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

# LEIBNIZ AND THE SECOND LAW OF THERMODYNAMICS

**Abstract:** *This article is a loose sequel to a previous article* Leibniz and the First Law of Thermodynamics (Theory of Science 46(1):89–114, 2024). *But this time I analyze in detail the modern debate between Leibniz, Newton, Clarke, and Descartes, anticipating later considerations regarding the Second Law of Thermodynamics. Although Leibniz's* aposteriori *proof refuting the Second Law of Thermodynamics turns out to be less convincing than his* apriori *proof in support of the First Law, both came to be reflected in the formulation of the Second Law of Thermodynamics. After all, as Leibniz himself stated, and also demonstrated in the* Protogaea, *physics can get by without it.*

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

# Leibniz a druhý termodynamický zákon

**Abstrakt:** *Tato studie je volným pokračováním studie* Leibniz a první termodynamický zákon (Teorie vědy 46(1):89–114, 2024). *Tentokrát však podrobněji analyzuji novověkou diskusi mezi Leibnizem, Newtonem, Clarkem a Descartem, předjímající pozdější úvahy ohledně druhého termodynamického zákona. Přestože se totiž Leibnizův* aposteriorní *důkaz v neprospěch platnosti druhého termodynamického zákona ukazuje být méně přesvědčivý než jeho* apriorní *důkaz ve prospěch platnosti prvního, do budoucí formulace druhého termodynamického zákona se přesto promítly oba. Jak ostatně Leibniz sám konstatoval, a v rámci* Protogaey *také prokázal, fyzika samotná si dokáže vystačit i bez něj.*

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

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## 1. Introduction

In this article I follow up on Leibniz's *apriori* argument against the Cartesian measure of force (m*v), as he presented it for the first time in his *Brevis demonstratio*, i.e., the so-called *vis viva controversy.* A detail analysis of the *vis viva controversy* is elaborated in my previous article *Leibniz and the First Law of Thermodynamics* published also by the *Theory of Science* journal in year 2024.[1] Despite their disagreement regarding the correct mathematical expression of force (*momentum,* or m*v according to Descartes versus *vis viva,* or m*$v^2$ according to Leibniz), both Leibniz and Descartes at least agreed that its quantity must be conserved (thus anticipating the First Law of Thermodynamics). Moreover, Papineau believes that the common basic structure of the original framework presented by Descartes, which was endorsed by Leibniz, was also shared by his opponents (Newton and Clarke). Whatever measure of force they proposed, they all allegedly agreed that all the force lost by one body in a collision is gained by another,[2] or, in Clarke's words, "that two soft unelastick Bodies […] do for this only Reason lose each of them the Motion of their Whole, because it is communicated and dispersed into a Motion of their small Parts."[3]

As confirmed by a contemporary text of unknown authorship,

> Leibniz's view apparently is that bodies which absorb a part of the force do not dissipate or annihilate it, but absorb it to the motion of their insides. Therefore, […] even if an identical quantity of motion were not conserved in the world (certainly in the way in which quantity of motion is conceived by Descartes and others after him), nevertheless the quantity of absolute forces remains (naturally) identical in them.[4]

[1] Kateřina Lochmanová, "Leibniz and the First Law of Thermodynamics," *Teorie vědy / Theory of Science* 46, no. 1 (2024).
[2] 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): 141.
[3] LC (C.5.99).
[4] "Nempe Leibnitii sententia est, corpora quae partem virium absorbent, eam non perdere vel extinguere, sed recipere in motus suos intestinos. Itaque secundum ipsum, etsi non eadem maneat quantitas motus in mundo (eo scilicet modo quo quantitas motus a Cartesio et aliis post ipsa aestimari solet), tamen eadem semper (naturaliter) manet in eae quantitas virium absolutarum […]" (LH, 35, 10, 15, fol. 1v, § 1; LO, 310).

The conservation of energy, Daggett does not hesitate to conclude, was therefore in excellent accord with the classical Newtonian science, whose laws regarded change as reversible.[5]

## 2. Decrease in Quantity of Motion

Nevertheless, even a brief examination of Clarke's position shows that neither he nor Newton himself in fact acknowledged the transfer of dissipated force from body to body. According to Clarke, the question ought to be posed differently:

> When two perfectly HARD un-elastick 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.[6]

As a contemporary source of unknown authorship assures us, in this respect Leibniz in fact principally

> disagrees with the most famous Newton, who recently in the Latin edition of his Optics on p. 343 determined that motion naturally diminishes, even tends to cease in nature, if it is not renewed by some special active principles.[7]

Thus, the only point on which they all three agreed is rather the very opposite of the original thesis. "I […] agree," Leibniz stated, "that the quantity of motion does not remain the same; and herein I approve what Sir Isaac Newton says, page 341 of his Optics, which the author here quotes."[8] "At length," Clarke confirms, "(upon the Demonstration I cited from Sir Isaac

[5] Cara N. Daggett, *The Birth of Energy: Fossil Fuels, Thermodynamics & the Politics of Work* (London: Duke University Press, 2019), 45.

[6] LC (C.5.99). Cf. *A Letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly* (WC, IV, 739f.), where Clarke no longer considers any loss of motion at all. Cf. a similar supposition by Július Krempaský [*Fyzika: Príručka pre vysoké školy technické* (Prague: SNTL, 1987), 83; 95n.; 98] as well as by Ján Chrapan et al. [*Experimentálna jadrová fyzika* (Prague: Nakladatelství technické literatury, 1982), 76n.], according to whom the sum of the kinetic energy of individual particles interacting in non-elastic collisions decreases.

[7] "In ea dissentit a celeberrimo Newtono, qui nuper in Optico Opere p. 343 editionis Latinae statuit motum naturaliter imminutum iri, imo cessaturum in natura, nisi per peculiaria quaedam principia actuosa repararetur" (LH, 35, 10, 15, fol. 1v, § 1; LO, 310).

[8] "Je demeure […] *d'accord, que la quantité du mouvement ne demeure point la mê*me, et en cela j'approuve ce qui se dit pag. 341 de l'Optique de M. Newton, qu'on cite icy" (LC, L.5.99).

Newton) he [i.e., Leibniz] is obliged to allow, that the Quantity of Motion in the World is not always the same."[9] In fact, he triumphed, "if it be denied, that the Bodies would lose the Motion of their Wholes [i.e., if the First Law of Thermodynamics is to be endorsed] […]: Then it would follow, that Elastick Hard Bodies would reflect with a double Force; viz. The force arising from the elasticity, and moreover all (or at least part of) the original direct force: Which is contrary to experience."[10] In a later text he claimed that the very opposite of this is the consensus corroborated by both reason and experience.[11]

## 3. The Theological Background

Despite its various alternative formulations throughout history, the First Law of Thermodynamics states that energy (of an isolated closed system) conserves, while its forms mutate. However, the Second Law of Thermodynamics adds that (with a highest probability) each mutation makes the energy less organized, and therefore less useful, AS IF it would be lost. Although, as Leibniz remarked, "what is absorbed by the small parts, is not lost absolutely […],"[12] such dissipation of energy (in the form of heat), or entropy, makes natural processes irreversible, which leads to the same, Newtonian conclusion: motion tends to cease in nature, if it is not renewed by some special active principles. In short – seeing that the two complementary Laws of Thermodynamics also seem to contradict each other[13] – Clarke's original statement (that the quantity of motion does not conserve) makes sense. And it is precisely in terms of this conclusion when I claim that the Second Law of Thermodynamics was discussed or anticipated in the Modern Age.

Of course, as one of my reviewers opposed: there still remains a key conceptual difference between the loss of energy in Leibnizian/Newtonian terms and the developed concept of *entropy* in terms of the Second Law of Thermodynamics. Neither Leibniz nor Newton could write about entropy, given that the phenomenon simply had not yet been captured in its contemporary physical sense. However, sometimes the forward-oriented physical description of a natural phenomenon is rather "a question of time." The formulation of the First Law of Thermodynamics, for example, could

[9] Ibid.
[10] Ibid.
[11] *A Letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly* (WC, IV, 739f.).
[12] "ce qui est absorbé par les petites parties, n'est point perdu absolument […]" (*Essay de dynamique,* GM, VI, 331).
[13] Daggett, *Birth of Energy*, 38.

had been derived directly from Newtonian dynamics by mathematicians as Laplace or Lagrange. And yet, as a matter of fact, it required the cooperation with engineers.[14]

Moreover, quite often the major obstacle consists rather in a sort of philosophical mindset, whose orientation contradicts the present-day view. For example, the feasibility of *perpetuum mobile* machine could also have been physically refuted right from the start, were it not for the belief in it, which was so convenient with the scholastic mindset.[15] On the other hand, even the absence of a quantum theory was no obstacle for Mendělejev, who proposed his periodic classification of chemical elements despite it. And that is the point that I am to address in this article.

For, while the First Law of Thermodynamics provided some comfort with its stability and harmony, the Second Law of Thermodynamics had exactly the opposite effect.[16] It is therefore not surprising that until the end of the modern age philosophy was more satisfied with the harmony promised by the principle of conservation.[17] For these reasons, the belief in the conservation of energy persisted even during the Enlightenment, although the world was generally no longer regarded as ordered by God.[18]

Moreover, thermodynamics generally differs from the wider trends of nineteenth-century science precisely in that it has intimate ties with Christianity.[19] Scholars dealing with energy employed at least two connotations of the concept of *energy* from the very beginning. The production of steam engines in the nineteenth century was not only of practical interest, but also of spiritual concern as its solution touched upon the broader relationship between Christianity, industrialization, and the planet.[20] This evident limitation that humanity faces – the world's fragility and the finitude of all living beings –, briefly: the entropy, opened up space to the God who is eternal and eternally energetic, as the Book of Isaiah had promised.[21]

Therefore, it may have been just because Clarke's theological interests prevented him from limiting himself to purely physical problems in his cor-

[14] John Ziman, *The Force of Knowledge* (Cambridge: Cambridge University Press, 1976), 26.
[15] Michal, *Perpetuum mobile včera a dnes*, 95.
[16] Ibid., 42.
[17] Ibid., 23.
[18] Ibid.
[19] Ibid., 54.
[20] Ibid., 77; Bruce Clarke. *Energy Forms: Allegory and Science in the Era of Classical Thermodynamics* (Ann Arbor: University of Michigan Press, 2001), 2.
[21] Iz (51:6).

respondence with Leibniz, as Newton (and Descartes) did,[22] that he would have been perfectly content to deny the First and endorse the Second Law of Thermodynamics at the kinematic level. However, as Leibniz's effort to avert entropy at the dynamic level proves, the opposition between the two was not merely theological, as Perl believes,[23] but involved the very core of Newtonian science.[24] "I have shown elsewhere," Leibniz wrote, "that there is a difference between the quantity of motion and the quantity of force."[25]

## 4. *Aposteriori* Proof

But while in his defence of the First Law of Thermodynamics Leibniz confronted Clarke with this assumption equipped with the *apriori*[26] proof introduced in my previous article,[27] he at first tried to dismiss the validity of the Second Law of Thermodynamics with the mere reference to sensory evidence. He claims that we never observe the loss of force by one body without the force being simultaneously transferred to another one.[28] He even ridiculed the notion that force could be transformed into the particles of

[22] Leroy Loemker, "Introduction: Leibniz as Philosopher," in *Philosophical Papers and Letters*, ed. Leroy Loemker (Chicago: University of Chicago Press, 1956), 32. While Descartes's *Le monde* is famous for its radical naturalism regarding the development of the planet Earth, without any reference to the biblical conception of the Book of *Genesis* (see *Letter to Mesland from 2.5.1644* (AT, IV, 119, § 22–26), Newton's duly theistic approach programmatically resigns on providing a rational explanation of the universe's origin [Paolo Rossi, *The Dark Abyss of Time* (Chicago: University of Chicago Press, 1984), 49; Margula Perl, "Physics and Metaphysics in Newton, Leibniz, and Clarke," *Journal of the History of Ideas* 30, no. 4 (1969): 526]; Christia Mercer, *Leibniz's Metaphysics: Its Origins and Development* (Cambridge: Cambridge University Press, 2021), 82. Although according to Perl, Leibniz, like Newton, would not allow religious reflections in a scientific explanation (Perl, "Physics and Metaphysics in Newton, Leibniz, and Clarke," 523), he, in accordance with his conciliatory disposition, in fact preferred reasoning supporting the harmony of faith and reason [see, for example, *Essais de Théodicée* (GP, VI, 264, § 247)].
[23] Perl, "Physics and Metaphysics in Newton, Leibniz, and Clarke," 523.
[24] Carolyn Iltys, "The Leibnizian-Newtonian Debates: Natural Philosophy and Social Psychology," *British Journal for the History of Science* 6, no. 24 (1973): 343.
[25] "J'ay montré ailleurs, qu'il y a de la difference entre la quantité du mouvement et la quantité de la force" (LC, L.5.99).
[26] *Untitled* (GP, IV, 398); *Letter to Bernoulli of 15 March 1697* (GM, III, 59); *Letter to De Volder of 30 June 1704* (GP, II, 270).
[27] See Lochmanová, *Leibniz and the First Law of Thermodynamics.*
[28] *Brevis Demonstratio* (A, VI, 4, 2027, § 27f.; GM, VI, 117).

a distinct body, and thus lost without leaving behind a mark or an effect.[29] Sensory evidence is also what he was probably thinking of when he stated that "while the Cartesians' view, according to which the amount of motion is conserved, contradicts all phenomena, our view is wonderfully supported by experience."[30]

Whether this was intended as an appeal to scientific evidence, or to a different kind of experience, Freudenthal nonetheless finds it precarious. In fact, we do observe that force is lost: balls cease to roll, mechanical clocks come to a halt,[31] whereby Leibniz himself acknowledged that the internal structure of bodies, to which the acquired force would be projected, certainly is not easily accessible,[32] and as a consequence requires an abstract geometrical approach[33] which he as yet planned to develop![34] He concludes that

> experience is insufficient for me to be aware of an infinity of insensible things in the body, but of which general consideration of the nature of body and of motion can convince me."[35] And if "a series of geometrical reasoning is necessary merely to explain the rainbow, one of the simplest effects of nature; so we can infer what a chain of conclusions would be necessary to penetrate into the inner nature of complex effects whose structure is so subtle that the microscope, which can reveal more than the hundred-thousandth part, does not explain it

[29] Gideon Freudenthal, "Perpetuum Mobile, The Leibniz–Papin Controversy," *Studies in History and Philosophy of Science* 33 (2002): 617. Viz *De legibus naturae* (GM, VI, 206).

[30] "Sed a nobis deprehensum est, ne in absoluta quidem vi conservanda naturam constantiae suae atque perfectionis dememinisse. Et Cartesianorum quidem opinio, qua quantitas motus conservatur, cum phaenomenis omnibus pugnat, nostra mirifice experimentis confirmatur" (*Untitled;* GP, IV, 398).

[31] Gideon Freudenthal, "Perpetuum Mobile, The Leibniz–Papin Controversy," 584; Papineau, "The *Vis viva* Controversy: Do Meanings Matter?," 129. However, it is quite understandable why the modern lay public really thought of a clock as a *perpetuum mobile.* Many believed that a *perpetuum* is any machine that remains in motion when it apparently no longer receives any energy from the outside [Michal, *Perpetuum mobile včera a dnes,* 34].

[32] Theophilus in *Nouveaux essais* (A, VI, 6, 325, III, 6, § 38/13f.; GP, V, 305, III, 6, § 38); *Foreword to Libellum elementorum physicae* (A, VI, 4, 2008, § 11–14). Cf. the confirmation of his assumption by contemporary physics (Krempaský, *Fyzika,* 194).

[33] *Dissertatio de arte combinatoria* (A, VI, 1, 187f., § 32f., 35–4; GM, V, 34, § 34f.; GP, IV, 56f., § 34).

[34] *Appendix to Letter to Huygens of 8/18 September 1679* (A, III, 2, 853; § 10–16; GM, II, 21f.).

[35] "Ne me sçauroit faire connoistre une infinité de choses insensibles dans les corps, dont la consideration generale de la nature du corps et du mouvement me peut convaincre" (*Letter to Antoine Arnauld of 14 July 1686;* A, II, 2, 75f., § 25–1; GP, II, 53; WFPT, 109, § 9).

> enough to help us much. Yet there would be some hope of achieving this goal, at least in part, if this truly geometrical analysis were established.[36]

Historically, this was a crucial methodological milestone, if internal energy (or heat) is to be a molecular matter, without having access to a precise knowledge of the situation and velocity vector of each molecule, which is, however, a necessary condition of precisely predicting their development. The contemporary reader knows how this principial contradiction was eventually resolved: by resigning on any other than a purely probabilistic knowledge of the microworld. Therefore, even a growth in the entropy of a closed system is not entirely unavoidable, merely highly probable.[37] But, so far, Leibniz's desire to attain perfect cognition remains adamant. He believed that if someone were to identify a single particle of matter, he would thereby comprehend the entire universe.[38] Based on this, Khamara justly labelled him as the author of the idea that so-called reductive or mechanistic descriptions of nature are dependent on the level of mereological analysis (i.e., analysis of whole-part relations).[39]

[36] "Suite de raisonnemens géométriques necessaire pour expliquer seulement l'arc en ciel, qui est un des plus simples effects de la nature, par *oû* nous pouvons juger combien de consequences seroient nécessaires pour pernet-rer dans l'interieur des mixtes, dont la composition est si subtile que le microscope, qui en decouvre bien plus que la cent-millieme partie, ne l'explique pas encor assés pour nous aider beaucoup" (*Appendix to Letter to Huygens of 8/18 September 1679*; A, III, 2, 853; § 10–16; GM, II, 21f.).

[37] Daggett, *Birth of Energy*, 80; Jürgen Jost, *Leibniz und die moderne Naturwissenschaft* (Berlin: Springer, 2019), 133; Ján Pavlík, "Informace, Ontologie, Entropie," *E-Logos: Electronic Journal for Philosophy* 11, no. 1 (2004): 17.

[38] *Letter to des Bosses of 7 November 1710* (GP, II, 412).

[39] Edward Khamara, Space, Time and Theology in the Leibniz-Newton Controversy (Frankfurt: Ontos Verlag, 2006), II. While according to Aristotle and Aristotelians a substantial whole could not be explained in terms of its *parts* since when they are isolated from the whole, their very character changes, Leibniz's anti-Aristotelian mereology hopes for a gradual penetration into the essence of a body through its parts. Even none of the seventeenth-century atomists would ever have argued that atoms could currently be separated from their natural bodies and made visible by chemical analysis. The classification of substances based on their chemical composition was not yet an option in the seventeenth century, as it depended on historical conditions that only gradually took shape towards the end of the seventeenth and the beginning of the eighteenth century [Ursula Klein, and Wolfgang Lefèvre, *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, MA: MIT Press, 2007), 45, 109]. Leibniz's *paradigm-altering idea* [Simon Winchester, *Exactly: How Precision Engineers Created the Modern World* (London: William Collins, 2018), 276] therefore departed from the Aristotelian limitations regarding the changes, manipulations, and transformations of bodies by separating and recombining their parts [Richard Hassing, "Leibniz without Physics," *The Review of Metaphysics* 56, no. 4 (2003): 755]. See also Hjalmar Fors, *The Limits of Matter: Chemistry, Mining* & *Enlightenment* (Chicago: University of Chicago Press, 2015), 111.

The mechanics of the time did not yet distinguish between the micro- and macro-level laws.[40]

How is it possible, then, that when Leibniz wanted to metaphysically refute the Second Law of Thermodynamics, he nonetheless started to invoke the phenomena,[41] (which was extremely unusual for him)?[42] Where did his proverbial rigorousness go with which he so vehemently emphasized that even that which can be deduced based on the regularities of observable bodily transformations can never be proved definitively?[43] Where did the assumption go he used to share with Clarke that the real existence of a phenomenon does not depend on whether it is in fact being observed, but on its principial observability?[44] It is therefore little wonder that later in his correspondence with Clarke he preferred to withdraw from his earlier assumption altogether and affirm *de facto* the very opposite – that it is a loss of force, rather than its conservation, which is observable (i.e., apparent):[45]

> The author objects that two soft or un-elastic bodies meeting together lose some of their force. I answer, no. 'Tis true, their wholes lose it with respect to their total motion; but their parts receive it, being shaken [internally] by the force of the concourse. And therefore, that loss of force is only in appearance. The forces are not destroyed but scattered among the small parts. The bodies do not lose their forces; but the case here is the same, as when men change great money into small.[46]

[40] Stephen Gaukroger, *The Collapse of Mechanism and the Rise of Sensibility: Science and the Shaping of Modernity, 1680–1760* (Oxford: Clarendon Press, 2010), 59. Therefore, although the anatomy of his time was also primarily concerned with artificially dismembered matters, it certainly did not add to its comprehensibility [Ephraim Chambers, *Cyclopaedia: Or, An Universal Dictionary of Arts and Sciences: Containing the Definitions of the Terms, and Accounts of the Things Signify'd thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine: The Whole Intended as a Course of Ancient and Modern Learning* (London: James and John Knapton, 1728), 3].

[41] Freudenthal, "Perpetuum Mobile, The Leibniz–Papin Controversy," 584.

[42] Domenico Bertoloni Meli, *Equivalence and Priority: Newton versus Leibniz* (Oxford: Clarendon Press, 1993), 100.

[43] *Untitled* (GP, VII, 199); *Letter to Sophia Charlotte and to Toland of Early December 1702* (A, I, 21, 722, § 12–15); *Letter to De Volder of 30 June 1704* (GP, II, 268); *Principia logico-metaphysica* (A, VI, 4, 1645, § 24–26); *De primae philosophiae emendatione* (GP, IV, 468).

[44] LC (L.5.52). Cf. a similar supposition already by Aristotle (Mt., 362a 2–5).

[45] On the other hand, Pokorný's mention of "motion apparently taken away in collision" ["pohyb, který zdánlivě odnímají při nárazu" in Joseph Moreau, *Svět Leibnizova myšlení.* Transl. Martin Pokorný (Prague: Oikoymenh, 2000), 128] is a consequence of creatively translating a passage in which Leibniz makes no mention of apparentness at all (*Untitled*; GP, IV, 397).

[46] "On m'objecte, que deux corps mols ou non-elastiques, concourant entre eux, perdent de leur force. Je reponds que non. I lest vray que les touts la perdent par rapport *à* leur mouve-

However, Leibniz never gave a more detailed description of how the living force is transmitted to the parts of bodies.[47] Not to mention the fact that in 1691 he allegedly denied his above conclusion regarding the conservation of force in inelastic collisions.[48] And, according to Huggett, his theory in fact cannot accommodate other than elastic collisions,[49] which raises the question why he resorted to such a construct at all. If every body can be divided into an infinite number of parts, and these into further parts, then there is no reason why dissipated force ought not to be projected into them each time.[50] Simply put, "no body is so small that it is without elasticity."[51] Thus, although Leibniz ultimately aspired to what is today (somewhat ironically) called Newtonian (or classical) theory of elastic collisions,[52] according to Papineau he, like Huygens on whose work Leibniz drew,[53] ought to have been content to draw theorems regarding inelastic collisions.[54]

ment total, mais les parties la reçoivent, étant agitées interieurement par la force du concours ou du hoc. Ainsi ce dechet n'arrive qu'en apparence. Les forces ne sont point detruites, mais dissipées parmy les parties menues. Ce n'est pas les perdre, mais c'est faire comme font ceux qui changement la grosse monnoye en petite" (LC, L.5.99).

[47] Domenico Bertoloni Meli, *Thinking with Objects: The Transformation of Mechanics in the Seventeenth Century* (Baltimore: Johns Hopkins University Press, 2006), 297.

[48] Iltys, "Leibniz and the *Vis Viva* Controversy," 30.

[49] An elastic collision is a collision in which kinetic energy is conserved [William 'S Gravesande, *Essai d'une nouvelle théorie sur le choc des corps: Fondée sur l'experience* (La Haye: T. Johnson, 1722), 17; Arthur Beiser, *Perspectives of Modern Physics* (New York: McGraw-Hill, 1969), 33, 137, 551; Arpád Kecskés, Aba Teleki, and Ľubomír Zelenický, *Jadrová fyzika* (Nitra: Univerzita Konštantína Filozofa, 2001), 109]. Although today elasticity is the subject of an entire field, earlier elastic deformation was regarded as a mysterious source of force arising *ex nihilo.* The impossibility to discover the cause of elasticity was due to the lack of knowledge of the structure of matter and of the character of intramolecular forces (Michal, *Perpetuum mobile včera a dnes,* 105).

[50] Nicholas Huggett, "Motion in Leibniz's Physics and Metaphysics," in *True Motion,* 2019 [in print], accessed December 15, 2023.

[51] "*Nullum corpus tam exiguum sit, quin elastrum habeat*" (*Specimen dynamicum*; GM, VI, 249, II, § 3; AG, 132).

[52] Carolyn Iltys, "The Decline of Cartesianism in Mechanics," *Isis* 64, no. 3 (1973): 366; Mark Wilson, "What I've Learned form the Early Moderns," *Synthese,* no. 196 (2019): 3472; Huggett, "*Motion in Leibniz's Physics and Metaphysics*," 58. The fact that Newton omitted elasticity from the *Principia* is pointed out in Leibniz's *Letter to Huygens of 20/30 February 1691* (GM, II, 85). In contrast, Leibniz's own reflections on elasticity began as early as the 1970s (Meli, *Equivalence and Priority*, 52 n.).

[53] Tzuchien Tho, *Vis, Vim, Vi: Declinations of Force in Leibniz's Dynamics* (Cham: Springer, 2017), 7.

[54] Papineau, "The *Vis viva* Controversy: Do Meanings Matter?," 128; Huggett, "Motion in Leibniz's Physics and Metaphysics," 77. However, given that collisions of perfectly rigid (hard)

However, as Jauering correctly responded, Leibniz in fact implicitly assumed that all interactions can be reduced to elastic collisions.[55] And that the assumption was not merely implicit is witnessed by a text of 1702:

> In fact, each body has an intrinsic motion, nor can it ever be brought to rest. This intrinsic force then turns to the outside when it performs the function of the force of elasticity, namely when intrinsic motion is prevented in its usual course. Therefore, each body is essentially elastic, not excluding water, as we are taught by cannon balls which it forcefully reflects. And the true and proper laws of motion could not be attained if all bodies were not elastic.[56]

Nonetheless, we are again told that the conservation of energy in elastic collisions need not be observable, in particular, when the bodies are non-cohesive, or soft, and as such appear to be inelastic: "So far, that force [of elasticity] is not always observable in the sensible parts of the bodies; namely, if they are not sufficiently cohesive."[57]

bodies by definition lead to the same results as collisions of perfectly elastic bodies [Richard Westfall, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century* (London: Macdonald, 1971), 151], it is not surprising that René Dugas [*Histoire de la mécanique* (Neuchâtel: Éditions du Griffon, 1950), 165, 169], Gaukroger (*The Collapse of Mechanism and the Rise of Sensibility*, 68), and Wilson ("What I've Learned from the Early Moderns," 3472) include Huygens among those who have studied elastic collisions. Thus, translated into contemporary terminology, by the collision of two perfectly hard bodies Huygens meant the collision of perfectly elastic bodies. In the same vein, Leibniz also extended his analysis of elastic collisions to inelastic collisions [Richard Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (Cambridge: Cambridge University Press, 1977), 126, 137].

[55] Anja Jauernig, "Leibniz on Motion and the Equivalence of Hypotheses," *The Leibniz Review*, no. 18 (2008): 20f. Also Roger Woolhouse, "Leibniz's Collision Rules for Inertialess Bodies Indifferent to Motion," *History of Philosophy Quarterly* 17, no. 2 (2000): 153n.

[56] "Revera enim omne corpus habet motum intestinum, neque unquam ad quietem deduci potest. Haec porro vis entestina sese extrorsum vertit, cum vis Elasticae oficium facit, quando scilicet motus intestinus in cursu suo solito impeditur, unde omne corpus essentialiter Elasticum est, ne aqua quidem excepta, quae quam violenter repercutiat, etiam pilae tormentariae docent. Et nisi Elasticum esset omne corpus, leges motuum verae et debitae obtineri non possent" (*Untitled*; GP, IV, 397). Also *Essay de dynamique* (GM, VI, 230).

[57] "Interim ea vis non semper sese conspicuam in ipsis sensibilibus corporum partibus reddit, cum eae scilicet non satis cohaerent" (*Untitled*; GP, IV, 397). The same terminology was also employed by Mariotte (Dugas, *Histoire de la mécanique*, 190) and Wallis (Meli, *Thinking with Objects*, 236). Note that by excluding water from the list of soft bodies based on their cohesiveness Leibniz *de facto* followed Aristotle (see Mt, 382a 10–14).

The answer to Clarke's question "when two perfectly HARD un-elastick Bodies lose their whole Motion by meeting together, what then becomes of the […] impulsive Force"[58] is that there are no inelastic hard bodies.

> The harder a body is […], the more elastic it is and the more forcefully it reflects. When bodies mutually jump apart in a collision, this happens due to the force of elasticity, which is why bodies always acquire the motion pertaining to the collision of their own force, to which the foreign impetus merely grants an opportunity to action and determination.[59]

This is also the reason why Leibniz was so critical of the Newtonian postulate of inelastic matter in his correspondence with Clarke.[60] According to him, while all collisions must be elastic, in the case of soft bodies this fact is not sufficiently evident, and so, in a contradiction to the original claim, they appear to be inelastic. Thus, as the *Essay de dynamique* also documents, Leibniz remained faithful to his conception from the *Theoria motus abstracti:*[61]

> Many make a distinction between hard and soft bodies, and of the hard ones themselves between Elastic and non-elastic […]. But bodies can be taken as Hard-Elastic without denying on that account that the elasticity must always come from a more subtle and penetrating fluid whose motion is disturbed by the tension or by the change of Elasticity.[62]

[58] LC (C.5.99). See also *Optice* (O, 342, quest. 23).
[59] "Quanto autem corpus est durius, tanto est elasticum magis fortiusque repercutit. Nempe in concursu, cum corpora a se invicem resiliunt, id fit per vim Elasticam, unde revera corpora motum a concursu proprium semper habent a vi sua propria, cui impulsus alienus tantum occasionem praebet agendi et ut sic dicam determinationem" (*Untitled*; GP, IV, 397). See also *Letter to Wolf* (GLW, 131); *Principia logico-metaphysica* (A, VI, 4, 1647, § 9–12); *Systeme nouveau* (GP, IV, 486); *Untitled* (GP, IV, 393); *Letter to Antoine Arnauld of 30 April 1687* (A, II, 2, 179, § 14–25; GP, II, 93); *Letter to De Volder of 20 June 1703* (GP, II, 251).
[60] Marius Stan, "Reflection: Perpetuum Mobiles and Eternity," in *Eternity: A History*, ed. Yitzhak Melamed (New York: Oxford University Press, 2016), 176.
[61] René Dugas, *Mechanics in the Seventeenth Century* (Neuchatel: Editions du Griffon, 1958), 478.
[62] "Plusieurs distinguent entre les corps durs et mols, et les durs mêmes en Elastiques ou non […] Mais on peut prendre les corps naturellement pour Durs-Elastiques, sans nier pourtant que l'Elasticité doit tousjours venir d'un fluide plus subtil et penetrant, dont le mouvement est troublé par la tension ou par le changement de l'Elastique" (*Essay de dynamique;* GM, VI, 228).

## 5. Materialistic Explanation

We know that Leibniz only gradually reached his definitive conclusion since in the *Confessio naturae* he claimed the opposite: that bodies do not receive their motion from a non-bodily principle proper to them (i.e., from an *entelechy* or *monad*), but mutually pass it to one another.[63] The trust that a purely materialistic explanation of the universe's early development can be reached even with a mere fleeting reference to the *Bible,* and with no reference to monadology,[64] did not fully leave him even later.[65] "*Not that*" he would think that the *aposteriori* proof issuing in monadology would not hold without an *apriori* one,[66] but it is as yet "not worth developing."[67] But if it holds that Leibniz already in

> his early conception of the function of the spirit – which is furthermore derived from an insufficient knowledge of natural laws – anticipated the issues of the Second Law of Thermodynamics, as well as that consequence of the growth of entropy which is the heat death of the universe[68]

then with respect to his late *Protogaea* this must hold twice.

For, based on the *Protogaea* (among others) it is also possible to refute the objection that Leibniz nonetheless did not recognize the heat changes accompanying the thermodynamic processes,[69] and that therefore

> the kinetic theory of heat, which not only prepared the human spirit to cognize the theorem of energy conservation, but also in its finest pull provided a proven theory of gases, as also a deepened conception of the findings of the Second Law of Thermodynamics, is supported purely by Newton's equation of motion.[70]

[63] *Confessio naturae contra atheistas* (GP, IV, 109).
[64] *Confessio naturae contra atheistas* (GP, IV, 106).
[65] George M. Ross, "Leibniz and the Origin of Things," in *Leibniz and Adam*, eds. Marcelo Dascal and Elhanan Yakira (Tel Aviv: University Publishing Projects, 1993), 252f.
[66] He therefore regarded the conservation equation as an *apriori* measure of force and at the same time an imaginary "Ariadne's thread" to help with orientation in the labyrinth of the continuum (Lubinianus in *Dialogus II*; DFS, 802n.; *Ars representatoria*; G&M, 581).
[67] "Non quod sine illo non valeat, sed quod non projici mereatur" (*Letter to Bernoulli of 15 March 1697*; GM, III, 59).
[68] Ján Pavlík, "Vis viva & vis mortua," *E-Logos: Electronic Journal for Philosophy* 21, no. 1 (2009): 48.
[69] Iltys, "Leibniz and the *Vis Viva* Controversy," 32, 34.
[70] "Auf Newtons Bewegungsgleichungen allein stützte sich die kinetische Theorie der Wärme, welche nicht nur die Geister für die Erkenntnis des Gesetzes der Erhaltung der Energie vorbereitete, sondern auch eine in ihren feinsten Zügen bestätigte Theorie der Gase und eine

In accordance with Saslow, who also denies both objections,[71] even in the Protogaea we can nonetheless read that "*heat and inner motion* come from fire or from light, that is, from a very subtle and penetrating spirit."[72] By adding that "so we have arrived at the motive cause which sacred history takes as the beginning of cosmogony,"[73] Leibniz explicitly endorsed the so called Mosaic approach,[74] as it was applied to (in Leibniz' words) "heat or another inner force"[75] with almost identical words by his predecessor Comenius.[76] "From the naturalist and philosophical point of view," Comenius's "work is appraised for contributing by its conception of heat […] as motion to the victory of the corpuscular theory."[77]

And finally, the last objection that Leibniz – with the exception of elastic collisions – did not present a solid empirical proof of his theory,[78] and

vertiefte Auffassung des Wesens des zweiten Hauptsatzes der Thermodynamik lieferte" [Albert Einstein, "Newton's Mechanik und ihr Einfluß auf die Gestaltung der theoretischen Physik," *Die Naturwissenschaften,* no. 15 (1927): 274].

[71] That is, the objection that Leibniz did not recognize the heat changes accompanying the thermodynamic processes, and that the kinetic theory of heat is supported purely by Newton's equation of motion. Precisely to explain retardation due to friction, according to Wayne Saslow ["A History of Thermodynamics: The Missing Manual," *Entropy* 22, no. 77 (2020): 13], Leibniz concluded that heat consists of the random motions of individual parts of matter (whereas Newton was somewhat inconsistent in this respect). For the Leibnizian conception in Newton see his *Optice* (O, III, 1, 380, q. 31).

[72] "Calor autem motusve intestinus ab igne est, seu luce, id est tenuissimo spiritu permeante" (*Protogaea*; P, 3–5, II). Even "fluidity arises from an inner movement and a certain degree of heat, as is indicated by experiments. For in the presence of reduced heat, water hardens to ice, while, in contrast, acidic liquids and those animated by a hidden motion harden with difficulty." ["fluiditas ab intestino est motu, et tanquam gradu caloris; quod indicant experimenta: Nam imminuto calore etiam aqua in glaciem consistit; dum contra corrodentes liquores, et ab occulto motu fortes, difficulter congelantur" (*Protogaea*; P, 2–4, II)]. See also his early claim, that "it would be easy to explain […] heat […] exclusively […] on the basis of changing of […] situation […], which […] change[s] […] purely on the basis of motion […]." [„Sola […] situs […] mutatione […] de […] calore […] facile explicari posset. […] Si […] per solum motum mutantur […]" (*Letter to Thomasius of 20./30.4.1669;* A, VI, 2, 437, § 8–10)].

[73] "Ita ad motricem caussam perventum est, unde Sacra quoque Historia Cosmogeniae initium capit" (ibid.).

[74] The Mosaic approach was based on the presupposition that all natural philosophy could be derived from the Holy Scripture, i.e., from *Pentateuch*.

[75] *Calor aut alia vis intus* (*De elevatione vaporum*; D, II, 2, 82n., § 3).

[76] *Physicae ad lumen divinu reformandae synopsis* (PS, 99, § 22/19; 102, VI, § 31/34; 130, VII, § 97/8f.); *Disquisitiones de caloris et frigoris natura* (DC, 279, § 40f./18–30); *De rerum humanarum emendatione consultatio catholica* (CC, 312, § 465/II, 3).

[77] Stanislav Sousedík, "*Shrnutí latinské Isagoge*," In *Dílo Jana Amose Komenského* 12 (Prague: Academia, 1978), 286.

[78] Iltys, "Leibniz and the *Vis Viva* Controversy," 32, 34.

did not even attempt to do so,[79] neglects the existence of two such thought experiments, both of which are unfortunately inconclusive.[80] The procedure of one of them consists in dividing the body A into four parts, of which each corresponds in size to the dimensions of body B and which in sum reach the original velocity of body A. The force of each of them must then be successively transmitted to the originally motionless body B.[81] I leave it to others to perform the experiment proving whether the body divided into several parts dissipates a smaller, same, or larger amount of energy than the original one, but the energy consumed by the collision itself cannot be entirely eliminated. The second proof then consists in connecting the bodies A and B with a sufficiently long rigid line on which let us assume the point H which is the entire system's centre of rotation. Let the point H be sufficiently close to body A and at the same time sufficiently far from point B so that if A is at rest, B is released. However, the details of this though experiment are unclear.[82]

## 6. Conclusion

The postulate that the universe's entire energy is conserved can be empirically verified in no other way than with the help of isolated closed systems.[83] Similarly, it would require a somewhat more complicated, dynamically isolated apparatus to reach a special empirical proof of the law of force conservation in inelastic collisions. However, Leibniz introduced no such isolated interactional mechanical systems in his treatises on conservation,[84] and strictly speaking he could not have done so. Although closed systems can certainly be theorized, and sometimes even posited without consequences for mathematics (as in the case of some machines, such as the steam engine), in fact there are no naturally existing closed systems. Haldan's claim that the law of energy conservation "has been verified again and again under all sorts of conditions"[85] thus needs to be taken with a grain of salt. The whole planet

[79] Gideon Freudenthal, "Perpetuum Mobile, The Leibniz–Papin Controversy," 618.
[80] Iltys, "Leibniz and the *Vis Viva* Controversy," 31, footnote 31.
[81] *De legibus naturae* (GM, VI, 207).
[82] Ibid.
[83] Iltys, "Leibniz and the *Vis Viva* Controversy," 27; Daggett, *Birth of Energy*, 36.
[84] Iltys, "Leibniz and the *Vis Viva* Controversy," 22.
[85] John S. Haldane, *Mechanism, Life and Personality: An Examination of the Mechanistic Theory of Life and Mind* (London: John Murray, 1913), 28. In spite of that it of course still holds that the laws of thermodynamics "are now so well established […] that they have lost their

and all life on it is evidently an open system, which is ultimately strongly dependent on the energy of the Sun. And no one can surmise whether at least the whole multiverse is a closed system.[86]

Despite that, Leibniz still outpaced Descartes since with his objections he pointed out that even the bodies A and B posited by Descartes are not an isolated system, if they are subject to the Earth's gravity, which certainly cannot be neglected.[87] The objection is by no means trivial, since only those who applied Leibniz's – or some similar – conception of force eventually reached generally acknowledged results. The different conceptions of force in the context of modern mechanics thus resulted in real, pragmatic differences.[88] What does it matter that in a dynamically isolated system not only the *live force* ($m*v^2$) is conserved, but also momentum ($m*v$),[89] if there are in fact, as the quantum theory reveals,[90] no dynamically isolated systems? Let us add that Leibniz did not scorn momentum ($m*v$): he merely, on Aristotle's model, attributed a somewhat less principal significance to it than he did to fully actualized energy ($m*v^2$).[91] He called it *vis mortua,* which is an infinitesimal (vector) component of the (scalar) *vis viva*.[92]

initial hypothetical character" (David Roger Oldroyd, *Earth Cycles: A Historical Perspective* (Westport: Greenwood Press, 2006), 173).

86 Daggett, *Birth of Energy*, 48. The whole hypothesis of the heat death of the universe is a consequence of (an allegedly incorrect generalization of) conditions valid for a thermally isolated system. On the other hand, the theory of relativity, the finite speed of light, as well as some astronomical observations suggest that the world could indeed constitute a finite system (i.e., containing a finite amount of matter) and thus isolated (Krempaský, *Fyzika,* 126, 132).

87 Pavlík, "Vis viva & vis mortua," 32; Gaukroger, *The Collapse of Mechanism and the Rise of Sensibility*, 63f.

88 Van Besouw, "The Wedge and the *Vis Viva* Controversy," 109; Iltys, "The Decline of Cartesianism in Mechanics," 358; Id., "The Leibnizian-Newtonian Debates," 358n. Therefore, I cannot agree with Jürgen Lawrenz [*Leibniz: The Nature of Reality and the Reality of Nature: A Study of Leibniz's Double-Aspect Ontology and the Labyrinth of the Continuum* (Cambridge: Cambridge Scholars Publishing, 2010), XXIII] that – although Leibniz never admitted defeat – in the end it became clear to him that his methodology in *Dynamics* and associated articles had entangled him in unmanageable complexities, which resulted into Newton's outcomes back again.

89 Krempaský, *Fyzika*, 76.

90 Ján Pavlík, "Dekoherentismus: 4. (a poslední) revoluce ve fyzice ve XX. století," *E-Logos – Electronic Journal for Philosophy* 11, no. 1 (2004): 67. See also Laurence Bouquiaux, "*Monads and Chaos: The Vitality of Leibniz's Philosophy*," Transl. Thomas Epstein, *Diogenes,* no. 161 (1993): 100; Carlo Rovelli, *L'ordine del tempo* (Milano: Adelphi, 2017), 74.

91 Van Besouw, "The Wedge and the *Vis Viva* Controversy," 115; See *Specimen dynamicum* (GM, VI, 238, I).

92 *Essay de dynamique* (GM, VI, 218); Untitled (GP, IV, 398).

While momentum is conserved only when translated in space, energy is conserved when translated in time.[93] Although Iltys (following Clarke)[94] claims that Cartesian momentum *de facto* describes force acting in time (since $m{*}v = m{*}a{*}t = F{*}t$), while kinetic energy describes force acting in space (since $v^2 = 2{*}a{*}s$; and $2{*}m{*}a{*}s$ or $\frac{1}{2}\, m{*}v^2 = F{*}s$),[95] Leibniz apparently integrated the *vis viva* over time.[96] However – given that a force cannot act in time without simultaneously acting in space and *vice versa* – the laws of conservation of momentum and energy can be seen as complementary aspects of the same motion (across space-time continuum).[97]

Anyway, with respect to the Second Law of Thermodynamics, it remains admirable that Leibniz anticipated later physics, even though he was not able to provide an argument as comprehensible as in the case of the *apriori* one. Seeing that he hardly managed to finish his *Monadology,* we can probably see his most fruitful contribution in developing a kinetic theory of heat, rather than in the proper theoretical foundation of a cohesive theory. However, given how progressively its formulation was approached, on the contrary, by his adversary Newton, it remains only to affirm Mackie's the words regarding infinitesimal calculus also with regard to thermodynamics:

> The benefits which, in the course of almost half a century, would have accrued to science from the harmonious connection […] of these two great philosophers, can hardly be too highly estimated, when we consider the valuable fruits of even their isolated labors.[98]

[93] Beiser, *Perspectives of Modern Physics*, 508; Krempaský, *Fyzika*, 81n.; Frank J. Blatt, *Modern Physics* (New York: McGraw-Hill, 1992), 358; Pavlík, "Vis viva & vis mortua," 28, note 69.

[94] (LC; C.5. note on § 93–95). See also his later *A Letter from the Rev. Dr. Samuel Clarke to Mr. Benjamin Hoadly* (WC, IV, 738 n.).

[95] Iltys, "Leibniz and the *Vis Viva* Controversy," 21; Westfall, *Force in Newton's Physics,* 23. Although neither source states it, the result was obtained by derivation ($dv^2/dt = 2{*}v = 2{*}a{*}t$, since $v = a{*}t$) and backward integration ($\int 2{*}a{*}t = a{*}t^2 = 2{*}a{*}s$, since $s = a{*}t^2/2$).

[96] Meli, *Equivalence and Priority*, 89.

[97] Pavlík, "Vis viva & vis mortua," 26.

[98] John Mackie, *Life of Godrey William von Leibnitz* (Boston: Gould, Kendall & Lincoln, 1845), 100.

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