

///// přehledová studie / survey article //////////////////////////////////////

**LEIBNIZ AND THE FIRST LAW OF THERMODYNAMICS**

**Abstract:** *The article presents the German philosopher G. W. Leibniz as a key precursor of the First Law of Thermodynamics. In this way, Leibniz tried to oppose Newton, who seems to have completely rejected the First Law of Thermodynamics, while at the same time remarkably anticipating the Second. Based on his polemics not only with Newton, from whose Laws of Motion thermodynamics originates, and with his advocate Samuel Clarke, but also with René Descartes, whose conception Leibniz partially followed, Leibniz's reasoning turns out to be the most convincing. It is certainly no coincidence that the later founders of thermodynamics frequently acknowledged him.*

**Keywords:** *Gottfried Wilhelm Leibniz; vis viva; energy; thermodynamics*

**Leibniz a první termodynamický zákon**

**Abstrakt:** *Článek představuje německého filozofa G. W. Leibnize jakožto klíčového předchůdce prvního termodynamického zákona. Leibniz se totiž touto cestou pokoušel oponovat zejména Newtonovi, jež první termodynamický zákon patrně zcela odmítal, zatímco současně pozoruhodně předjímal druhý. Na základě polemiky nejen s Newtonem, z jehož pohybových zákonů přitom termodynamika skutečně vychází, resp. s jeho obhájcem Samuelem Clarkem, jakož i s René Descartem, na jehož pojetí Leibniz částečně navazoval, se však Leibnizova argumentace ukáže být vůbec nepřesvědčivější. Jistě tudíž není náhodou, že se pozdější zakladatelé termodynamiky nezřídka hlásili právě k němu.*



**Klíčová slova:** *Gottfried Wilhelm Leibniz; vis viva; energie; termodynamika*

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## 1. Introduction

In this article I argue that Leibniz is to be regarded as a legitimate precursor of the First Law of Thermodynamics, rather than Newton, as Einstein indicated.<sup>1</sup> For although according to Perl “concepts which do not occur in developed theories are not in themselves of great significance,”<sup>2</sup> the modern definition of *energy* in fact originated no later than in 1802, when Thomas Young claimed allegiance to Leibniz’s *vis viva* concept (i.e.,  $mv^2$ ).<sup>3</sup> Until then, energy had not been associated with fuel in any significant way even in the context of thermodynamics itself and the term was rarely used and was regarded as mere poeticism due to Newton’s disdain.<sup>4</sup>

It is no surprise, therefore, that Geikie praised Leibniz’s theory of the Earth precisely for anticipating aspects of modern physics<sup>5</sup> and that according to others Leibniz even espoused the law of conservation of mechanical energy as it is formulated today.<sup>6</sup> For only the contemporary conception of *energy* makes it possible to quantify cases when mechanical energy is transformed to other forms, as suggested in Leibniz’s *Protogaea*.

Unlike Descartes, who held that the originally chaotic matter was eventually ordered by natural laws,<sup>7</sup> Leibniz believed that God created a fully ordered world, whereby this order is merely accidentally transformed in the course of history.<sup>8</sup> The *Protogaea* first discloses the Earth flourishing,

<sup>1</sup> Albert Einstein, “Newton’s Mechanik und ihr Einfluß auf die Gestaltung der theoretischen Physik,” *Die Naturwissenschaften* 15 (1927): 274.

<sup>2</sup> Margula Perl, “Physics and Metaphysics in Newton, Leibniz, and Clarke,” *Journal of the History of Ideas* 30, no. 4 (1969): 526. Cf. Cara N. Daggett, *The Birth of Energy: Fossil Fuels, Thermodynamics & the Politics of Work* (London: Duke University Press, 2019), 17.

<sup>3</sup> Wayne Saslow, “A History of Thermodynamics: The Missing Manual,” *Entropy* 22, no. 77 (2020): 5.

<sup>4</sup> Daggett, *The Birth of Energy*, 3.

<sup>5</sup> Archibald Geikie, *The Founders of Geology* (New York: The Macmillan Company, 1905), 81.

<sup>6</sup> Eberhard Tiemann, “Lebendige Kraft wird Energie: Leibniz Beitrag zur Kinetik,” *Unimagazin Leibniz: Auf den Spuren des groen Denkers*, no. 3/4 (2006): 44; Jan Pavlık, “Vis viva & vis mortua,” *E-Logos: Electronic Journal for Philosophy* 21, no. 1 (2009): 21, footnote 53. See also Marius Stan, “Reflection: Perpetuum Mobiles and Eternity,” in *Eternity: A History*, ed. Yitzhak Melamed (New York: Oxford University Press, 2016), 173.

<sup>7</sup> *Discourse de la methode* (AT, VI, 42, § 19–23; 43, § 13–16).

<sup>8</sup> See, for example, *Letter to Louis Bourguet of 22 March 1714* (GP, 3, 565). See also Claudine Cohen and Andre Wakefield, “Introduction,” in *Protogaea: Sive de prima facie telluris et antiquissimae historiae vestigiis in ipsis naturae monumentis dissertatio*, eds. Claudine Cohen and Andre Wakefield (Chicago: University of Chicago Press, 2008), XXII or Evaristo lvarez Muoz, “Del origen del planeta al significado de los fosiles: La geologia de Leibniz,” in *Leibniz y las ciencias*, ed. Juan Arana (Madrid: Plaza y Valdes, 2013), 165. Curiously, David R. Oldroyd

arranged in a certain way, and then the Earth devastated, with its history recorded in fossils and stratigraphic layers. Thus, the Earth from the very beginning must have contained all the forces that had the task of ultimately transforming it to its present-day form.<sup>9</sup> The planet's contemporary shape is thus in the first place a consequence of continual transformations, which are of two types: those caused by the planet's own proper action and those caused by the actions of animals.

Regarding the planet itself, its hot active core enables it to deal with all minerals and composed substances as chemists do in the laboratory,<sup>10</sup> whereby it is capable not only of composing and decomposing them, but also of transporting, re-unifying, or uncovering them. And while the spontaneous processes of inorganic matter need to be distinguished from the agency of organic animals, which is to various degrees deliberate, the two are nonetheless intimately connected.<sup>11</sup> In any case, the overall sum of the active forces in the universe remains constant, and it is right: "It is extremely reasonable that the same force is always conserved in the universe."<sup>12</sup>

Therefore, Leibniz begins his critique of Newton's assumption that the active forces in the universe are naturally declining, which is why they must be constantly renewed by God himself, already in the fourth paragraph of his first letter to Clarke. Not only according to Newton "motions [...] are constantly decreasing" in the world<sup>13</sup> [rejection of the First Law of Thermodynamics], but there is an "increase in irregularities [...] which will probably grow with time"<sup>14</sup> [acceptance of the Second Law of Thermodynamics].<sup>15</sup> Leibniz's point of departure here probably was the twenty-third question of Newton's *Optics*, as correctly identified by Clarke in a note on Leibniz's first

[*Earth Cycles: A Historical Perspective* (Westport: Greenwood Press, 2006), 31] attributes to Leibniz, on the contrary, a Cartesian conception (i.e., the assumption of original chaos).

<sup>9</sup> Cohen and Wakefield, "Introduction," XXII.

<sup>10</sup> See P (26–27, § 9).

<sup>11</sup> Miguel Escribano-Cabeza, "Chemistry and Dynamics in the Thought of G. W. Leibniz I," *Foundations of Chemistry* 23, no. 2 (2021): 149.

<sup>12</sup> "Il es raisonnable que la même force se conserve tousjours dans l'univers" (*Discours de Métaphysique*; GP, IV, 442, § 17; AG, 49, § 17).

<sup>13</sup> "Motus [...] perpetuo decrescunt" (*Optice*; O, 343, quest. 23).

<sup>14</sup> "Irregularitatibus [...], quaeq; verisimile est fore ut longinquitate temporis majores usq; evadant" (*Optice*; O, 345f., quest. 23).

<sup>15</sup> Due to the concept of *verisimilitude*, the claim by Ilya Prigogine and Isabelle Stengers [*Order out of Chaos: Man's New Dialogue with Nature* (New York: Bentam Books, 1984), 124] that Boltzmann, not Newton, who first expressed the Second Law of Thermodynamics on the basis of probability must therefore be rejected.

letter.<sup>16</sup> There Newton wrote that “motion can arise and cease [rejection of the First Law of Thermodynamics], but due to the cohesion of liquid bodies, the friction of their parts and the weakness of the flexible force in solid bodies there is always a much higher tendency in all parts for motion to cease than to arise [acceptance of the Second Law of Thermodynamics].”<sup>17</sup>

Even with his fourth answer, Clarke still assures us that “Sir Isaac Newton has given a Mathematical Instance (page 341 of the Latin Edition of his *Optics*) wherein Motion is continually diminishing and increasing in Quantity, without any communication thereof to other Bodies.”<sup>18</sup> The first two of the indicated reasons, i.e., the cohesion of liquids and viscosity, are developed by Newton in even more detail: “Vortices of oil, water, or some other, even more liquid substance could certainly maintain their motion longer – without the matter being clear of all cohesion, while its inner parts would not be subject to friction or transmission of motion, which indeed cannot be secured – which is why it will happen that motion is decreasing constantly.”<sup>19</sup>

To the three reasons listed by Newton, Clarke originally added a fourth one, inertia,<sup>20</sup> but eventually came to take it back.<sup>21</sup> For perfect illustration, he did not omit to contribute an example of his own, since “The present Frame of the Solar System (for instance) according to the present Laws of Motion will in time fall into Confusion [a consequence of the Second Law of Thermodynamics]; and perhaps, after That, will be amended or put into a new Form.”<sup>22</sup> And, perhaps to be certain to disperse all doubt, he even compared it to the passing character of the human body: “Tis in the Frame of the World, as in the Frame of Mans Body: The Wisdom of God does not consist, in making the present Frame of Either of them Eternal, but to last

<sup>16</sup> Jan Palkoska, “vod,” in *Gottfried W. Leibniz – Samuel Clarke: Korespondence*, ed. Jan Palkoska (Prague: Oikoymenh, 2020), 43.

<sup>17</sup> “Motum & nasci posse & perire. Verum, per tenacitatem corporum fluidorum, partiumq; suarum attritum, visq; elasticae in corporibus solidis imbecillitatem; multo magis in eam certem partem vergit natura rerum, ut pereat Motus, quam ut nascatur” (*Optice*; O, 341, quest. 23).

<sup>18</sup> LC (C.4.38).

<sup>19</sup> “Vortices ex Oleo, vel Aqua, vel alia aliqua materia adhuc magis fluida, possent quidem diutius Motum suum retinere; verum, nisi materia illa omnis plane tenacitatis expers esset, interq; partes ejus neq; Attritus esset ullus, neq; communicatio Motus, (quod fingi sane non potest;) omnino futurum esset, ut Motus perpetuo decresceret” (*Optice*; O, 343, quest. 23).

<sup>20</sup> LC (C.4.39).

<sup>21</sup> LC (C.5.99).

<sup>22</sup> LC (C.2.8).

so long as be thought fit.”<sup>23</sup> Little does it matter that the only one who could ever re-evaluate the fitness of the permanence of the *status quo* is only God himself (i.e., it should rather say *as He thought fit*, not *as be thought fit*) and that this was his purpose from the very beginning.<sup>24</sup> At least the amount of motion in the world is certainly not constant,<sup>25</sup> and is furthermore subject to dissipation. “Since those various motions that can be observed in the universe are constantly decreasing,” Newton concludes, “it is entirely necessary to resort to some active principles, if those motions are to be conserved and grow again.”<sup>26</sup>

## 2. Energy Conservation

It is entirely expectable that Leibniz categorically rejected both points of departure. In the first place, he claimed that an identical quantity of [living] force (*vis viva*) is always conserved in the universe,<sup>27</sup> or that there is “the same quantity of total and absolute force, or of action [...], the same quantity of respective force, or of reaction; and finally, the same quantity of directive force.”<sup>28</sup> Thus, living force in his conception anticipates the modern conception of energy [acceptance of the First Law of Thermodynamics], since “according to my opinion, the same force and vigour remains always in the world, and only passes from one substance to another, agreeably to the laws of nature, and the beautiful pre-determined order.”<sup>29</sup> To not only postulate his claim, but also support it, and to refute Newton’s arguments thereby, he was obliged to account not only for Newton’s laws of motion, but also for his principle of gravitation<sup>30</sup> (or rather its germ in the form of Galileo’s law of

<sup>23</sup> LC (C.2.8).

<sup>24</sup> LC (C.2.9).

<sup>25</sup> See also the following remark about “the Active Forces, which are in the Universe, diminishing” (LC; C.3.13f).

<sup>26</sup> “Quoniam igitur varii illi Motus, qui in Mundo conspiciuntur, perpetuo decrescunt universi; necesse est prorsus, quo ii conservari recrescere possint, ut ad actiosa aliqua principia recurramus” (*Optice*; O, 343, quest. 23).

<sup>27</sup> *Discours de Métaphysique* (A, VI, 4, 1556, § 18/12f.; GP, IV, 442, § 17; AG, 49, § 17; WPPT, 69, § 17; S, 72, § 17).

<sup>28</sup> “La même quantité de la force totale et absolue, ou de l’action; la même quantité de la force respective, ou de la reaction; la même quantité enfin de la force directive” (*Principes de la nature et de la grâce*; GP, VI, 603, § 11; AG, 210f., § 11).

<sup>29</sup> “Selon mon sentiment, la même force et vigueur y subsiste tousjours, et passe seulement de matiere en matiere, suivant les lois de la nature, et le bel ordre preétabli” (LC, L.1.4).

<sup>30</sup> Within Newtonian mechanics the Laws of Motion (which only involve linear motion) are fully independent of the law of gravitation (i.e., of the curvilinear component of actual mo-

free fall)<sup>31</sup> the universality of which was yet to be proven. And precisely to this purpose Leibniz used the then accepted<sup>32</sup> Torricelli's principle that two interconnected heavy bodies cannot move on their own due to gravitational force without a drop of their common centre of gravitation.<sup>33</sup>

Thus, according to Leibniz, in mechanics it holds that “the struggling of many heavy bodies with one another finally gives rise to a motion through which there results the greatest descent, taken as a whole. For [...] all heavy things strive with equal right to descend in proportion to their heaviness and [...] the one case results in the motion which contains as much descent of heavy things as is possible.”<sup>34</sup> As Palkoska states, here Leibniz was probably thinking of the so-called catenary, or chain-curve, as solved after Johannes Bernoulli by Leibniz and Huygens.<sup>35</sup> In theory, based on Galilean relativity, bodies could still maintain motion across an equipotential plane, but on the assumption that the mutual position of two points can never be perfectly horizontal or perfectly vertical, as Bristol had claimed,<sup>36</sup> will the

tions). Thus, while Newton's three laws of motion can plausibly be regarded as a generalization of Cartesian mechanics – since in both it is assumed that all motion is naturally rectilinear – his gravitation theory stands apart to such an extent that it comprises an accelerated curvilinear component that cannot be reduced to uniform rectilinear motion [Terry Bristol, “Reconsidering the Foundations of Thermodynamics from an Engineering Perspective,” *Preprints* (2018): 10; Carolyn Iltys, “The Decline of Cartesianism in Mechanics,” *Isis* 64, no. 3 (1973): 370].

<sup>31</sup> François Duchesneau, “Leibniz's Theoretical Shift in the *Phoronomus* and *Dynamica de Potentia*,” *Perspectives on Science* 6, no. 1/2 (1998): 97; Richard S. Westfall, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century* (London: Macdonald, 1971), 4. Although the discovery of mixed motion, i.e., the simultaneous but independent actions of two separate motions (inertial and gravitational) was one of Galileo's key achievements, it remained largely unknown to his contemporaries since there was hardly any publication to inform about it [Wolfgang Lefèvre, *Minerva Meets Vulcan: Scientific and Technological Literature: 1450–1750* (Cham: Springer, 2021), 88].

<sup>32</sup> Gideon Freudenthal, “Perpetuum Mobile, The Leibniz–Papin Controversy,” *Studies in History and Philosophy of Science* 33, no. 3 (2002): 584. See, among others, *Letter to Leibniz by Unknown Author* (I, 81).

<sup>33</sup> “Duo gravia simul coniuncta ex se moveri non posse, nisi centrum commune gravitatis ipsorum descendat” (T, 99).

<sup>34</sup> “Communi pluribus corporibus se luctantibus talis demum oritur motus, per quem fit maximus descensus in summa. [...] Enim [...] omnia pondera pari jure ad descendendum tendunt pro ratione gravitatis, et ut hic prodit motus, quo continetur quam maximus gravium descensus” (*De rerum originatione radicali*; GP, VII, 304; AG, 151; PA, 17).

<sup>35</sup> Palkoska in PA (17, § 108); Stanislav Michal, *Perpetuum mobile včera a dnes* (Prague: SNTS, 1981), 109.

<sup>36</sup> Bristol, “Reconsidering the Foundations of Thermodynamics,” 8.

path between them always be the result of a certain type of combination of the two components.<sup>37</sup>

While for Descartes the shortest connection between two points would in all circumstances be a straight line, after Leibniz's silent introduction of Newtonian gravitation, motion is composed not only of the horizontal component with constant speed but also of the vertical component with gravitational acceleration. Although Bristol gives no further reasons for his assumption, Leibniz's doubts regarding the validity of the Euclidean definition of the line segment as the shortest connection between two points<sup>38</sup> were also noted by Risi.<sup>39</sup> By adding that if the gravitational centre of the system drops, it thereby acquires sufficient force to be elevated to its original height, Leibniz completed Torricelli's principle.<sup>40</sup>

### 3. Quantity of Motion Conservation

At first glance, Leibniz's procedure may seem unnecessarily complicated: it would have sufficed to appeal to Descartes's authority. Already Descartes in his *Principles of Philosophy* attributed to God the function of maintaining an identical quantity of motion and rest across the universe<sup>41</sup> and, like Leibniz, regarded this as an evident consequence of God's perfection, his unchangeability or constancy.<sup>42</sup> Leibniz, on the other hand, tried to prove, based on the universal validity of gravitation, that even Descartes's principle of conservation of motion is ultimately no less misguided than the Newtonian belief in its decrease, if the measure of its quantity is the product of mass and velocity ( $mv$ ), or momentum, i.e., the quantity of motion.<sup>43</sup>

<sup>37</sup> For example, Leibniz's silence regarding the uniform horizontal effect in his reply to Papin probably indicates his doubts about using this kind of motion to ground gravitational acceleration [Alberto G. Ranea, "The Apriori Method and the Actio Concept Revised: Dynamics and Metaphysics in an Unpublished Controversy between Leibniz and Denis Papin," *Studia Leibniziana* XXI, no. 1 (1989): 47].

<sup>38</sup> See *In Euclidis πρώτα* (GM, V, 188, § 2f.; LH, 35, 1, 5, fol. 18r).

<sup>39</sup> *In Euclidis πρώτα* (GM, V, 188, § VII/2f.).

<sup>40</sup> Freudenthal, "Perpetuum Mobile, The Leibniz–Papin Controversy," 585.

<sup>41</sup> *Principia philosophiae* (AT, VIII, 61, § 10–24).

<sup>42</sup> *Ibid.* Cf.: "But we have come to understand that even nature while conserving the absolute force does not forget about its constancy and perfection." ["Sed a nobis deprehensum est, ne in absoluta quidem vi conservanda naturam constantiae suae atque perfectionis dememinisse" (*Untitled*; GP, IV, 398)].

<sup>43</sup> *Untitled* (GP, IV, 398).

Since in the five common machines velocity and mass mutually replace each other, it is quite understandable that many mathematicians decided to deduce motive effects from the momentum, or the product of the body's mass and its velocity.<sup>44</sup> If both the law of action and reaction and the law of mechanical energy conservation in general can be applied to gravitational interaction, why couldn't it be applied in connection with the law of momentum conservation?<sup>45</sup> According to Leibniz, this is a deeply rooted assumption that motion with its velocity is a real, absolute entity, and that therefore a change in its quantity ought to be due to creation or annihilation, which are reserved to God.<sup>46</sup> It is therefore no wonder that by publishing his critique of Cartesian mechanics, *Brevis demonstratio*, in 1686 he initiated a debate that occupied the attention of most European natural philosophers for the next fifty years.<sup>47</sup> In the same year, he developed a similar topic within his *Discourse on Metaphysics* and *Specimen dynamicum*, and of course also in his later correspondence with Clarke.

The criticism was entirely constructive, since he proposed replacing the law of momentum conservation by the law of force conservation: "In wholes whose parts cannot exist at the same time [i.e., in those in motion] it must be of even less wonder that their quantity is not conserved as identical. But the impulsive force itself (or the status of bodies of which the change of place is born) is something absolute and subsistent."<sup>48</sup> When two bodies of the same mass fall with identical initial velocity, their total momentum is exactly twice the momentum of one such body (of the same velocity):

$$m_1 = m_2 = 5 \text{ kg}; m = m_1 + m_2 = 10 \text{ kg}; v_0 = 1 \frac{\text{m}}{\text{s}}; t = 2 \text{ s}; a = 10 \frac{\text{m}}{\text{s}^2}; v = v_0 + (at) \\ \rightarrow p_2 = 2p_1$$

$$p_1 = m_1 v = 5[1 + (10 \times 2)] = 105 \text{ kg} \frac{\text{m}}{\text{s}}$$

$$p_2 = m v = 10[1 + (10 \times 2)] = 210 \text{ kg} \frac{\text{m}}{\text{s}},$$

<sup>44</sup> *Brevis Demonstratio* (GM, VI, 117; L, 296).

<sup>45</sup> Pavlík, "Vis viva & vis mortua," 33.

<sup>46</sup> *De causa gravitatis* (GM, VI, 202, § 12).

<sup>47</sup> David Papineau, "The *Vis viva* Controversy: Do Meanings Matter?," *Studies in History and Philosophy of Science* 8, no. 2 (1977): 111; Carolyn Iltys, "Leibniz and the *Vis Viva* Controversy," *Isis* 62, no. 1 (1971): 21.

<sup>48</sup> "Tota, quorum partes simul esse non possunt, eo minus mirum esse debet, quantitatem ejus eandem non conservari. Sed vis ipsa motrix (seu status rerum, unde mutatio loci nascitur) est absolutum quiddam et subsistens" (*De causa gravitatis*; GM, VI, 202, § 12).



yet this does not hold for an identical body and twice the original velocity:<sup>49</sup>

$$m = 5 \text{ kg}; v_{0(1)} = 1 \frac{\text{m}}{\text{s}}; v_{0(2)} = 2v_{0(1)} = 2 \frac{\text{m}}{\text{s}}; t = 2 \text{ s}; a = 10 \frac{\text{m}}{\text{s}^2}; v = v_0 + (at) \rightarrow p_2 \neq 2p_1$$

$$p_1 = mv_{(1)} = 5[1 + (10 \times 2)] = 105 \text{ kg} \frac{\text{m}}{\text{s}}$$

$$p_2 = mv_{(2)} = 5[2 + (10 \times 2)] = 110 \text{ kg} \frac{\text{m}}{\text{s}}.$$

And while the potential energy, and therefore the work done in lifting a one-pound body to the height of four feet is actually equal to the potential energy of a four-pound body at the height of one foot (I replaced the pounds and feet with kilograms and metres for simplicity's sake):

$$m_1 = 1 \text{ kg}; h_1 = 4 \text{ m}; E_p = mgh = 1 \times 10 \times 4 = 40 \text{ J}$$

$$m_2 = 4 \text{ kg}; h_2 = 1 \text{ m}; E_p = mgh = 4 \times 10 \times 1 = 40 \text{ J};$$

and their kinetic energy is also quantitatively identical:

$$v = \sqrt{(2gh)}^{50}$$

$$E_{k1} = \frac{1}{2} m_1 v^2 = \frac{1}{2} \times 1 [\sqrt{(2 \times 10 \times 4)}]^2 \doteq 40 \text{ J}$$

$$E_{k2} = \frac{1}{2} m_2 v^2 = \frac{1}{2} \times 4 [\sqrt{(2 \times 10 \times 1)}]^2 \doteq 40 \text{ J},$$

their momentum is not:<sup>51</sup>

$$p_1 = m_1 v_1 = 1[\sqrt{(2 \times 10 \times 4)}] \doteq 9 \text{ kg} \frac{\text{m}}{\text{s}}$$

$$p_2 = m_1 v_2 = 4[\sqrt{(2 \times 10 \times 1)}] \doteq 18 \text{ kg} \frac{\text{m}}{\text{s}}.$$

<sup>49</sup> *De causa gravitatis* (GM, VI, 202f., § 12).

<sup>50</sup> According to Pavlik, "Vis viva & vis mortua," 22, the formula for calculating velocity [ $v = \sqrt{(2gh)}$ ] is implied by Galilei's formula for calculating trajectory [ $h = \frac{1}{2}gt^2$ ]. It is not evident to me how the formula came to include the quantitative variable  $g$ , as this is already contained in velocity itself. The author's procedure probably was that into the formula  $h = \frac{1}{2}gt^2$  he first replaced the product of acceleration and time with velocity (since  $v = gt \rightarrow h = \frac{1}{2}v^2$ ) and then deduced the correct formula  $v = \sqrt{(2s)}$  from it. Since the quantitative variable  $g$  is equally inappropriate in both bodies, this error does not affect the difference in their momentum at all.

<sup>51</sup> *Discours de Métaphysique* (A, VI, 4, 1556–1558, § 17; GP, IV, 442–444, § 17; AG, 49–51, § 17; WFPT, 69–71, § 17; S, 72–74, § 17).

Therefore, given that the momentum ( $mv$ ) underestimates the influence of velocity in favour of mass, it should be compensated by squaring the velocity, i.e., using the  $mv^2$  measure instead.

The possibility to measure the causal effects of the force by work was acknowledged also by Descartes.<sup>52</sup> He also stated that the same force that lifts a weight to a certain height can lift a double weight to half the height.<sup>53</sup> However, he did not reach Leibniz's observation that the two cases differ principally with respect to momentum. Leibniz, on the contrary, insisted that the proof he presented is quite primitive and that Descartes's error in this respect is a consequence of his overt trust in his own thought that had not ripened sufficiently.<sup>54</sup>

The concept of *force* had been regarded as problematic for a long time and together with it Descartes's conception was convincingly contested.<sup>55</sup> As Leibniz did not hesitate to point out, "when two mathematicians, who are clearly among the most talented, fought with me about this matter, in part through letters, in part in public, one came over entirely into my camp, and the other came to the point of abandoning all his objections after much careful airing and candidly confessed that he did not yet have a response to one of my arguments."<sup>56</sup> It thus seems likely that Newton and Clarke asserted to Leibniz's view. Since based on Newton's Second Law of Motion, to attain a double velocity a double force is required<sup>57</sup> and kinetic energy rises with the square of velocity, it is evident that a quadruple energy would be required.<sup>58</sup>

<sup>52</sup> Jip van Besouw, "The Wedge and the *Vis Viva* Controversy: How Concepts of Force Influenced the Practice of Early Eighteenth-Century Mechanics," *Archive for History of Exact Sciences* 71 (2017): 123.

<sup>53</sup> *Traité de la mécanique* (DO, V, 435f.).

<sup>54</sup> *Brevis demonstratio* (GM, VI, 119).

<sup>55</sup> Van Besouw, "The Wedge and the *Vis Viva* Controversy," 111. Cf. the same assertion already by Gabrielle E. du Châtelet. *Institutions de Physique* (Paris: Prault, 1740), 6.

<sup>56</sup> "Eaque de re cum duo Mathematici ingenio facile inter primos mecum partim per literas partim publice contulissent, alter penitus in castra mea transiit, alter eo devenit, ut objectiones suas omnes post et accuratam ventilationem desereret, et ad meam quandam demonstrationem nondum sibi multam responsionem suppetere candidè fateretur" (*De ipsa natura*; GP, IV, 506, § 4; AG, 157, § 4). According to Palkoska (in PA, 56), Leibniz is probably thinking of Johannes Bernoulli and Christiaan Huygens; according to Roger Ariew and Daniel Garber ["On Nature Itself," in *Philosophical Essays*, eds. Roger Ariew and Daniel Garber (Cambridge: Hackett Publishing Company, 1989), 157, footnote 221] it is Bernoulli and Malebranche. See also *Essay de dynamique* (GM, VI, 217).

<sup>57</sup> *Theodicée* (GP, VI, 120, § 30).

<sup>58</sup> See Pavlík, "Vis viva & vis mortua," 22.

#### 4. Uniformity of Gravitation

Newton himself approached Leibniz's conception of force especially in propositions 39–41 of his *Principia*, but he never acknowledged it explicitly.<sup>59</sup> Instead of it, he distanced himself from the matter<sup>60</sup> and Clarke, on Newton's example, preferred to attack another of Leibniz's alleged tacit assumptions – that gravitation ought not to have a uniform effect ( $g \neq \text{const.}$ ) – which provided him with a suitable pretext for inclining to Descartes.<sup>61</sup> Apparently, the terms *non/uniform gravitation* [or more precisely: *non/uniform gravitational field*] already at that time signified precisely the non/dependence of gravitational force on the square of the distance from its point of application, as testified by a contemporary source of unknown authorship: “whether mass is conceived popularly as uniform and consisting of parallel directions, or as if the directions aimed at the centre and gravitations varied according to the distances from the centre.”<sup>62</sup> A body, or a “heavy point [...] falling with a uniformly accelerated absolute motion” which “compresses the same curve in its individual points with the force of a body of uniform mass”<sup>63</sup> is what we still associate with *uniform gravitation* today.

However, the claim (approved by Descartes) that the fall of a one-pound body from a height of four feet ought to generate the same effect as the fall of a four-pound body from a height of one foot seems to contradict the Cartesian theory of uniform gravitation. “At first glance it is clear,” Michal claims, “that a body falling from a height of four feet falls to the ground faster than when it falls from a height of one foot.”<sup>64</sup> If gravitation is to be uniform according to Descartes, and therefore it must impress the same amount of impulsive force into the falling body within a time ( $g = \text{const.}$ ), then the impulsive force of the body is proportional to its velocity, not to

<sup>59</sup> Van Besouw, “The Wedge and the *Vis Viva* Controversy,” 138, footnote 90.

<sup>60</sup> John Mackie, *Life of Godfrey William von Leibnitz* (Boston: Gould, Kendall & Lincoln, 1845), 99f.; Carolyn Iltys, “The Leibnizian-Newtonian Debates: Natural Philosophy and Social Psychology,” *British Journal for the History of Science* 6, no. 24 (1973): 373; Van Besouw, “The Wedge and the *Vis Viva* Controversy,” 111.

<sup>61</sup> Papineau, “The *Vis viva* Controversy: Do Meanings Matter?,” 133.

<sup>62</sup> “Sive gravitas vulgari modo concipiatur ut sit uniformis, et constet directionibus parallelis; sive directiones tendant ad centrum, et gravitationes varient pro distantia a centro” (LH, 35, 10, 15, fol. 2v, § 1; LO, 307f.).

<sup>63</sup> “Problema etiam ab hoc solutum alia ratione solvit; nempe curvae ejus conditionis, ut in ea descendens grave punctum motu naturaliter accelerato eandem curvam in singulis punctis premat vi ubique aequali ponderi corporis absolute” (LH, 35, 10, 15, fol. 2r, § 2; LO, 309).

<sup>64</sup> “I na první pohled je přece jasné, že těleso padající z výšky čtyř loktů dopadne na zem rychleji, než padá-li z výšky jednoho lokte.” (Michal, *Perpetuum mobile včera a dnes*, 107).

the square of its velocity.<sup>65</sup> As Clarke had not missed,<sup>66</sup> the same view “of those that can overcome the same number of gravitational impulses”<sup>67</sup> was verbally proclaimed also by Leibniz. The assumption of uniform gravitation was even part of Leibniz’s own argument explicitly formulated “against the Cartesians.”<sup>68</sup>

Not only “Galilei assumed in heavy [bodies] a motion which is equally accelerated in equal times, it has also been proven with reasons and experiments,”<sup>69</sup> i.e., with those experiments that Desaguliers accuses Leibniz of ignoring.<sup>70</sup> As Clarke correctly noted, Galilei’s “propositions are allowed by all mathematicians, not excepting Mr. Leibnitz himself.”<sup>71</sup> While the path ( $s = \frac{1}{2}gt^2$ ), and therefore the required energy across the uniform gravitational field really grow/decrease with the square of time, this is not the case with gravitational acceleration ( $g = \text{const.}$ ). “Therefore [...] if the heavy body were at rest, as at the beginning, with equal times, as in the case of impressed impact, to times correspond forces, not spaces of rising or falling, as I claimed before.”<sup>72</sup>

As verified by Koyr and Cohen, the passages where Clarke preferred to advocate uniform gravitation for these reasons were written for him by Newton – who even adjusted his own *Principia* to it.<sup>73</sup> Once Newton became aware that, strictly speaking, his laws of motion do not imply that gravitation ought to produce constant acceleration, he proceeded to address this defect. So the beginning of the *Scholio* to the laws of motion in the third edition of the *Principia* assures us that uniform gravitation, acting on the falling body in the same way, compresses the body in equal time intervals with the same

<sup>65</sup> Papineau, “The *Vis viva* Controversy: Do Meanings Matter?,” 133.

<sup>66</sup> LC (C.5, footnote on § 93–95).

<sup>67</sup> “Quae aequalem numerum impressionum gravitatis vincere possunt” (*De legibus naturae*; GM, VI, 209).

<sup>68</sup> “Meo argumento [...] contra Cartesianos prolato” (*De causa gravitatis*; GM, VI, 195).

<sup>69</sup> “Galilaeus [...] supposuit [...] in gravibus motum aequalibus temporibus aequaliter acceleratum, sed etiam rationibus atque experimentis confirmare nisus est” (*ibid.*).

<sup>70</sup> John Theophilus Desaguliers, “An Account of Some Experiments Made to Prove That the Force of Moving Bodies Is Proportionable to Their Velocities,” *Philosophical Transactions* 32 (1723): 169f.

<sup>71</sup> LC (C.5, footnote on § 93–95).

<sup>72</sup> “Nempe [...] si grave quiesceret, ut ab initio, semper aequalibus temporibus tantundem ictus imprim, adeoque vires esse ut tempora, non ut spatia ascensuum vel descensuum, quemadmodum ego quidem existimaveram” (*De causa gravitatis*; GM, VI, 195).

<sup>73</sup> Alexandre Koyr and Bernard Cohen, “Newton & The Leibniz-Clarke Correspondence: With Notes on Newton, Conti, & Des Maizeaux,” *Archives Internationales d’Histoire des Sciences* 15, no. 58/59 (1962): 118f., 121.

forces, which is why it produces the same velocities and in the entire time compresses with the entire force, whereby it gives rise to the entire velocity proportional to time.<sup>74</sup> Unfortunately, as Dijkterhuis notes,<sup>75</sup> here Newton used the term *impressed force* in a sense that is very different from the one he attributes to it by *Definition IV*. In the case of *Definition IV* it was a force acting on the body from the outside, whereby it was explicitly stated that the force does not remain in the body. Furthermore, in the eighth definition he omitted to leave out the original opposite claim that although gravitation manifests itself as uniform when close to the Earth's surface, "weight in one and the same body is greater near the earth and less out in the heavens."<sup>76</sup>

If Clarke noted the inconsistency, he could not find fault with Newton for it, so he was obliged to forcibly attribute it to Leibniz. It was commonly accepted at the time<sup>77</sup> that, strictly speaking, gravitation ought not to be regarded as uniform, so it was not difficult to find it, among others, in the Leibniz-inspired Jacob Hermann. For, as Desaguliers states, Hermann and others followed and defended Leibniz's opinion accurately, so that any answer for him was also answer for them.<sup>78</sup> However, de facto Clarke was criticizing not Leibniz himself, but merely Hermann, who:

In his *Phoronomia* [...] represents that this is founded upon a false supposition, that bodies thrown upwards receive from the gravity which resists them, an equal number of impulses in equal times [Clarke's view]. Which is as much as to say, that gravity is not uniform [Hermann's view]. [...] I suppose, he means that the swifter the motion of bodies is upwards, the more numerous are the impulses; because the bodies meet the (imaginary) gravitating particles.<sup>79</sup>

Clarke then only needed to contrast Hermann's conclusion that "the weight of bodies will be greater when they move upwards, and less when they move downwards"<sup>80</sup> with the commonly accepted assumption of uniform gravity.

<sup>74</sup> PM (21, schol.).

<sup>75</sup> Eduard Jan Dijkterhuis, *The Mechanization of the World Picture*, ed. Carry Dikshoorn (Oxford: Clarendon Press, 1961), 476. See PM (2).

<sup>76</sup> "Pondus [...] in corpore eodem majus prope terram, minus in coelis" (*Philosophiae naturalis principia mathematica*; PM, 5, def. 8; NP, 407, def. 8).

<sup>77</sup> Papineau, "The *Vis viva* Controversy: Do Meanings Matter?," 137.

<sup>78</sup> Desaguliers, "An Account of Some Experiments," 270.

<sup>79</sup> LC (C.5, footnote on § 93–95). Papineau, "The *Vis viva* Controversy: Do Meanings Matter?," 137 erroneously refers to p. 125 of Alexander's edition, but it is the previous page (X, 124).

<sup>80</sup> LC (C.5, footnote on § 93–95).

Of course, we can add that even if Leibniz really applied the assumption of non-uniform gravitation in his critique of Descartes, he would certainly do so according to the contemporary conception as indirectly, not directly proportional to the (square of) distance from its source. Strictly speaking, the assumption of a uniform gravitational field (unlike an electromagnetic field, such as the one of a capacitor) is just an approximation valid only at a small scale,<sup>81</sup> which is a condition staunchly met by Leibniz’s example. “For,” Leibniz defended his procedure, “the maximum precise interval of the distance from the centre [of the Earth] in which it is difficult to approach the centre between those that are falling, cannot make a principal difference, which is why in equal times there occurs a compression of equal velocities.”<sup>82</sup> For completeness’s sake let us add that even if in motion perpendicular to the gravitational field’s lines of force, which Leibniz also considered,<sup>83</sup> the curving of the Earth’s surface is omitted,<sup>84</sup> it cannot be omitted here. However, the real point of Clarke’s reasoning did not concern gravitational uniformity as such, but rather motions across a uniform field, i.e., throws.

## 5. Clarke’s Objections

According to Clarke’s extensive and apparently invincible objection, it is first of all necessary to account for the time of the body’s fall, or rise:

The reason of his inconsistency [...] was his computing [...] the quantity of impulsive force, from the quantity of [...] matter and of the space [...], without considering the time of [...] ascending. [...] But in this supposition, Mr. Leibnitz is greatly mistaken. Neither the Cartesians, nor any other philosophers

<sup>81</sup> Frank J. Blatt, *Modern Physics* (New York: McGraw-Hill, 1992), 51. Even the constant  $g$  itself is constant only with some approximation. If it were to generally hold that  $E_p = mg_{(\text{const.})}h$ , no space flights would be possible since an infinite amount of energy would be needed to overcome the Earth’s field of gravity. In fact, it holds that  $G = \frac{kM}{(R+h)^2}$  where  $M$  and  $R$  stand for the mass and radius of the Earth,  $h$  for the body’s height above the Earth’s surface (Pavlık, “Vis viva & vis mortua,” 32). It is therefore no wonder that Leibniz preferred to avoid constants (ibid., 22), given that no truly universal constant had been discovered (Prigogine and Stengers, *Order from Chaos*, 203).

<sup>82</sup> “Nam ob maximam a centro (nempe telluris) distantiam exiguum intervallum, quo grave apud nos inter cadendum centro accedit, nullum facere potest discrimen notabile, ac proinde vel hinc oriatur aequalibus temporibus aequalis celeritatum impressio” (*De causa gravitatis*; GM, VI, 197). See also *Specimen dynamicum* (GM, VI, 244, I, § 15).

<sup>83</sup> *Specimen dynamicum* (GM, VI, 243, I, § 15).

<sup>84</sup> Pavlık, “Vis viva & vis mortua,” 33, footnote 76.

or mathematicians ever grant this, but in such cases only, where the times of ascent or descent are equal. [...] (From whence by the way, it plainly follows, that if there be always the same impulsive force in the world, as Mr. Leibnitz affirms, there must be always the same motion in the world, contrary to what he affirms. But Mr. Leibnitz confounds these cases where the times are equal with the cases where the times are unequal: and chiefly that of bodies rising and falling at the ends of the unequal arms of a balance [... is by him confounded with that of bodies falling downwards and thrown upwards, without allowing for the inequality of the time.<sup>85</sup>

In this way, Leibniz allegedly disregarded one of the factors of force, namely time. However, seeing that the motion of a body thrown after rebounding vertically upwards is uniformly decelerated, it is (omitting dissipation) the same uniformly accelerated motion in the opposite direction and its time of duration is therefore (after subtracting the impressed velocity) the same. If the magnitude of the impulsive force were to be proportional to time, then – in contradiction to Clarke’s explanation<sup>86</sup> – a body thrown with lesser force (and therefore moving with lesser velocity, i.e., in a longer span of time), would fall deeper than a body thrown with greater force.

And regarding the claim “that although a body at the end of the unequal arms of a balance, by doubling its velocity, acquires only a double impulsive force, yet, by being thrown upwards with the same doubled velocity, it acquires a quadruple impulsive force,”<sup>87</sup> it needs to be added that in the case of the motion of a weight decelerated by a counter-weight it is no longer an instance of free fall. Thus, although it holds that “equal bodies with equal velocities cannot have unequal impulsive forces,”<sup>88</sup> in this case the velocities are not equal. But none of Leibniz’s texts to which Clarke directly refers<sup>89</sup> mentions balance scales,<sup>90</sup> whether equal-arm ones or non-equal-arm ones.

<sup>85</sup> LC (C.5, footnote on § 93–95). See also his later *A Letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly* (WC, IV, 738f.).

<sup>86</sup> *A Letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly* (WC, IV, 739f.).

<sup>87</sup> “Affirming, that although a body at the end of the unequal arms of a balance, by doubling its velocity, acquires only a double impulsive force, yet, by being thrown upwards with the same doubled velocity, it acquires a quadruple impulsive force” (LC; C.5, footnote on § 93–95).

<sup>88</sup> LC (C.5, footnote on § 93–95).

<sup>89</sup> *Brevis demonstratio* (GM, VI, 118); *De causa gravitatis* (GM, VI, 199); *De legibus naturae* (GM, VI, 204); *Specimen dynamicum* (GM, VI, 244n.).

<sup>90</sup> Palkoska’s translation (PA, 166 and 167) – probably under the influence of Clarke’s interpretation (see *A Letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly*; WC, IV,

A similar confusion also gave rise to Clarke’s claim that in Leibniz’s conception “this body, with one and the same degree of velocity, would have twice as much force when thrown upwards, as when thrown horizontally: which is a plain contradiction.”<sup>91</sup> But seeing that the individual throws de facto differ only in their initial velocity,<sup>92</sup> both cases would again involve a uniformly decelerated, or accelerated, motion [ $v = v_0 \pm \sqrt{(2gh)}$ ]<sup>93</sup> with a kinetic energy of  $\frac{1}{2} mv^2$ , or  $mv^2$  in Leibniz’s conception. And finally, the claim that at the moment the body is launched, its kinetic energy is still null (as it is stored in potential energy yet) certainly does not mean that the body would never drop, as Newton’s observations<sup>94</sup> were elaborated by Clarke:

Therefore if the action of gravity [...] be supposed in the middle of the first part of time, to be of one degree; it will, in the middle of the second, third, and fourth parts of time, be of three, five, and seven degrees, and so on; [...] and, by consequence, in the beginning of the time it will be none at all; and so the body, for want of gravity, will not fall down.<sup>95</sup>

Analogically, the weight of the body will not change even when it is thrown upwards, despite Clarke’s conviction: “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.”<sup>96</sup> But, in fact, its original impressed kinetic energy will just be exhausted, after which the opposite acceleration, bestowed by gravitation, will prevail.

739n.) – speaks of oscillating balances, rather than of the unequal arms of a balance scale (i.e., of differing moments of force).

<sup>91</sup> LC (C.5, footnote on § 93–95).

<sup>92</sup> Or: “tangible bodies acquire the same velocities, falling perpendicularly from the same height, whether their trajectory is perpendicular or inclined” [“Gravia easdem acquirunt celeritates, si ex eadem altitudine perpendiculari descendant quacunque licet via perpendiculari vel inclinata” (*Dynamica de potentia*; GM, VI, 455, II, I, prop. 33)].

<sup>93</sup> See Jiř Wagner, *Přklady z fyziky* (Liberec: Vysok škola strojn a textiln, 1984), 10.

<sup>94</sup> Iltys, “The Leibnizian-Newtonian Debates,” 373. See Koyr and Cohen, “Newton & The Leibniz-Clarke Correspondence,” 121.

<sup>95</sup> LC (C.5, footnote on § 93–95).

<sup>96</sup> *Ibid.*



## 6. Conclusion

The conclusions of this analysis are all the more surprising, given that Clarke's note accurately reproduces the observations of Newton himself. And although repetition of experiments was not a method by which recruited the converts to either of the camps,<sup>97</sup> Palkoska used the extensive note on paragraphs C.5.93–95, which points out the internal contradictions of Leibniz's own theory, together with the reference to the "particular experimental proofs of the stated assumptions in Newton's *Optics*,"<sup>98</sup> as an instructive example of the difference "between the Newtonian experimental and Leibniz's hypothetical approach to the relationship between metaphysical and empirical issues."<sup>99</sup>

Such assessment is supported not only by the correspondence with Clarke, but also by some apparently pro-Newtonian 18th-century testimonia.<sup>100</sup> The practice of attributing to Newton "opinions he did not have and words pronounced by others"<sup>101</sup> is widespread.<sup>102</sup> One of the ideas frequently attributed to Newton as being his original is also the emphasis placed on experiment.<sup>103</sup> Unlike Newton (who described tidal phenomena possibly without ever seeing the sea<sup>104</sup> and whose most famous experiment with a bucket is

<sup>97</sup> Iltys, "The Leibnizian-Newtonian Debates," 376.

<sup>98</sup> I.e., apparently the cohesion or friction of liquids and the weakness of solid bodies' elasticity.

<sup>99</sup> "Mezi newtonovským 'zkušnostním (experimental)' a Leibnizovým 'hypotetickým' přístupem ke vztahu mezi metafyzickými a empirickými otázkami" (Palkoska, "Úvod," 46). Also Perl, "Physics and Metaphysics in Newton, Leibniz, and Clarke," 526.

<sup>100</sup> Karin Verelst, "Leibniz vs. Newton: Intransparency vs. Inconsistency," *Synthese* 191, no. 13 (2014): 22.

<sup>101</sup> „Názory, které neměl, a slova, jež za něj vyslovili jiní." [Ivan Saxl, "Isaac Newton: Alchymista, filosof, heretik," in *Matematika v proměnách věků*. Vol. 6, edited by Jindřich Bečvář (Prague: Matfyzpress, 2010), 7].

<sup>102</sup> Also Nicholas Huggett, "Motion in Leibniz's *Physics and Metaphysics*," in *True Motion*, 2019 [in print], accessed December 15, 2023.

<sup>103</sup> Saxl, "Isaac Newton," 34; Van Besouw, "The Wedge and the *Vis Viva* Controversy," 133.

<sup>104</sup> At least according to Edward Dolnick, *The Clockwork Universe* (New York: HarperCollins Publishers, 2011), 162, and Mark Brake, *The Science of the Big Bang Theory: What America's Favorite Sitcom Can Teach You about Physics, Flags, and the Idiosyncrasies of Scientists!* (New York: Skyhorse Publishing, 2019), 196.

entirely<sup>105</sup> inconclusive),<sup>106</sup> Leibniz allegedly was not an outstanding observer of nature (he was heavily short-sighted),<sup>107</sup> so that he apparently must have made all the sketches and other observations from the *Protogaea*<sup>108</sup> up, and

<sup>105</sup> More precisely, it does not imply the existence of absolute space. Apparently, Newton also tried to forcibly bring an experiment into accord with his own theory [William Newman, "Geochemical Concepts in Isaac Newton's Early Alchemy," in *The Revolution in Geology from the Renaissance to the Enlightenment*, ed. Gary Rosenberg (Boulder: Geological Society of America, 2009), 47] in connection with Boyle's reintegration of nitrogen (see *Of Natures Obvious Laws & Processes in Vegetation*; IU, fol. 2r–2v). Finally, even his proof of the four basic principles of geometric optics contradicted experience (Julius Krempasky, *Fyzika: Prrucka pre vysok školy technicke* (Prague: SNTL, 1987), 306.

<sup>106</sup> Herman Erlichson, "The Leibniz-Clarke Controversy: Absolute versus Relative Space and Time," *American Journal of Physics* 35, no. 2 (1967): 91, 93; Michael Friedman, *Foundations of Space-Time Theories: Relativistic Physics and Philosophy of Science* (Princeton: Princeton University Press, 1983), 122, 275; John Randolph Lucas, *Space, Time and Causality: An Essay in Natural Philosophy* (Oxford: Clarendon Press, 1984), 133; Julian Barbour, *The Discovery of Dynamics: Absolute or Relative Motion?: A Study from a Machian Point of View of the Discovery and the Structure of Dynamical Theories* (Cambridge: Cambridge University Press, 1989), 670f.; Richard Arthur, "Space and Relativity in Newton and Leibniz," *The British Journal for the Philosophy of Science* 45, no. 1 (1994): 222; Howard Stein, "Some Philosophical Prehistory of General Relativity," in *Foundations of Space-Time Theories*, eds. John S. Earman, Clark N. Glymour, and John J. Stachel (Mineapolis: University of Minnesota Press, 1977), 15; Robert Disalle, *Understanding Space-Time: The Philosophical Development of Physics from Newton to Einstein* (Cambridge: Cambridge University Press, 2006), 14; Ori Belkind, "Newton's Conceptual Argument for Absolute Space," *International Studies in the Philosophy of Science* 21, no. 3 (2007): 274; Marco Giovanelli, "Leibniz Equivalence: On Leibniz's (Bad) Influence on the Logical Empiricist Interpretation of General Relativity," PhilSci archive, accessed December 15, 2023; Herbert Pfister and Markus King, *Inertia and Gravitation: The Fundamental Nature and Structure of Space-Time* (Dordrecht: Springer, 2015), 5; Hans Poser, *Leibniz' Philosophie: ber die Einheit von Metaphysik und Wissenschaft* (Hamburg: Felix Meiner Verlag, 2016), 335; Kateřina Lochmanov, "Analysis situs v kontextu Leibnizovy korespondence s Clarkem," PhD diss., University of Ostrava, 2021, 83; also *Letter to Burnett of 8/18 May 1697* (GP, III, 205); *Pices et Fragments concernant la Question de l'Existence et de la Perceptibilit du 'Mouvement Absolu'* (HO, XVI, 232, no. 8); *Huygens's Letter to Leibniz of 24 August 1694* (GM, II, 192); *Letter to Huygens of 4/14 September 1694* (GM, II, 199).

<sup>107</sup> Jurgen Jost, *Leibniz und die moderne Naturwissenschaft* (Berlin: Springer, 2019), 14; John T. Merz, *Leibniz* (London: William Blackwood and Sons, 1902), 126; John Mackie, *Life of Godfrey William von Leibnitz*, 271, 275.

<sup>108</sup> See Toshihiro Yamada, "Stenonian Revolution or Leibnizian Revival?: Constructing Geo-History in the Seventeenth Century," *Historia Scientiarum* 13, no. 2 (2003): 88f.; Carl Ch. Beringer, *Geschichte der Geologie und des Geologischen Weltbildes* (Stuttgart: Ferdinand Enke Verlag, 1954), 27; Dale Jacquette, "Leibniz's Empirical, Not Empiricist Methodology," in *Tercentary Essays on the Philosophy and Science of Leibniz*, eds. Lloyd Strickland, Erik Vynckel, and Julia Weckend (Cham: Springer, 2017), 195.

he was also not a successful experimenter,<sup>109</sup> despite his immense interest in all kinds of empirical discoveries, which he took seriously.<sup>110</sup>

Whether Leibniz was an empiricist or not, we can conclude with Jost that his systematic thought brought him to physical insights which are comparable in depth and significance with those reached by naturalists deriving from observations and experiment.<sup>111</sup> Leibniz's utmost interest never was to refute those insights, merely to perfect them. For, as also contemporary physicists confirm, the more minutely we examine nature, the more evidence we obtain regarding the profound order, "that underlies the complications and confusions of experience."<sup>112</sup>

Therefore "the principles of mechanics remain true and also those of statics which depend on them and concern the equilibrium of heavy bodies. Also the rules of motion which the excellent men, Huygens, Wrenn, Mariotte, and Newton, have established by experiments remain true. These truths discovered in experience are not attacked by me, but I rather find their origin in our principle."<sup>113</sup> How absurd it thus sounds when Mackie asserts that no one but Leibniz was so unwilling to recognize the high merits of Newton's *Principia*, and no one but he assailed their influence on the continent.<sup>114</sup> However, the same certainly does not hold of the laws of motion formulated by Descartes, who allegedly would have been able to lay the foundations of real physics, had he manifested greater patience in describing the sensible and lesser weakness for describing the invisible.<sup>115</sup> Anyway, as the Second Law of Thermodynamics demonstrates, both would be necessary.

<sup>109</sup> Although David R. Oldroyd ["Early Geology in Focus," *Metascience*, no. 21 (2012): 571] admires Leibniz's "'curious' experiment to reproduce the impression of a spider," as confusingly described by Rhoda Rapaport ["Leibniz on Geology: A Newly Discovered Text," *Studia Leibnitiana* 29, no. 1 (1997): 8], Leibniz in fact referred to a common goldsmith praxis in the respective passage (*Protogaea*; P, 48f., § 18), rather than to his own experiment.

<sup>110</sup> Jost, *Leibniz und die moderne Naturwissenschaft*, 14.

<sup>111</sup> *Ibid.*, 14.

<sup>112</sup> Arthur Beiser, *Perspectives of Modern Physics* (New York: McGraw-Hill, 1969), 592.

<sup>113</sup> "Imo verae etiam manent regulae motuum quas viri insignes, Hugenius, Wrennus, Mariottus et Newtonus experimentis confirmatae tradidere. Tantum abest, ut ea usu comperta veritates a me impugnerent utius fons earum in principio nostro aperitur" (LH, XXXV, 9, 7, Bl. 11v).

<sup>114</sup> Mackie, *Life of Godfrey William von Leibnitz*, 104f.

<sup>115</sup> *Untitled* (GP, IV, 302, 309); *De secretione animali* (D, II, II, 90).

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