into Errour.

Clarke's free-fall arguments were taken directly from Newton, who had chosen to remain in the background of the controversy.[116] The arguments in his 'Fifth reply' in the correspondence of 1716 with Leibniz were very close to those made in his 1728 'Letter to Mr. Benjamin Hoadly'. Clarke presented four main refutations of *vis viva* drawn from the free-fall case. The first argument attacked Leibniz' concept of 'force' and *monads* from a philosophical viewpoint. The second presented a Newtonian interpretation of the free fall experiments of 'sGravesande and Poleni. The third utilized the concept of gravitational force. The final argument was based on Newton's accelerative concept of 'force' applied to bodies projected upwards.

(1) Clarke disagreed with the philosophical basis behind Leibniz's concept of 'force'. He considered the question of what could possibly produce the 'force' of motion of a falling body if this 'force' was measured by mv^2, since he did not agree with Leibniz that living force was an essential property of monads. He argued that 'In the Nature of Things . . . every Effect must necessarily be proportionate to the cause of that Effect; that is to the Action of the Cause of the Power exerted at the Time

[115] Ibid., 381–2. Clarke's italics.
[116] Alexandre Koyré and I. Bernard Cohen, 'Newton and the Leibniz-Clarke correspondence', *Archives internationales d'histoire des sciences*, xv (1962), 63–126.

when the Effect is produced. To suppose any Effect proportional to the Square or Cube of its Cause, is to suppose that an Effect arises partly from its Cause and partly from Nothing.'[117]

With regard to a body in motion, Clarke believed that the portion of the force arising from the quantity of matter as its cause is necessarily proportional to its quantity of matter, and the force arising from the velocity is proportional to its velocity. 'If the *Forces* were as the *Square* of the velocity, all that *part* of the *Force* which was *above* the (simple) *Proportion* of the *Velocity* would arise either out of *Nothing* or (according to Mr. Leibniz's Philosophy) out of some *living soul* essentially belonging to every Particle of Matter.'[118] This pointed up the fundamental differences between the philosophical interpretations of 'force' in the dynamics of Newton and Leibniz. For Leibniz 'force' was a substance, an inherent internal principle of matter, a tendency or striving toward motion. For Newton and his followers impressed forces were external, acted to change a body's state of rest or uniform motion and afterwards no longer remained in the body.

(2) In his 1729 paper Clarke answered the experimental arguments of Poleni and 'sGravesande:[119]

> When a Body projected with a double Velocity, enters deeper into snow or soft clay or into a heap of springy or elastic parts, than in proportion to its Velocity; t'is not because the Force is more proportional to the Velocity; but because the Depth it penetrates into a soft Medium, arises partly from the Degree of the Force or Velocity, and partly from the Time wherein the Force operates before it be spent. [$s = 1/2\ vt$]

Like Pemberton, Desaguliers, and Eames, Clarke interpreted the fall of bodies through soft substances in terms of the duration of the motion through them. The impression can be explained by considering the momentum, dependent on the velocity, with which the body hits the soft clay. The Newtonian force impressed on the clay is to be measured by this momentum in proportion to the time during which it acts while moving through the clay.

(3) Clarke's third argument, taken directly from Newton, was based on the concept of gravitational force or weight and appeared in the 'Fifth reply' of his correspondence with Leibniz.[120] In the case of a single falling, accelerating body the uniform action of gravity generates equal velocities in equal times hence equal amounts of momentum in equal times. But in the case of *vis viva* the force is measured by the space. In the first part of a series of equal times, the body will gain one part of *vis viva*, ($v_1^2=1$). During the second moment it gains three parts of *vis viva*, ($v_2^2—v_1^2=4-1$

[117] Clarke, op. cit. (114), 383.
[118] Ibid., 383–4.
[119] Ibid., 387
[120] Clarke, 'Fifth reply', *Leibniz-Clarke correspondence*, op. cit. (2), pp. 338–9, footnote.

$=3$); in the third moment it gains five parts, ($v_3^2 - v_2^2 = 9 - 4 = 5$), in the fourth it gains seven parts ($v_4^2 - v_3^2 = 16 - 9 = 7$), etc. So unequal increments of *vis viva* are added, depending on the velocity the body has at the beginning of each instant. Newton and Clarke argued that the gravitational force, hence the body's weight which produces the motion would have to vary to produce this result. The force of gravity

> will be proportional to the time and to the velocity acquired. And by Consequence in the Beginning of the Time it [the action of gravity] will be none at all and so the body for want of gravity [weight] will not fall down. And by the same way of arguing when a body is thrown upwards its gravity will decrease as its velocity decreases and cease when the body ceases to ascend, and then for want of gravity, it will rest in the Air, and fall down no more. So full of absurdities is the Notion of the Learned Author in this particular.[121]

The *vis viva* hypothesis thus implied to Clarke that the body's weight which produced its force of motion in free fall would increase, and this was clearly absurd. Near the surface of the earth, where gravity can be assumed uniform, $F = mg = mv/t$, hence the body's weight does not vary. But $mg \neq mv^2$ since on such a hypothesis the weight would vary in equal increments of time. [$F = \frac{mv}{t} = \frac{1(1)}{1} = \frac{1(2)}{2} = \frac{1(3)}{3} = \frac{1(4)}{4}$; or $1 = 1 = 1 = 1$.

$F = mg \neq \frac{mv^2}{t}; \frac{1(1)^2}{1} \neq \frac{1(2)^2}{2} \neq \frac{1(3)^2}{3} \neq \frac{1(4)^2}{4}$ or $1 \neq 2 \neq 3 \neq 4$.]

(4) In a fourth argument in the 1729 'Letter to Hoadly' Clarke related the time of fall to the concept of 'force', mv. Clarke discussed the inverse problem of throwing bodies upward until they came to rest under the action of gravity. He cited the importance of considering the time by saying that the space described by a body in motion is not as the 'force' alone but as the 'force' and the time taken together.[122] 'A body thrown

[121] Ibid. For comparison see the following two fragments written by Newton and quoted in Koyré and Cohen, op. cit. (116), 118; inserts are Koyré's and Cohen's.

> And upon these rules of ascending and descending, Galileo demonstrated that projections would, in spaces void of resistance, describe Parabolas. And all Mathematicians (not excepting Mr. Leibniz himself) unanimously agree that he was in the right. And yet Mr. Leibniz would have us measure the force imprest, not by the velocity generated to which it is proportional, but by the space of ascent to which it is not proportional.

In a second fragment Newton wrote (ibid., 119):

> The [weight or] gravity of the body which by its action impresses these impulsive forces upon the body acts with three times more force in the second part of [the] time than in the first and with five times more force in the third part of the time than in the first and with seven times more force in the fourth part of the time than in the first and so on. Which is as much as to say that the falling body grows heavier and heavier as it falls, and becomes three times heavier in the [middle of the] second part of the time than in the [middle of the] first and so on. Or that the weight of the body is proportional to the time of its falling. And by consequence that in the beginning of the first part of the time the body hath no weight at all. Which is contrary to the hypothesis of uniform gravity and to experience itself.

[122] Clarke, op. cit. (114), 384.

upwards with *double* force [$2mv$] will be carried *four times* as high, before its motion be stopped by the uniform Resistance of Gravity; because the *double Force* will carry it *twice as high* in the same Time and moreover require *twice the Time* for the uniform Resistance to destroy the Motion.'[123] That is, if a body is thrown upward with velocity v rising to height s in time t, then when the 'force', mv, is doubled, $v=2$, and $t=2$, since $v \propto t$; but because $s \propto t^2$, when $t = 2$, s will equal 4, i.e. 'four times as high'.

Samuel Clarke's analysis of the problem of free fall echoed that of Newton and his other followers. The scientific bureaucracy which had formed around Isaac Newton was epitomized by Clarke's devotion to and his dependence on Newton's ideas, notes, and manuscript drafts. The Newtonians, however, were a far more cohesive group than the Leibnizians, at least until Newton's death in 1727. The free-fall experiments which formed the basis of the debates between the two groups were discussed by many, but repeated by hardly anyone. Without evaluating the inherent adequacy of the experiments for establishing the conclusions drawn, the followers saw in them support for their prior commitments. The repetition of the experiments was not the method by which converts to either system were produced.

4. *Conclusion*

In the preceding analysis I have tried to show how intellectual and metaphysical positions taken by scientists can provide emotional psycological commitments which determine supposedly 'objective' analyses of elements as fundamental to science as experiments. Strong loyalties on the part of scientists to systems of nature prevented communication from taking place among adherents to opposing philosophies. Experiments have often been held to be the basis for objectivity and consensus among scientists. Yet the same experiment can be interpreted in a number of equally valid ways depending on the scientific metaphysics within which it is analysed. Observers can easily be convinced that what they are seeing verifies a certain interpretation of nature.

It is commonly taught that all sides of a problem must be analysed objectively before a conclusion is made, an opinion is formed, or a position taken, in accordance with the so-called scientific method. But, because of the emotional commitments of social groups to certain views of nature, such objectivity is rarely, if ever possible.

The above study has shown that instead of communicating, each group used the same data to strengthen its own analysis of nature. In the 1720s two strong opposing schemes of knowledge developed simultaneously, each using the other in its process of self-definition. It was not until the 1740s that integrations between the two systems of nature began to occur, as a few natural philosophers recognized the validity of both interpretations

[123] Ibid., 385.

of 'force'. Yet the dichotomies between the underlying views of nature remained unresolved. Processes which contributed to the partial resolution of the *vis viva* controversy will be analyzed in a future paper.

For the present it may be suggested that the above analysis of the Leibnizian-Newtonian debates may be useful in interpreting other controversies which have occurred in the history of science. Furthermore, in the social and political ferment of the modern crisis over nature, it can be seen that individuals develop loyalties to organizations holding mechanistic or organic views of nature, both legacies of the Newtonian and Leibnizian philosophies. The imprinting of these contradictory philosophies causes the members of social groups to interpret data and experiments from within their own perspective. Because of socio-psychological considerations such as those developed in section 1, objective analysis of and communication between these deeply divergent world views may not be possible.