British Journal for the History of Philosophy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rbjh20

Cassirer and energetics: an investigation of Cassirer's early philosophy of physics

Marco Giovanelli

To cite this article: Marco Giovanelli (2023): Cassirer and energetics: an investigation of Cassirer's early philosophy of physics, British Journal for the History of Philosophy, DOI: 10.1080/09608788.2023.2206854

To link to this article: https://doi.org/10.1080/09608788.2023.2206854

BRITISH JOURNAL FOR THE HISTORY OF PHILOSOPHY
https://doi.org/10.1080/09608788.2023.2206854

Routledge
Taylor & Francis Group

Cassirer and energetics: an investigation of Cassirer's early philosophy of physics

Marco Giovanelli

Department of Philosophy and Educational Sciences, Università degli Studi di Torino, Torino, Italy

ABSTRACT
At the turn of the twentieth century, Helm and Ostwald were the most prominent supporters of so-called 'energetics', which aimed to unify all physics by employing the sole concept of energy, without relying on mechanical models. This paper argues that Cassirer's interest in the history of the energy principle and the energetic controversy is entangled with the main themes of his philosophy of physics up to the 1920s: the opposition between the a priori and the a posteriori and the substance-concept and the function-concept. These interwoven motifs are not always easy to disentangle. The paper suggests that Cassirer's interpretation of the energy principle can serve as a guiding thread that runs through Cassirer's philosophy of physics up to the 1920s.

ARTICLE HISTORY Received 20 August 2022; Revised 20 April 2023; Accepted 20 April 2023

KEYWORDS Ernst Cassirer; Marburg neo-Kantianism; energetics; substance-concept vs. function-concept; relativized a priori

Introduction

The "simultaneous discovery" of the principle of conservation of energy by Julius Robert J. ("Bemerkungen"), Hermann von Helmholtz (*Über die Erhaltung der Kraft*) and others between 1842 and 1847 is undoubtedly one of the most outstanding achievements in the history of physics (Kuhn, "Energy Conservation"). In the following decades, the principle not only gained rapid consensus among physicists but had a significant impact on philosophy, literature, and society more broadly (Elkana, *The Discovery*, 175ff.). By the mid-1880s, the possibility of unifying all of physics through the sole concept of energy – without relying on mechanical 'models' or 'pictures' of phenomena – seemed to be at hand. This research program became known as 'energetics'. It was briefly popular in Germany at the turn of the twentieth century, mainly thanks to the indefatigable zeal of its principal proponents: Georg Helm

CONTACT Marco Giovanelli ✉ marco.giovanelli@unito.it Department of Philosophy and Educational Sciences, Università degli Studi di Torino, Via S. Ottavio 20, Torino 10124, Italy

(*Lehre von der Energie*, "Über die analytische") and Wilhelm Ostwald ("Studien zur Energetik").

The first public discussion on the energetic program occurred in September 1895 at the Lübeck *Naturforscherversammlung*. On that occasion, Helm ("Zustand") was invited to present a technical overview of 'the present state of energetics', while Ostwald (*Die Überwindung*) contributed with a more philosophy-oriented presentation of the energetic worldview as an antidote to 'scientific materialism'. However, what was supposed to be the triumphant introduction of 'energetics' into mainstream physics was ultimately a debacle due to the cross-fire objections of Ludwig Boltzmann ("Ein Wort") and Max Planck ("Gegen die neuere Energetik"). Helm (*Die Energetik*) and Ostwald (*Vorlesungen*) reacted by articulating the energetic program more coherently in the following years, but energetics never fully restored its reputation among physicists. Nevertheless, it continued to exert broader cultural influence outside of physics, especially in Germany.

Starting with Robert Deltete's seminal dissertation ("The Energetic Controversy") the history of energetics as an ultimately ill-fated scientific research program has been investigated in detail (see also Deltete, "Helm"). With that said, the reception of the energetic worldview among philosophers has been largely neglected. This paper hopes to contribute to filling this gap in the literature by researching the impact of energetics on German neo-Kantianism (Riehl, *Die Philosophie der Gegenwart*, 137–179; Höfler, *Zur gegenwärtigen Naturphilosophie*, 15–60). In particular, it aims to show that Ernst Cassirer's continued, albeit cautious, confrontation with the energetic movement is crucial to understanding the origin and the interplay of the main themes of his early philosophy of science: his conception of the a priori (Heis, "Realism, Functions, and the a priori"), his celebrated distinction between the substance-concept and the function-concept (Heis, "Ernst Cassirer"). Just how these two thematic threads are woven together in Cassirer's argumentative fabric is not always immediately apparent. However, the paper argues that Cassirer's interest in the history of the energy principle and the energetic program can serve as a proverbial *fil rouge* that runs throughout his philosophy of physics up to the 1920s.

Cassirer moved from Berlin to Marburg to study with Hermann Cohen and Paul Natorp in the Winter of 1896, when the dispute between energetics and mechanism was raging (see Cassirer, *The Problem of Knowledge*, 96f.). Marburg philosophers were familiar with the issues at stake, primarily thanks to the mediation of the Marburg-adjacent historian of science Kurd Lasswitz ("Die moderne Energetik," "Ueber Psychophysische"), who corresponded with Ostwald (Lasswitz to Ostwald, Apr. 9, 1892; Ostwald, *Briefwechsel*, Doc. 117; Ostwald to Lasswitz, Apr. 10, 1892; Doc. 118). Natorp showed an interest in studying the topic around that time (Natorp to Laßwitz, Sep. 31, 1892; Holzhey, *Cohen und Natorp*, Vol. 2, Doc. 25; Natorp to Laßwitz, Mar.

21, 1897, qtd. in 210fn.). In those years, a "little school" started to gather in Marburg (Cohen to Natorp, Apr. 19, 1897; Vol. 2, Doc. 42). Cohen and Natorp used a series of philosophical prizes (*Preisaufgaben*) to support their students. For the 1898–1899 academic year, the argument proposed by Natorp required an examination of Leibniz's philosophy of the foundation of mathematics and mechanics (1:382). The winner of the competition was the young Cassirer, who soon emerged as the "rising star" of the Marburg group (Natorp to Görland, Nov. 21, 1898; Vol. 2, Doc. 45). Cassirer worked further on the manuscript, using part of it as the basis for his dissertation on Descartes (Cassirer, "Descartes"), which, by the end of 1901, became the first chapter of a book on Leibniz, *Leibniz' System in seinen wissenschaftlichen Grundlagen*, published in 1902.

Leibniz' System has often been dismissed as a "youthful mistake" (but see Ferrari, *Il giovane Cassirer*). However, this paper argues that, in investigating Leibniz's role in the pre-history of the energy principle, the book prefigures key themes in his later philosophy of physics (Section 1). Cassirer appears to primarily concentrate on two aspects of Leibniz's contribution. As far as (a) its *content* is concerned, Leibniz understood his conservation principle as a 'principle of coordination' (*Zuordnungsprinzip*). It does not postulate the existence of an entity which remains *identical* behind all natural processes; it introduces the concept of 'work' as the common measure that allow to establish the quantitative *equivalence* of qualitatively heterogeneous phenomena. If there were no such measure, Leibniz argues, the mathematical science of nature would be impossible. Thus, Cassirer claims that, regarding (b) its *justification*, Leibniz implicitly treated his conservation principle as a principle a priori (in the neo-Kantian sense of the expression) as a *condition sine qua non* for the possibility of the mathematical science of nature.

The interlocking between issues of (a) content and (b) justification is not always easy to disentangle. Cassirer often passes from one to the other and vice versa without alerting the reader. However, this paper contends that an examination of Cassirer's evolving stance towards the concept of energy and the 'energetic controversy' provides a valuable perspective for comprehending their relationship. In Cassirer's works from the early 1900s, the discovery of the energy principle, particularly through the work of Mayer, is seen by Cassirer as an extension of Leibniz's reasoning to encompass non-mechanical phenomena (Section 2.1). In Cassirer's masterpiece from 1910, *Substanzbegriff und Funktionsbegriff*, the history of the energy principle becomes the paradigmatic example of how, in the development of physics, function-concepts have gradually superseded substance-concepts. (Section 2.2). Ostwald's conception of energy as a 'substance' appears to Cassirer as a misappropriation of Mayer's heritage (Section 2.3). However, Cassirer became more cautious in attributing the energy principle the status of a principle a priori. By the 1920s, when he published *Zur Einstein'schen*

Relativitätstheorie, Cassirer appears to be ready to grant a priori status only to the general requirement of the "unity of nature". Under which conditions the latter is possible is a matter of empirical research (Section 3).

As some of his contemporary interlocutors already noticed, Cassirer seemed to stretch the boundaries of his 'Kantianism' to the point where it was no longer recognizable as such. Building on previous research (Giovanelli, "Motivational Kantianism"), this paper suggests that Cassirer attempted to address these concerns in his writings from the 1930s. In his last epistemological monograph, "Determinismus und Indeterminismus", Cassirer introduces the category of "statements of principle" to characterize the role played in physical theories by certain general rules that seem to apply to *all* domains of physics (the energy principle, the principle of least action, the entropy principle, etc.). At the same time, he explicitly deprives the a priori of any content, relegating it to a mere regulative role. By emphasizing this point, the paper hopes to contribute to revisiting Cassirer's role in contemporary philosophical debate. Cassirer has been regarded as a forerunner of "structural realism" (Gower, "Cassirer, Schlick and 'Structural' Realism") or an early proponent of a "liberalized version" of the a priori (*Friedman, Dynamics of Reason*, 65ff.). This paper suggests that Cassirer might also be seen as one of the first twentieth-century philosophers to have perceived the importance of the "meta" character of certain statements from physics (Lange, *Because without Cause*).

1. Leibniz and the conservation of mechanical work: Cassirer's *Leibniz' system*

In *Leibniz' System*, Cassirer complains that in the historical literature of his time,[1] Leibniz's contribution to the discovery of the principle of conservation of energy was usually limited to the establishment of the principle of conservation of the *vis viva* in elastic collisions (Cassirer, *Leibniz' System*, 308ff.). Nevertheless, Cassirer argues that for Leibniz, the *vis viva* controversy was only an example of a more general problem: "[t]he question of the mutual measurability [*Meßbarkeit*] processes that pertain to different areas" of physics (308ff.). According to Leibniz, for qualitatively different mechanical effects to be quantitatively compared, the "general definition of an abstract unity" is needed (304). In principle, the choice of the unit is arbitrary. However, it must be assumed that the measurement yields identical results in the chosen unit (304). In this assumption, Cassirer argues, "the essential content of the principle of conservation is already implicit" (306). For any quantity that arises *ex nihilo* and disappears *ad nihilum*, the constancy of the measuring unit chosen would not be guaranteed. According to Cassirer,

---

[1] Dühring, *Kritische Geschichte*; Helm, *Lehre von der Energie*; Mach, *Die Geschichte*; Planck, *Das Princip*.

Leibniz's contribution to the history of the energy principle was the choice of 'mechanical work' as a common denominator (*Nenner*) to establish the quantitative equivalence of qualitatively different phenomena. From this point of view, Leibniz's polemic against the Cartesians was nothing more than an attempt to extend to dynamics (the science of motion) the application of the concept of 'work', which, in Cassirer's view, Descartes had already applied to statics (the science of equilibrium).

Cassirer provides additional details in his commentaries on the German translation of Leibniz's *Hauptschriften* (Leibniz, *Hauptschriften*), which he was working on at the time (Cassirer to Natorp, Dec. 13, 1902; Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 18, Doc. 55). In the history of statics, Descartes is usually credited for having introduced the 'principle of virtual displacements'. In doing so, according to Cassirer, Descartes understood the significance of the product of weight p times vertical displacement s, that is, of what was later called *work*: "In the concept of 'work' and in the *virtual principle*", Cassirer argues, Descartes introduced an "exactly comparable and unified measure" of the effects that causes produce (Cassirer, *Das Erkenntnisproblem*, 1:338). Equilibrium exists in a machine if the virtual works $ps, p_1 s_1, \ldots$ cancel each other if their algebraic sum is zero. Descartes, relying on a pre-critical form of apriorism, considered this principle to be as certain as $1 + 1 = 2$ (Cassirer, *Leibniz' System*, 96; my emphasis).

"Everything else that Leibniz develops here in detail is already given there immediately" (Cassirer, "Footnontes," 1:248; fn. 183). In Cassirer's reconstruction, Leibniz recognized that Descartes failed to extend his principle from statics to dynamics (Cassirer, *Leibniz' System*, 96). At the very first instant (when the equilibrium is disturbed) the virtual velocities are proportional to the virtual displacements $v = \mathrm{d}s/\mathrm{d}t$, $v_1 = \mathrm{d}s_1/\mathrm{d}t$. As Cassirer explains, in Leibniz's view, Descartes mistakenly assumed that the proportionality $s{:}s_1 = v{:}v_1$ applied also to 'actual' motions (Cassirer, "Footnontes," 1:248; fn. 183). Using Galileo's law of free fall, Leibniz showed that this is not the case. The distance travelled by the falling body is represented as the integral of the velocity over time, that is, in Cassirer's own notation:

$$s = \int_0^t v\mathrm{d}v = \frac{v^2}{2} \quad s_1 = \int_0^t v_1\mathrm{d}v_1 = \frac{v_1^2}{2}1 \qquad M0001$$

Thus, the correlation between the velocities v and v_1 acquired by two bodies starting from rest and their heights s and s_1 is then $s{:}s_1 = v^2{:}v_1^2$ (Cassirer, "Footnontes," 1:249f.; fn. 183). If two bodies with the same *vis mortua* or virtual work, $ps = p_1 s_1$ are dropped, and friction is neglected, they will be able to return to their respective initial heights. However, according to (1), when they touch the ground, $pv \neq p_1 v_1$, but $p\frac{v^2}{2} = p_1\frac{v_1^2}{2}$. Leibniz concluded that $p\frac{v^2}{2}$ should be taken as the measure of the so-called *vis viva*, the capacity of a moving body to do work. The amount of work expanded by raising a body p at the height s is not lost; it is obtained again by allowing p to achieve the velocity $v = \sqrt{2s}$. If this were not the case, the principle *causa aequat effectum* would be violated, opening the possibility of a *perpetuum mobile*.

According to Cassirer, by establishing this equation, Leibniz achieved more than demonstrating Descartes' error (Leibniz, *Mathematische Schriften*, 6:117ff). Leibniz established the quantitative equivalence between disparate phenomena – the state of a body suspended at a certain height and the process of falling from a certain height – using work *ps* as a unit of measure. The requirement of conservation of mechanical work is nothing but the condition for the invariability of *ps* as the chosen unit. By generalizing this result, "Leibniz arrives at the establishment of the general *concept of work* as the fundamental unit to which every physical process must be related in the first place" (Cassirer, *Leibniz' System*, 305). For any mechanical change (the compression of a spring, the rotation of a water mill, etc.), the 'cause', can be measured with reference to a 'standard effect', the lifting of a standard weight p to a certain height s. A cause is double then another, if it can raise twice the weight to the same height or the same weight to twice the height: "Everything that happens, no matter how dissimilar it may appear to subjective observation, must be able to be uniformly objectified in the pure difference of work quantities" (305). The work lost by a mechanical system by transitioning its final state must be the same that it gains when it returns to the same initial state no matter what the mechanism involved in the transition (Planck, *Das Princip*, 99, 102ff. Helm, *Lehre von der Energie*, 35, 42, 93).

Leibniz has often been accused of having transformed mechanical work into a metaphysical entity (Lasswitz, *Geschichte der Atomistik*, 2:470ff.). However, Cassirer claims that the very opposite is the case. In Leibniz's philosophy, one can already glimpse the emergence of the general tendency to substitute the "concept of being [*Seinsbegriff*] with with the *concept of function* [*Funktionsbegriff*]" (Cassirer, *Leibniz' System*, 539). The conservation of mechanical work does not postulate the 'indestructibility' of a thing (*Ding*) but imposes the condition (*Bedingung*) of the numerical correspondence between certain quantities, the "requirement of fixed and unambiguous *numerical relationships* in the transition between the special areas of physical events" (308). The postulation of such univocal coordination (*eindeutige Zuordnung*) exhausts the content of the conservation of mechanical work, without any need to introduce mechanical work as a separate reality. If 'work' could be created or destroyed, then the principle of coordination would be violated:

> The consideration of various concrete individual areas as are presented by experience […] is taken as a basis; the first logical question that arises concerns the conditions under which a mutually univocal coordination [*gegenseitig eindeutige Zuordnung*] and an invertible correspondence between the elements of the different series is possible. […] After *a separate unit of measurement* [*Maßeinheit*]

> has been defined for each of the areas to be compared, the requirement is that each quantitatively determined value in one series [*Reihe*] can be assigned one and only one variable in each other series. Under this condition, the particular measure of an individual area can continue to measure and represent every process within the overall system. As one can see, a purely ideal relationship is established between different points of comparison as they are given to the senses, without this being a new reality of its own that has a detached physical existence in addition to the special content under consideration.
>
> (Cassirer, *Leibniz' System*, 306; my emphasis)

Ultimately, Leibniz viewed his conservation principle as nothing but a "postulate of the univocality [*Eindeutigkeit*] of the proportions [*Maßverhältnisse*] when two elements are represented by different physical performances [*Leistungen*]" (308). Leibniz's choice of mechanical work as a unit of measure did not imply the reduction of all phenomena to mechanics – it only depended on the fact that mechanical effects are more easily measurable than other effects. Instead of reducing each individual process to qualitatively *similar* phenomena, that is, to mechanical ones, Leibniz used 'mechanical work' as a numerical scale, the unit of which serves as a common denominator for the quantitative comparison of qualitatively *different* phenomena.

Thus, rather than viewing his conservation principle as a *consequence* of the "mechanical interpretation of phenomena" (319), Leibniz viewed the latter as an *instance* of a worldview that satisfies this principle (306). If mechanical work were not conserved, then causes would produce different effects depending on the unit of measure chosen, and nature would be without laws; the whole science of dynamics would become something indeterminate and contradictory, *quiddam vagum et absonum* (Leibniz, *Mathematische Schriften*, 3:210): As Leibniz argues against Johann Bernoulli (3:208ff.), this requirement is nothing less than a *condition of the possibility of dynamics as a science* (402; my emphasis). In this way, Cassirer attempts to present Leibniz's attitude towards the energy principle as a chapter in the "prehistory of criticism" (Cassirer to Natorp, Nov. 26, 1901; Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 18, Doc. 43). In a typical neo-Kantian style, Cassirer could claim that one can call the conservation of mechanical work a priori not because it is fully independent of experience but because it serves as a condition of the possibility of scientific experience.

In attributing this sort of proto-transcendental argument to Leibniz, Cassirer emphasizes what he saw as Leibniz's fundamental contribution to the history of the energy principle. Leibniz conceded that the exceptions to the conservation principle are at first sight overwhelming. If a stone falls to the ground and stays there, what becomes of the mechanical work initially given to it? Indeed, the quantity of mechanical work appears to be conserved only in elastic collisions. Because macroscopic collisions are at least partially inelastic, "[t]he entire material of observations, therefore, forms a single major contradiction against the principle" (Cassirer, *Leibniz' System*, 321). However, rather than abandoning the universality of his principle in the face of empirical evidence, Leibniz considered it to be more fundamental than the latter. The *vis viva* that is apparently lost in inelastic collisions *must* be redistributed to the motion of the bodies' minute parts (Cassirer, *Leibniz' System*, 321).

On Cassirer's reading, Leibniz's confidence in the universal validity of his conservation principle paved the way to a completely general principle of energy conservation, which applies to processes which are not purely mechanical. In the nineteenth century, it was surmised that the mechanical work that seems to have disappeared in non-elastic collisions could be *measured* in the form of heat. The discovery of the 'mechanical equivalent of heat' implies that a fixed number of work units corresponds to a unit of heat (the heating or cooling of a standard body), just as a fixed number of meters corresponds to one foot. This result was soon generalized to include all non-mechanical processes. It was assumed that *any* change of state of a physical system, whether derived from heat, electricity, or magnetism, can always be transformed directly or indirectly into a proportional amount of mechanical work.

All pioneers of energy conservation agreed on the *content* of this "equivalence law" (311), but they disagreed on its *justification*. Helmholtz considered the energy principle as the consequence of the 'mechanical view of nature' of the fact that all forces of nature are mechanical (central forces that have a potential) (318). For Mayer the energy principle was grounded on the metaphysical axiom *causa aequat effectum* independently of every particular view of nature (318). As one might expect, in Cassirer's view, Mayer's conception "shows surprising agreement with Leibnizian ideas, down to the last detail" (164): that the 'cause *equals* the effect' $c = e$ does not mean that the cause and the effect are *identical* entities, that heat is ultimately motion; it means that there is a quantitative *equivalence* between heat and motion, however different they may appear. This equivalence is the necessary condition of the quantitative comparability of phenomena and not a mere accident of the mechanical theory of heat.

2. Energetics and the distinction between substance-concept and function-concept

2.1. From the lecture to the book

If as an historian of philosophy he treated Leibniz as a chapter of the "prehistory of criticism" (IX), as an historian of science, Cassirer seems to treat Leibniz a chapter of the "prehistory of energetics" (310, 336).[2] Cassirer's "whiggish" historical approach (Ferrari, "Cassirer and the History of Science") might

---

[2] See Hiebert, *Historical Roots* for a similar interpretation.

raise the eyebrows of most scholars today; however, it sheds light on his philosophical agenda. Cassirer attributes to Leibniz the same conception of energy he would defend on a theoretical basis in epistemological writings that appeared in the years immediately following, which he was already actively working on (Cassirer to Natorp, Dec. 13, 1902; Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 18, Doc. 55). By 1905, the first volume of *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit* was finished, and Cassirer planned to add a second volume. However, he also realized that a third systematic volume was required (Cassirer to Natorp, Jul. 31, 1905; Vol. 18, Doc. 70). It is revealing that, when mentioning the scientific literature he was reading at that time in a letter to Natorp, Cassirer wrote "physics, in particular, energetics" (Cassirer to Natorp, Jun. 28, 1906; Holzhey, *Cohen und Natorp*, Vol. 2, Doc. 100), mentioning Ostwald's lectures on natural philosophy (Ostwald, *Vorlesungen*). Indeed, the energeticists' writings, especially Helm's work (Helm, *Die Energetik*), seem to have been the source of many of Cassirer's remarks on the energy principle from that time.

The first volume of *Das Erkenntnisproblem* was presented as a habilitation thesis written at the University of Berlin in April. In July 1906, Cassirer held his *Probevorlesung* to obtain the *venia legendi* for philosophy. The title of the lecture, "Substanzbegriff und Funktionsbegriff", reveals that the core idea of the theoretical counterpart of *Das Erkenntnisproblem* was already clearly defined at that time. The lecture presents the history of atomism as a paradigmatic example of the evolution from substance-concept to function-concept (Cassirer, "Substanzbegriff und Funktionsbegriff," 7ff.). Nevertheless, Cassirer concedes, even though its purely conceptual meaning has gradually become more prominent, the "atom" is ultimately nothing but the scaled model of macroscopic material bodies (8). On the contrary, according to Cassirer, the concept of energy contains in itself an element that protects it from the danger of this hypostatization. For this reason, "modern *energetics* elevated the question of the general relationship between substance-concept and function-concept to a new and higher point of view" (8).

Cassirer points out that "[t]he energy law is an 'integral law' [*Integralgesetz*]. It can therefore be formulated when the processes are compared as a *whole*" (8). For this reason, the emergence of the concept of energy does not depend upon the establishment of adequate models (*Modelle*) or pictures (*Bilder*) of the structure of matter or the nature of heat. Mayer, the founding father of modern energetics, had already emphasized the logical advantage of the energy concept against the use of mechanical models. Heat and motion are 'the same' not because they have any property in common, because heat is nothing but the rapid motion of particles; they are 'the same' because they can be substituted for each other *salva efficacia* when it comes to their capacity to produce effects: "In the conversion of heat into motion two qualitatively different processes are given between which we discover the constant quantitative relationship of transition and thus a purely functional dependency” (9). Although only experience can determine for each class of phenomena the equivalent for a definite amount of mechanical work. The ‘requirement’ (*Forderung*) that such fix equivalents exist serves as “a guideline for empirical research” (13).

Cassirer conceded that a historical objection could be raised against the functional conception of energy. Mayer (“Bemerkungen”) often seemed to treat energy “as a persistent thing ‘behind’ the phenomena, which from our subjective point of view only takes on different forms and hides itself from us under different covers” (Cassirer, “Substanzbegriff und Funktionsbegriff,” 11). However, this reading of Mayer’s work is superficial. When Mayer claims that a value of a certain quantity in the initial state of a physical change is the same in the final state, he does not postulate the “indestructibility” of a permanent substance. By establishing the quantitative equivalence across different physical domains, he does not postulate the “transformability” of the same entity into different forms. The “substantiality” that Mayer ascribes to energy is “nothing other than a *constancy of pure numerical relationships*” (12). The more one tries to penetrate nature, the more one encounters numerical values and functional relations among them. Parallel to the ‘arithmetization of mathematics’, which occurred in the second half of the nineteenth century (Cassirer, “Kant und die moderne Mathematik”), the emergence of energetics should be seen as the ‘arithmetization of physics’.

Energetics flattered itself as being a purely descriptive ‘physics of measurable quantities’, in contrast to the speculative ‘physics of models’ represented by mechanism. However, this opposition misses the essential epistemological point. As Cassirer (“Review”) put it in a lengthy review of a book by Richard Hönigswald (*Beitraege*), the opposition between mechanism and energetics should instead be conceived as an opposition between kinematic-geometric methods (the motion of particles in space) and algebraic methods (relations between numerical variables), between the space-concept (*Raumbegriff*) and the number-concept (*Zahlbegriff*) (Cassirer, “Review,” 94). The energetic ideal of a purely observational physics is illusory. The transformation of empirical material into the language of abstract numerical relations is no less theory-laden than its translation into the language of abstract kinematic-geometrical relations. The essential point is that this transformation is pursued in different directions. (1) Mayer’s algebraic approach represents the “interest of ‘specification’” (94): phenomena are quantitatively compared but remain side by side in all their qualitative diversity; (2) Helmholtz’s kinematic-geometric approach expresses the “interest of ‘homogeneity’” (94): qualitatively different phenomena are reduced to a single class of phenomena: the motion of particles under the reciprocal influence of central forces.

We have lingered on these little-known texts in order to show how the interpretation of the energy principle that Cassirer presented in his book on Leibniz was progressively inserted into his more ambitious philosophical project without substantial alteration. Most of this material would be included in an expanded form in his monumental *Substanzbegriff und Funktionsbegriff*, which was finished by July 1910. In the part of the book dedicated to mathematics, the number-concept (Chapter 2) and the space-concept (Chapter 3) are presented as two instances of the prevalence of the function-concept in the history of mathematics compared to the genre-concept of traditional logic. In the part dedicated to the natural sciences (Chapter 4), Cassirer indicated the history of the energy principle the paradigmatic example of the triumph of the function-concept over the substance-concept in history of physics (See also Natorp, *Die logischen Grundlagen*, 349f.; 372f. *Logik*, §39). Specifically, the energetics is presented as the manifestation of that primacy "of the the concept of *space*, […] [over] that of *number*" that Cassirer introduced Hönigswald-review (Cassirer, *Substanzbegriff und Funktionsbegriff*, 189; tr. 251).

2.2. The energy principle as a coordination principle

Due to its 'arithmetical' nature, "[t]he mathematical foundation of energetics" incorporates in a particularly perspicuous form "all those methods of 'construction of series' [*Reihenbildung*]" (195; tr. 260) that characterize the mathematical-physical formation of concepts (*Begriffsbildung*), in opposition to that of traditional logic. Physics uses classificatory concepts in the formulation of initial, crude, empirical generalizations. Different observable qualities of the physical world are grouped into "certain abstract types" (252; tr. 180) (mechanical, thermal, electrical processes, etc.). However, physics "seeks to express the properties of the body or of the process it is investigating by constantly taking up into its determination new 'parameters'" (199; tr. 150; slightly modified). Each physical system can be characterized fully by a specification of the possible states it can assume. Each state is described by a set of simultaneous numerical values: position and velocity for mechanical systems, temperature, pressure and volume for thermal systems, the electric and magnetic field strengths for electromagnetic systems, etc.. A process is the passage of a physical system from an initial state to a final state – i.e. the change in value of the corresponding parameters – if it is subjected to influences from without or exerts an action on the outside.

As Cassirer points out, however, "the insertion of the sensible manifold into a series of the purely mathematical structure remains inadequate, as long as these series are *separated* from each other" (Cassirer, *Substanzbegriff und Funktionsbegriff*, 252; tr. 190). It is not enough to represent the state of a system in terms of the values of certain parameters and its evolution as their increase or decrease (252; tr. 190). The task of the mathematical science of nature is not thereby exhausted: "in fact, in principle, it is not yet begun" (252; tr. 190). The construction of mathematical physics is completed when we also discover "a constant numerical relation governing the transition from one series [*Reihe*] to the others" (252; tr. 190).

The discovery of the "relation of equivalence of motion and heat" (253; tr. 190) was the first step in this direction. Joule's famous paddle wheel experiment[3] shows that the mechanical work done by a falling body in raising a load is shown to stand in a constant relation to the friction-caused increase in the water's temperature. The mechanical equivalent of heat, "once discovered, […] was soon extended beyond this starting-point" (253; tr. 190). The 'mechanical equivalents' of other phenomena (electrical, chemical, etc.) could be established via the mediation of thermal effects. Equal non-mechanical changes of state could always be related to equal changes in the temperature of a standard body, which in turn correspond to a fixed amount of mechanical work. This empirical relation was then turned into "a universal requirement [*Forderung*] imposed on the 'totality' [*Allheit*] of possible physical manifolds in general" (253; tr. 190; translation modified).

Cassirer attempts to present this result in a more abstract form. In his notation, different series A, B, C, … can be taken to represent mechanical, electrical, and thermal processes. The members of each series are the states of different physical systems, $A_1, A_2, A_3, \dots A_n, B_1, B_2, B_3 \dots B_n$, $C_1, C_2, C_3, \dots C_n$. Each state can be put into a one-to-one correspondence with a set of parameters (say, height, velocity, temperature, field strengths, etc.) that can be labelled as $a_1, a_2, a_3, \dots a_n, b_1, b_2, b_3 \dots b_n, c_1, c_2, c_3, \dots c_n$ (254; tr. 190). Cassirer's claim is that different processes A, B, C, … "stand in a definite physical *relation of exchangeability* [*Austauschverhältnis*]" (254; tr. 191). This means that "any member of A can be replaced by a definite member of B or C without thereby changing the capacity of producing effects [*Wirkungsfähigkeit*] of the physical system in which this *substitution* is assumed" (254; tr. 191; slightly modified). More precisely, equal *differences* or changes in the series A correspond to equal differences in the series B, which in turn correspond to equal differences in the series C, etc. For each series, one can choose a standard change as a unit of measure. In this way, one can quantitatively compare any change to any other change by knowing the conversion coefficients between different units, that is, their respective 'equivalents'.

---

[3] Joule, "On the Mechanical Equivalent of Heat.".

As Cassirer emphasizes, however, in practice "[w]e do not compare the different classes with each other directly, but [we] create for this purpose a *common series* [*geneinsame Vergleichsreihe*], to which they are all equally related" (254; tr. 191). It is only a historical and technological accident that we have chosen mechanical work, the changing of the height of a standard body, as the common series and work units as a common denominator (245; tr. 191). In principle, "any arbitrary single series" could have been chosen (245; tr. 191). Indeed, non-mechanical changes of state may not always be directly convertible into a mechanical effect. However, they are often transformable into their thermal equivalents. The lifted weight can be 'substituted' by, say, a water calorimeter. If the calorimeter has consumed a certain number of heat units, we can determine its mechanical equivalent in work units.

"This relation of possible 'substitution'" (254; tr. 191) means that whatever process one uses to measure a change of state, the *same* numerical value expressed in work units will be obtained. In this way, one can coordinate (*zuordnen*) a 'unique value' (*eindeutiger Wert*) *E* with "the momentary state of a given physical system" with respect to an arbitrarily chosen zero state (199; tr. 150). This number *E* is what we call 'energy' (254; tr. 191). In principle, one could measure changes in height, velocity, electric charge distribution and chemical composition separately, by coordinating each individual process "with the multitude of corresponding equivalents" (254; tr. 191). However, it is more convenient to ascribe to each change "a certain value 'of' energy, which draws all these coordinations into a single pregnant expression" (254; tr. 191). The increase or decrease of energy in different processes *A*, *B*, *C* can be uniquely quantified in terms of the change of height of a standard body, that in terms of mechanical work

In Cassirer's view, the requirement of a one-to-one quantitative correspondence between different series *A*, *B*, *C*, … exhausts the essential meaning of the principle of conservation of energy. A common numerical scale (mechanical work) is constructed, the unit of which, like the unit of energy, serves as a common denominator for comparison. If a certain amount of mechanical work were to appear or disappear without compensation, the condition of mutual univocal coordination between the series *A*, *B*, *C*, … would have been violated. In this sense, the energy principle is the condition of the univocality of the coordination (*Eindeutigkeit der Zuordnung*) between different series of changes:

> The law of energy directs us to coordinate every member of a manifold with one and only one member of any other manifold, in so far as to any *quantum* of motion, there corresponds one *quantum* of heat, to any *quantum* of electricity, one quantum of chemical attraction, and so on. In 'work' as a measure-concept [*Maßbegriff der Arbeit*], all these determinations of magnitude are related to a common denominator [*Nenner*]. If such a connection is once established,

> then every numerical difference that we find within one series can be completely expressed and reproduced in the appropriate values of any other series. The unit of comparison, which we take as a basis, can vary arbitrarily without the result's being affected. If two elements of any field are equal when the same amount of work corresponds to them in any series of physical qualities, then this equality must be maintained, even when we go over to any other series for the purpose of their numerical comparison. *In this postulate, the essential content of the principle of conservation is already exhausted, for any quantity of work which arose 'from nothing' would violate the principle of the mutual univocal coordination* [wechselseitig eindeutigen Zuordnung] *of all series* […] In any case, it appears that energy in this form of deduction is never a new thing but is a unitary system of reference on which we base measurement. All that can be said of it on scientific grounds is exhausted in the quantitative relations of equivalence that prevail between the different fields of physics.
> (253f.; tr. 190; translation modified; my emphasis)

The energy principle should therefore be thought of as a *coordinating principle* rather than a *conservation principle*. It does not postulate the existence of energy as a 'substance' that remains *identical* behind the changes undergone by phenomena; it introduces a 'functional relationship', a one-to-one correspondence among different but quantitatively *equivalent* phenomenal changes. Energy, conceived as a single *substance*, is a *quid* that is common to motion, heat, magnetism and electricity, without being reducible to any of these. Instead, energy as a functional *relation* is nothing more than a rule according to which changes in disparate phenomena can be compared along a common measurement scale.

2.3. Helm versus Ostwald

From an empirical point of view, it is irrelevant whether one regards the energy principle as a conservation or a coordinating principle, and energy as a substance or a causal relation (Cassirer, *Substanzbegriff und Funktionsbegriff*, 255; tr. 192). According to Cassirer, the choice ultimately depends on our general idea of the nature of the scientific construction of concepts (*Begriffsbildung*) in general (261; tr. 192), and in particular of the notion of 'abstraction': (a) *conceptual abstraction*, as conceived by traditional logic, establishes that a definite class of elements has a characteristic in common; (b) *mathematical abstraction* establishes that a series of elements are in the same relationship with a certain given element. (a) leads to the conception of energy as "the assumption of a *property* common to all bodies" (262; tr. 197). (b) sees the introduction of the energy-concept as "the creation of a highest common *standard of measurement* for all changes in general" (262; tr. 197). If one applies (a), it is "almost necessary to embrace a substantial interpretation of energy" (262; tr. 197), as if energy were a *substratum* in which the qualitative differences of the phenomena are dissolved. On the contrary, (b) provides a partition of physical changes into disjoint equivalence classes "by coordinating a certain work-value, a certain quantity of energy, to every individual member of the compared series" (262; tr. 197). Heat, motion, and electricity, etc., do not share some qualitatively identical thing; they are quantitatively equivalent because they produce the same quantity of effects if measured in work units.

The opposition between these two conceptions of *abstraction* is well exemplified by the reception of Mayer's work among the energeticists, Helm and Ostwald. Both considered Mayer a practitioner of a picture-free ideal of physics, yet they arrived at surprisingly different conclusions about Mayer's merits in the history of the energy principle (see Deltete, "The Energetic Controversy," 133ff.):

- Helm considered Mayer a precursor of the idea of energetics as a "pure system of relations [*ein reines Beziehungstum*]" (Helm, *Die Energetik*, 20, 362) between the observable parameters which determine the 'state' of a material system (Cassirer, *Substanzbegriff und Funktionsbegriff*, 263; tr. 198).
- According to Ostwald, Mayer's most important contribution to energetics was paving the way to the idea of energy as "a real substance and not just as a mathematical abstraction" (Ostwald, "Studien zur Energetik," 566; see Cassirer, "Substanzbegriff und Funktionsbegriff," 10).

The Helm-Ostwald debate within the energetic movement shows that the ideal of a purely phenomenological, picture-free physics was instrumental to Helm's relational conception of energy but could not protect Ostwald from transforming a unitary system of relations into a single thing. Ostwald's 'energetics' was meant to be an alternative to the imminent "conquest of scientific materialism", in the name of a physics based only on observable quantities (Ostwald, "Studien zur Energetik," 566). What we see is nothing but radiating energy; what we touch is nothing but mechanical work made by compressing a body, etc. Thus, ultimately, only energy exists (566). In this way, however, Ostwald fell into "the same dogmatic confusion that energetics charges against materialism" (Cassirer, *Substanzbegriff und Funktionsbegriff*, 255; tr. 192; slightly modified). The requirement of univocality of a quantitative coordination between different phenomena is transformed into the existence of a single undifferentiated thing, indeed 'the' thing *par excellence* (255; tr. 192). *Le roi est mort, vive le roi!*, as Cassirer would put it some years later (Cassirer, "[Die philosophischen Probleme]," 69). Matter as a substance is dead, long live the substance of energy (Cassirer, *Substanzbegriff und Funktionsbegriff*, 255; tr. 192).

Thus, the energeticists' cultural battle against materialism and mechanism in the name of a hypothesis-free description of natural phenomena misses the fundamental epistemological problem. In Cassirer's view, the advantage that energetics might claim over mechanism is "not a matter of entirely excluding 'hypotheses'" (251; tr. 189) but of how these hypotheses were used. One must distinguish between hypotheses based on purely numerical relations and hypotheses based on kinematic-geometrical models: (a) 'Mechanism' is the attempt to unify qualitatively different phenomena by reducing everything to *one* class, local motion, by providing mechanical 'pictures' (*Bilder*) of the phenomena, thereby eliminating their qualitative features; (b) 'energetics' attempts "to establish the *minimum of conditions*, under which we can still speak of a 'measurability' [*Meßbarkeit*] of phenomena in general" (269; tr. 202) without thereby extinguishing their individual qualitative features. As Cassirer had pointed out in the Hönigswald-review (Cassirer, "Review"), the search for the unit of nature lies at the basis of both the energetic and the mechanical worldview (Cassirer, *Substanzbegriff und Funktionsbegriff*, 269; tr. 202), only it is pursued in different directions. The dispute between energetics and mechanism can ultimately only be judged before the tribunal of the history of physics.

Cassirer seems to suggest that the history of physics had already expressed its verdict, however (408; tr. 407). Attempts to reduce all phenomena to mechanics have repeatedly failed; the alternative program of reducing all physics to electrodynamics was equally unsuccessful (Planck, *Die Einheit des Physikalischen Weltbildes*). At first sight, the history of physics appears "as a phantasmagoria, in which each new picture [*Bild*] displaces all the earlier ones, only itself to disappear and be annihilated by another" (Cassirer, *Substanzbegriff und Funktionsbegriff*, 353; tr. 266). However, Cassirer insists that in this succession of theories and models, there is always "a certain inner form of connection with each other, no matter how variegated and diverse in their succession" (353; tr. 266). The energy principle applies to all areas of physics and has maintained its validity despite the demise of individual theories. This 'invariance' cannot be a coincidence. The energy principle is more fundamental than any particular theory. The hypothesis can be made that principles of this kind "persist in the advance from theory to theory *because* they are the conditions of *any* theory" (357; tr. 269; first emphasis mine): the conditions a priori of the possibility of physics in general. However, this hypothesis can only be *provisional*. The transcendental philosopher must bear in mind that the it is always possible to discover 'better' constitutive principles in an infinite convergent process (357; tr. 269). Only the last, unattainable 'invariant' should be considered the true a priori.

3. Measure-concepts versus things-concepts. Cassirer's reflections on the energy principle in the 1920s

Cassirer returned to the philosophy of physics only after the confirmation of general relativity in 1919 (Cassirer, *Zur Einstein'schen Relativitätstheorie*). In the writings from this period, he presents the same interpretation of the energy principle he had defended in the past, contrasting Helmholtz and Mayer on the one hand (Cassirer, *Idee und Gestalt*, 288) and Ostwald and Helm on the other (Cassirer, "[Die philosophischen Probleme]," 69ff.). However, an interesting novelty can be observed. Cassirer resorts, although somewhat in passing, to the characterization of the energy principle which had been adopted by the young (Das Princip). One of the advantages of the Planck's approach is that the definition of the *concept* of energy is independent of the *principle* of conservation of energy. This separation allowed Cassirer to formulate his position in a more precise way, but it also induced him to modify it.

Planck defines the 'energy' E of a physical system as the amount of external effects, measured in work units, necessary for a system to pass in whatever way from its current state S' to an arbitrary chosen zero state S. As Cassirer rightly points out, this definition of the *concept* of energy "at first leaves it entirely undecided as to whether there exists a *univocal value* [*eindeutiger Wert*] of what is here called 'energy'" (Cassirer, *Zur Einstein'schen Relativitätstheorie*, 46; tr. 385). The energy of a change of state has a univocal value $E(S \to S')$ if the amount of external effects (as measured in work units) produced outside the system when it passes from the given state S' to the normal state S does not depend on the process (mechanical, electrical work, heat, etc.) of bringing the system from the given state S' to the null state S. The *principle* of conservation of energy requires that energy has a "univocal value [*einen eindeutigen Wert*] [E], [that] does not depend upon the type of transition" (46; tr. 385). If the system undergoes some process in which, in the end, it returns to its original state, the energy of the system is the same as it was at the beginning, $E' - E = 0$,[4] that is, $E = \text{const.}$

The measure-concept of energy (*Maßbegriff*) acquires an objective physical meaning by means of the measure-principle (*Maßprinzip*) of conservation of energy. Indeed, as Cassirer points out, "[if] this independence did not exist […] it would follow that what we called 'energy' is not a universal physical determination, energy would not be a *universal constant of measure*" (46; tr. 385; my emphasis). In this case, "we would then have to *search* for other empirical values that meet the fundamental requirement of the univocality [*Eindeutigkeit*]" (46f.; tr. 385) or introduce new forms of energy in order to

---

[4] A common analogy is climbing a mountain: the change in height from the base to the summit is independent of the path.

achieve the required path-independence. However, the opposite is also true: “if energy is once established as a *constant of measurement*, it thus becomes a *constant of nature* also, a ‘concept of a definite object’” (47; tr. 385).

Yet “*only experience can teach us*” (46; tr. 385; my emphasis) whether the path-independence of energy is realized in nature. If the mechanical equivalent of energy of a particular path were greater than that of another, $E' - E > 0$, we could employ the first to gain the work and then give back only a part of this in returning to the original configuration. Thus, a *perpetuum mobile* would be possible. However, despite much effort, perpetual motion devices have never been constructed. In the face of this negative result, Cassirer argues, using one of his favourite quotations from Goethe, that the best strategy is to transform a problem into a postulate: “Experience had shown that there is no such system”; the theory made this problem into the “postulate that there *cannot* and *must* not be such” (Cassirer, *Zur Einstein'schen Relativitätstheorie*, 44; tr. 383). The apparently accidental *fact* that no *perpetuum mobile* has ever been constructed is transformed into a necessary mathematical *requirement* that energy must be path-independent.

If this requirement is satisfied, the same value E is obtained no matter which process one uses to transform S' back into S. In other words, the energy of a system is a single-valued function of the parameters that determine its instantaneous state. From a physical point of view, it therefore seems legitimate to regard “energy […] as a sort of ‘reserve supply’ [*Vorrat*] of the physical system, the quantity of which is completely determined by the totality of the magnitudes of the states, which belong to the system involved” (47; tr. 385). Energy thus resembles a substance that can be ‘stored’, ‘transferred’, ‘consumed’, etc.

From an epistemological point of view, however, this passage from a measure-concept (*Maßbegriff*) to a thing-concept (*Dingbegriff*) is unjustified.[5] The energy principle deals only with *differences* between energy levels; i.e., it attaches an energy value E to the *change* from one physical state S to another S'. We consider energy an objective property of a system because we always obtain the same number $E(S' \rightarrow S)$ for a certain change of state, no matter which path the undoing of the change of state occurs on: the “univocality of measurement [*Eindeutigkeit der Maßbestimmung*]” is the only guarantee of the “univocality of the object [*Eindeutigkeit der Objektbestimmung*]” (47; tr. 385).

---

[5] It is worth noting that Cassirer seems to miss Planck's point. For Planck (*Das Princip*, 244ff.) It was *advantageous* to treat energy as a substance in the case of electromagnetic phenomena, where a flux of energy (Poynting vector) analogous to the flow of a fluid is defined. However, as (*Untersuchungen*, note 31) objected, energy parcels lack individuality; thus, energy cannot be a substance. The Planck-Hertz debate may serve as a more subtle example of the dialectic between substance-concept and function-concept then the Ostwald-Helm controversy.

Cassirer did maintain his stance regarding the *content* of the energy principle; however, it seems to have changed his attitude concerning its *justification*. In a letter to Moritz Schlick, Cassirer seems to suggest that the requirement of the *Eindeutigkeit der Zuordnung* – the sameness of numerical value associated with a physical quantity by different methods of measurement – is the only a priori condition of the possibility of physics (Cassirer to Schlick, Oct. 23, 1920; Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 18, Doc. 88). The physicist does not have to ask *whether* this univocality is possible, but merely *how* it is possible – i.e, what are the minimum necessary and sufficient conditions for obtaining it (Cassirer, *Zur Einstein'schen Relativitätstheorie*, 99; tr. 374). The energy principle is the condition of the possibility of attributing a unique value *E* to a physical change of state. However, this condition is not a priori. In Kantian parlance, the energy principle is (1) a *constitutive* principle, since it constitutes 'energy' as a quantitative determination of a physical system, that can be compared with that of any other; however; (2) it is an a posteriori principle, since its justification is the empirical fact of the non-existence of a *perpetuum mobile*. The energy principle is not a condition the 'fact' of the possibility of science, as it was in Cassirer's Leibniz book; it is only the condition of the 'fact' of the impossibility of a *perpetuum mobile*.

Schlick dismissed this compromise unconvincing. (Schlick, "Kritizistische," 102, "Erkenntnistheorie und moderne Physik," 313). However, Cassirer seems to develop this line of argument in his writings from the 1920s. The history of the energy principle is presented more cautiously as an example of the prevalence of the 'physics of principles' over the 'physics of models' (Cassirer, "[Die philosophischen Probleme]," 64ff. *Zur Einstein'schen Relativitätstheorie*, 16ff.).[6] Cassirer's aim was to reject 'models' and 'pictures', as Helm and Ostwald urged, but to acknowledge with Planck the "primacy of 'principles' over 'models'" (Cassirer, *Philosophie der symbolischen Formen*, 540f.; tr. 463). Indeed, although the young Planck was a supporter of 'mechanical world view', he insisted that the energy principle was more fundamental than the latter since it was based on the impossibility of a *perpetuum mobile* (540f.; tr. 463). In this sense, Cassirer embraced Planck's view that the unity of the 'physical worldview' should not be understood as a reduction of different branches of physics to one another but as their integration under common 'general principles'. Over time, the consensus on the fundamental unifying principle has changed, with the principle of least action replacing the energy principle by the turn of the century (541; tr. 464). Nevertheless, the general tendency of searching for progressively more fundamental principles has remained constant (Cassirer, "Die Einheit der Wissenschaft," 125).

---

[6] See also Cassirer, *Gesammelte Werke*, Vol. 4, Doc. I; fragment of 13/6/1922.

Conclusion

This paper has attempted to demonstrate how Cassirer's interest in the history of the energy principle and the energetic movement can serve as a blueprint to investigate the evolution and interplay of two of the main themes of his philosophy of physics up to the 1920s. (a) In terms of *content*, Cassirer treats the energy principle as a paradigmatic illustration of the passage from substance-concept to function-concept in the history of science; (b) as far as its *justification* is concerned, Cassirer frequently uses the energy principle to make the case for his 'liberalized' version of the a priori. These two lines of argument (a) and (b) were already fully formed in his first historical monograph on Leibniz (Section 1) and were later integrated into Cassirer's theoretical work in the 1910s. (Section 2). However, Cassirer appears to have progressively renounced his former ambition to indicate specific principles like the energy principle as a priori, even provisionally. By the 1920s, Cassirer appears to have come to the conclusion that only the possibility of a progressive unification of physics under more overarching principles can be assumed a priori.

As some critics complained, Cassirer seems to have thrown in the towel on 'Kantianism'. However, in the Swedish years (1933–1940), in particular in *Determinismus und Indeterminismus*, Cassirer articulated his position more systematically, as it has been shown more extensively in previous research (Giovanelli, "Motivational Kantianism"). On the one hand, he attributed to the 'statements of principle', like the energy principle, the principle of least action, etc. an autonomous status as *constitutive* but not as a priori conditions on the formulation of the laws of nature (Cassirer, *Das Erkenntnisproblem*, 127ff.; tr. 110ff.). On the other hand, he attributed to the a priori a weaker *regulative* meaning that motivates the search for the laws of nature without providing any condition on their formulation. What can be established a priori is only *that* it must always be possible to transform facts into laws, and laws into principles, not *how* this is possible. Cassirer himself conceded that it was questionable whether, "as a 'neo-Kantian'", he "was permitted to draw such conclusions" (Cassirer, "Determinismus und Indeterminismus," VIII; tr. xxiii).

Nevertheless, Cassirer's emphasis on the role of 'principles' in physics is possibly an unappreciated by-product of Cassirer's attempt to preserve Kant's crucial insight in the face of the significant changes in the foundations of the natural sciences (Giovanelli, "Motivational Kantianism"). In recent scholarship, Cassirer is predominantly viewed as either a proponent of a modified version of the a priori or a precursor to structural realism. However, Cassirer can also be regarded as one of the first philosophers to acknowledge the 'meta' nature of certain statements in physics (Lange, *Because without Cause*). Regarding its content, the energy principle, like any statement in physics, sets up a functional equation among various quantities. However, its justification lies in that it can be used as a 'principle' instead of just an equation, not as a single law of nature, but as a condition on the formulation of all possible laws of nature.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Boltzmann Ludwig. "Ein Wort der Mathematik an die Energetik." *Annalen der Physik* 57 (1896): 39–71.

Cassirer Ernst. "[Die philosophischen Probleme der Relativitätstheorie]." 13 lectures at the University of Hamburg October 13, 1920 to January 26, 1921. 1920–1921. Publ. in Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 8, 29–116,

Cassirer Ernst. "[Footnontes and Commentaries]." In: Leibniz, Gottfried Wilhelm. *Hauptschriften zur Grundlegung der Philosophie*. Ed. by Ernst Cassirer. Trans. by Arthur Buchenau. Vol. I: 2 vols. Hamburg: Meiner, 1904.

Cassirer Ernst. *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*. Vol. 1. Berlin: B. Cassirer, 1906. Repr. in Cassirer, *Gesammelte Werke*, Vol. 2.

Cassirer Ernst. *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*. Vol. 4: Von Hegels Tod bis zur Gegenwart (1832–1932). Berlin: B. Cassirer, 1932–1940. German manuscript, 1940.

Cassirer Ernst. "Descartes' Kritik der mathematischen und naturwissenschaftlichen Erkenntnis." PhD thesis. Universität Marburg, 1899.

Cassirer Ernst. "Determinismus Und Indeterminismus in Der Modernen Physik. Historische Und Systematische Studien Zum Kausalproblem." *Göteborgs Högskolas Årsskrift* 42 (1936):I-265. Repr. in Vol. 19. Engl. trans. *Determinism and indeterminism in modern physics. Historical and systematic studies of the problem of causality*. New Haven: Yale University Press, 1956.

Cassirer Ernst. "Die Einheit der Wissenschaft." 1931. Two lectures given on October 21 and October 28, 1931 for the program *Hochsculfunk* aired by the radio station *Deutsche Welle*. Pub. in Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 8, 117–134.

Cassirer Ernst. *Gesammelte Werke. Hamburger Ausgabe*. Ed. by Birgit Recki. 26 vols. Hamburg: Meiner, 1998–.

Cassirer Ernst. "Review of Hönigswald, Beitraege." *Kant-Studien* 14 (1909): 91–98. Repr. in Cassirer, *Gesammelte Werke*, Vol. 9, 447–459.

Cassirer Ernst. *Idee und Gestalt. Goethe/Schiller/Hölderlin/Kleist. Fünf Aufsätze*. Berlin: B. Cassirer, 1921. Repr. in Vol. 9, 241–435.

Cassirer Ernst. "Kant und die moderne Mathematik. (Mit Bezug auf Bertrand Russells und Louis Couturats Werke über die Prinzipien der Mathematik)." *Kant-Studien* 12 (1907): 1–49. Repr. in Vol. 9, 37–82.

Cassirer Ernst. *Leibniz' System in seinen wissenschaftlichen Grundlagen*. Marburg: Elwert, 1902. Repr. in Vol. 1.

Cassirer Ernst. *Nachgelassene Manuskripte und Texte*. Ed. by John Michael Krois. 18 vols. Hamburg: Meiner, 1995–.

Cassirer Ernst. *Philosophie der symbolischen Formen. Dritter Teil: Phänomenologie der Erkenntnis*. Berlin: B. Cassirer, 1929. Repr. in Vol. 13. Engl. trans. *The philosophy of symbolic forms. Volume three: the phenomenology of knowledge*. With an intro. by Charles W. Hendel. New York: Yale University Press, 1957.

Cassirer Ernst. “Substanzbegriff und Funktionsbegriff.” Probevorlesung an der Königlichen Friedrich-Wilhelms-Universität in Berlin (26. Juli 1906). 1906. Repr. in Cassirer, *Nachgelassene Manuskripte und Texte*, Vol. 8, 3–16.

Cassirer Ernst. *Substanzbegriff und Funktionsbegriff. Untersuchungen über die Grundfragen der Erkenntniskritik*. Berlin: Bruno Cassirer, 1910. Repr. in Cassirer, *Gesammelte Werke*, Vol. 6. Engl. trans. Marie Taylor Swabey, ed. *Substance and Function, and Einstein’s Theory of Relativity*. Chicago, London: Open Court, 1923.

Cassirer Ernst. *The Problem of Knowledge in philosophy, science, and history since Hegel*. New Haven: Yale University Press, 1950.

Cassirer Ernst. *Zur Einstein’schen Relativitätstheorie. Erkenntnistheoretische Betrachtungen*. Berlin: B. Cassirer, 1921. Repr. in Vol. 10. Engl. trans. Marie Taylor Swabey, ed. *Substance and Function, and Einstein’s Theory of Relativity*. Chicago, London: Open Court, 1923.

Deltete Robert J. “Helm’s History of Energetics. A Reading Guide.” In: Helm, Georg Ferdinand. *The Historical Development of Energetics*. Trans., with an introd., by Robert J. Deltete. Dordrecht: Springer, 2000, 4–45.

Deltete Robert J. “The Energetic Controversy in late Nineteenth-century Germany. Helm, Ostwald and their Critics.” PhD thesis. Yale University, 1983.

Dühring Eugen. *Kritische Geschichte der allgemeinen Principien der Mechanik*. Berlin: Theobald Grieben, 1873.

Elkana Yehuda. *The Discovery of the Conservation of Energy*. Cambridge: Harvard University Press, 1975.

Ferrari Massimo. “Cassirer and the History of Science.” In: *The Philosophy of Ernst Cassirer. A Novel Assessment*. Ed. by J. Tyler Friedman and Sebastian Luft. Berlin/Boston: De Gruyter, 2015, 261–284.

Ferrari Massimo. *Il giovane Cassirer e la scuola di Marburgo*. Milan: Angeli, 1988.

Friedman Michael. *Dynamics of Reason. The 1999 Kant lectures at Stanford University*. Stanford, Calif.: CSLI Publ., 2001.

Giovanelli Marco. “Motivational Kantianism: Cassirer’s Late Shift Towards a Regulative Conception of the a Priori.” *Studies in History and Philosophy of Science* 95 (2022): 118–125.

Gower Barry. “Cassirer, Schlick and ’Structural’ Realism. The Philosophy of the Exact Sciences in the Background to Early Logical Empiricism.” *British Journal for the History of Philosophy* 8 (2000): 71–106.

Heis Jeremy. “Ernst Cassirer’s *Substanzbegriff Und Funktionsbegriff*.” *HOPOS: The Journal of the International Society for the History of Philosophy of Science* 4 (2014): 241–270.

Heis Jeremy. “Realism, Functions, and the a Priori. Ernst Cassirer’s Philosophy of Science.” *Studies in History and Philosophy of Science* 48 (2014): 10–19.

Helm Georg Ferdinand. *Die Energetik nach ihrer geschichtlichen Entwickelung*. Leipzig: Veit, 1898.

Helm Georg Ferdinand. *Lehre von der Energie. Historisch-kritisch entwickelt*. Nebst Beiträgen zu einer allgemeinen Energetik. Felix, 1887.

Helm Georg Ferdinand. “Über Den Derzeitigen Zustand Der Energetik.” *Verhandlungen der Gesellschaft deutscher Naturforscher und Ärzte* 67 (1895): 28–33.

Helm Georg Ferdinand. “Über Die Analytische Verwendung Des Energieprinzips in Der Mechanik.” *Zeitschrift für Mathematik und Physik* 35 (1890): 307–320.

Helmholtz Hermann von. *Über die Erhaltung der Kraft. Eine physikalische Abhandlung*. Berlin: Reimer, 1847.

Hertz Heinrich. *Untersuchungen über die Ausbreitung der elektrischen Kraft*. Leipzig: Barth, 1892.

Hiebert Erwin N. *Historical Roots of the Principle of Conservation of Energy*. University of Wisconsin, Madison: The State Historical Society of Wisconsin for The Department of History, 1962.

Höfler Alois. *Zur gegenwärtigen Naturphilosophie*. Berlin: Springer, 1904. 3–136.

Holzhey Helmut. *Cohen und Natorp*. vols. 2. Basel: Schwabe, 1986.

Hönigswald Richard. *Beitraege zur Erkenntnistheorie und Methodenlehre*. Leipzig: Fock, 1906

Joule James Prescott. “On the Mechanical Equivalent of Heat, As Determined by the Heat Evolved by the Friction of Fluids.” *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 31 (1847): 173–176.

Kuhn Thomas. “Energy Conservation as an Example of Simultaneous Discovery.” In: Clagett, Marshall. *Critical Problems in the History of Science*. Madison.: University of Wisconsin Press, 1959, 321–56.

Lange Marc. *Because without Cause. Non-causal Explanations in Science and Mathematics*. New York: Oxford University Press, 2016.

Lasswitz Kurd. “Die moderne Energetik in ihrer Bedeutung für die Erkenntniskritik.” *Philosophische Monatshefte* 29 (1893): 1–30, 177–197.

Lasswitz Kurd. *Geschichte der Atomistik*. vol. 2. Hamburg/Leipzig: Voss, 1890.

Lasswitz Kurd. “Ueber psychophysische Energie und ihre Factoren.” *Archiv für systematische Philosophie* 1 (1895): 46–64.

Leibniz Gottfried Wilhelm. *Hauptschriften zur Grundlegung der Philosophie*. Ed. by Ernst Cassirer. Trans. by Arthur Buchenau. Vol. I: 2 vols. Hamburg: Meiner, 1904.

Leibniz Gottfried Wilhelm. *Leibnizens mathematische Schriften*. Ed. by Carl Immanuel Gerhardt. 7 vols. Halle: Schmidt, 1850.

Mach Ernst. *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit*. German. Prag: J.G. Calve, 1872.

Mayer Robert Julius von. “Bemerkungen über die Kräfte der unbelebten Natur.” *Annalen der Chemie und Pharmacie* 43 (1842): 233–240.

Natorp Paul. *Die logischen Grundlagen der exakten Wissenschaften*. Leipzig Berlin: Teubner, 1910.

Natorp Paul. *Logik (Grundlegung und logischer Aufbau der Mathematik und mathematischen Naturwissenschaft) in Leitsätzen zu akademischen Vorlesungen*. 2nd ed. Marburg: Elwert, 1910.

Ostwald Wilhelm. *Aus dem wissenschaftlichen Briefwechsel Wilhelm Ostwalds. Briefwechsel mit Ludwig Boltzmann, Max Planck, Georg Helm und Josiah Willard Gibbs*. Ed. by Hans-Günther Körber and Grete Ostwald. Berlin: Akademie Verlag, 1961.

Ostwald Wilhelm. *Die Überwindung des wissenschaftlichen Materialismus*. Vortrag, gehalten in der 3. allgemeinen Sitzung der Versammlung der Gesellschaft Deutscher Naturforscher und Ärzte zu Lübeck am 20. September 1895. Leipzig: Veit, 1895.

Ostwald Wilhelm. “Studien zur Energetik.” *Berichte über die Verhandlungen der Sächsischen Akademie der Wissenschaften zu Leipzig* 43 (1891): 271–288.

Ostwald Wilhelm. *Vorlesungen über Naturphilosophie. Gehalten im Sommer 1901 an der Univ. Leipzig*. Leipzig: Veit, 1902.

Planck Max. *Das Princip der Erhaltung der Energie*. Leipzig: Teubner, 1887

Planck Max. *Die Einheit des Physikalischen Weltbildes*. Vortrag gehalten am 9.12 .1908 in Leiden. Leipzig: Hirzel, 1909.

Planck Max. "Gegen die neuere Energetik." *Annalen der Physik* 57 (1896): 72–78.

Riehl Alois. *Die Philosophie der Gegenwart. Acht Vorlesungen*. Leipzig: Teubner, 1902.

Schlick Moritz. "Erkenntnistheorie und moderne Physik." *Scientia* 45 (1929): 307–316. Repr. in Schlick, *Gesamtausgabe*, Vol. 1.6, 161–174.

Schlick Moritz. *Gesamtausgabe*. Ed. by Friedrich Stadler and Hans Jürgen Wendel. Berlin: Springer, 2006.

Schlick Moritz. "Kritizistische oder empiristische Deutung der neuen Physik? Bemerkungen Zu Ernst Cassirers Buch: *Zur Einsteinschen Relativitätstheorie*." *Kant-Studien* 26 (1921): 96–111