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INHALT

ENERGY[1]

Ernst Müller

In physics, ‘energy’ describes the ability to do work. However, it was not the concept of energy itself that triggered an epistemic revolution in the middle of the nineteenth century. It was the law of the conservation of energy. In general terms, this law states that in a closed system the sum of the energy supplied is equal to the sum of the energy released (first law of thermodynamics). Thus, the perpetual motion machine is refuted: No machine can deliver more energy than had been put in. This epistemic shift was complemented by the second law of thermodynamics, which became particularly relevant beyond science, influencing both worldviews and cultural production in the late nineteenth and early twentieth centuries. It states that not all forms of energy can be converted into each other at will. In a closed system, all energy is ultimately transformed into heat and is thus no longer usable for work (entropy).

‘Energy’ became a defined concept in physics toward the mid-nineteenth century. Introduced into science, it united previously disconnected physical subfields. But the concept was also widely applied beyond physics, where it served to subject other disciplines to the methodology of physics, thereby often establishing them as sciences in the first place. As the law of the conservation of energy was so pervasive throughout nature, physics now became the leading science. Thus, the concept of energy reconciled the engineering, physiological, chemical, physical and economic knowledges of the time.

If the concept gave rise to and legitimated various worldviews, it was not least because its ‘discovery’ corresponded very closely to the economic, social, and cultural conditions of rising industrial capitalism; a consistent distinction of ‘factual history’ and cultural semantics can, thus, hardly be maintained. Rather, the concept of energy must be read in the contexts of the economization of the human, the rationalization of work and the development of efficient machines and their energetic resources. Because different disciplines and practices are involved in its genesis, but also because word, concept, and term developed asynchronously, the semantic upheavals associated with the concept of energy can only be described by taking an interdisciplinary approach and including a broader field of words (transformation, life force, heat, power, work, entropy, heat death, dispersion, etc.). This ambivalent situation between ideological mobilization and scientific fact can be observed on two other nineteenth century concepts, evolution and the cell. All of these terms manifest the general tendency of replacing universalistic-philosophical concepts with scientific concepts, backed by the epistemic authority of science and its method(s). They are, of course, based on philosophical assumptions, but they are legitimized experimentally and mathematically. The concept of energy is not merely an expression of this discursive shift but the very moment of its inception.

The fact that the concept of energy is situated in a wide cultural network of epistemic conditions perhaps explains why it was formulated nearly simultaneously by scientists working independently of each other (above all by Julius Robert Mayer, James Prescott Joule, and Hermann von Helmholtz). Thomas Kuhn, who sees the theorem of energy conservation as the most impressive example of a simultaneous discovery, names no less than twelve researchers between 1842 and 1847 who suggested different formulations of the term.[2]

1 This article is the translation of a previously published text: Ernst Müller: “Energie,” in: Annika Hand/Christian Bermes/Ulrich Dierse (eds.): *Schlüsselbegriffe der Philosophie des 19. Jahrhunderts*, Hamburg 2015, pp. 127-143.

2 Thomas Kuhn: “Energy Conservation as an Example of Simultaneous Discovery (1969),” in: idem: *The Essential Tension. Selected Studies in Scientific Tradition and Change*, Chicago 1977, pp. 66–104.

The concept of energy had already become the subject of its own history around 1900: In the (nationalistically tinged) priority dispute over whom to credit with its formulation, contemporary protagonists began reconstructing the story; renowned physicists (from Helmholtz and Wilhelm Ostwald to Werner Heisenberg, Heinrich Hertz and Max Planck) affirmed the significance of 'energy' by narrating its contested history. Ernst Mach, for instance, raised the law of energetic equivalence to a paradigm capable of illuminating epistemologically a variety of different theories in science. It thus had special relevance for historians and philosophers of science.[3] While (no doubt instructive) lexical conceptual histories have examined the concept mainly in view of its use in various disciplines,[4] only more recent works have revealed connections between the scientific-technical and cultural-social aspects of the concept, that is, between the concepts of energy and work.[5]

I. PRESERVATION AND TRANSFORMATION BEFORE 'ENERGY'

Viewed from a history of ideas perspective, it was above all the figure of *conservation*, rooted in various sciences, that preceded the concept of energy: Already Descartes had postulated the conservation of all mechanical forces existing in the world. Leibniz had built on this, though his treatment lacked the aspect of transformation: Since bodies did not communicate with each other, the universe, in his view, was a system of bodies, always containing the same amount of force. The principle of conservation had also been prominent since Antoine Laurent de Lavoisier's disposal of the phlogiston theory through the law of conservation of mass. Mayer, for instance, considered Lavoisier's law and his own law of the conservation of energy as different expressions of one and the same relationship of cause and effect. And just as there had been intuitions of energy conservation, so too had the impossibility of perpetual motion machines been anticipated early; in 1789, for example, the French Academy of Sciences decided not to accept any more patents based on the perpetual motion machine.

Even though the protagonists of the law of energetic equivalence spoke out against *Naturphilosophie*, the romantic idea of a unified force acting through the whole of nature retained a central place within culture[6] and continued to exert fascination. In *Von der Weltseele* (1798), for example, Schelling assumes the world to be constituted by the unity and tension of two stable and indestructible forces – a positive and a negative force. His ascending order from lower to higher forces (light, magnetism, electricity, chemistry, organisms) seems almost like a research program for processes of transformation. Luigi Galvani's sensational frog's leg experiments in 1791 had already associated the 'life force' with electrical and magnetic forces, Alessandro Volta's invention of the battery showed connections between electricity and chemical affinity, and Wilhelm Herschel's discovery of infrared radiation showed connections between light and heat. Johann Wilhelm Ritter discovered the chemical effect of light, Hans Christian Oersted the magnetic effect of electric current, Humphry Davy the generation of heat and light by electric current, August Seebeck the transformation of heat into electricity, and, finally, Michael Faraday discovered the transformability of magnetism into electricity (1831). The Romantic experiments on the transformation of these mysterious qualities were not aimed at industrial use and did not become economically significant in their times.

The law of the conservation of energy emerged within two other discourses: physiology and the engineering sciences with their 'heat engines' (steam engines, locomotives). Turning their back both to Romantic

3 Ernst Mach: *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit* (1872), second edition, Leipzig 1909; Thomas Kuhn: "Energy Conservation as an Example of Simultaneous Discovery (1969)," in: idem: *The Essential Tension. Selected Studies in Scientific Tradition and Change*, Chicago 1977, pp. 66–104; Yehuda Elkana: *The Discovery of the Conservation of Energy*, Harvard University Press 1974.

4 Max Jammer: "Energie," in: Joachim Ritter (ed.): *Historisches Wörterbuch der Philosophie*, vol. 2: D–F, Basel 1972, pp. 494–499; Werner Conze: "Arbeit," in: Otto Brunner/Werner Conze/Reinhart Koselleck (eds.): *Geschichtliche Grundbegriffe. Historisches Lexikon zur politisch-sozialen Sprache in Deutschland*, vol. 1, Stuttgart 1972, pp. 154–215.

5 See, for example, Stephen G. Brush: *The Temperature of History. Phases of Science and Culture in the Nineteenth Century*, New York 1978; Crosby Smith: *The Science of Energy. A Cultural History of Energy Physics in Victorian Britain*, London 1998; Bruce Clarke/Linda Henderson (ed.): *From Energy to Information: Representation in Science and Technology, Art and Literature*, Stanford 2002; Elizabeth R. Neswald: *Thermodynamik als kultureller Kampfplatz. Zur Faszinationsgeschichte der Entropie 1850–1915*, Berlin 2006; Christian Kassung: *EntropieGeschichten. Robert Musils 'Der Mann ohne Eigenschaften' im Diskurs der modernen Physik*, München 2001.

6 See, for example, Herbert Breger: *Die Natur als arbeitende Maschine. Zur Entstehung des Energiebegriffs in der Physik 1840–1850*, Frankfurt a. M./New York 1982, p. 104.

Naturphilosophie and to classical physics, both disciplines shared much epistemic ground. Both, after all, deal with heat and its conversion into mechanical power.

II. SIMULTANEOUS DISCOVERY OF ENERGY CONSERVATION

Neither Mayer nor Helmholtz discovered the law in pure physics, but in physiology. The Swabian bureaucrat (Oberamtswundrat) and physical autodidact Mayer credited his experience as a ship doctor as the inspiration for his thoughts on energy conservation. For instance, he noticed that in warmer climates, arterial and venous blood had a slightly different color. This, he inferred, must be due to a lower oxygen consumption of the organism's metabolism. Helmholtz, like Mayer, was also a physician and an academic physiologist before he was appointed professor of physics in Berlin in 1871. When Helmholtz (and Mayer) worked on decay and fermentation, the consumption of substances in muscle actions and physiological heat phenomena, their work was directed directly against the theory of vital force (vis vitalis). Helmholtz, in fact, was part of a renegade group of Johannes Müller's students, who – with Emil du Bois-Reymond at their head – asserted a physico-chemical reductionism against the teachings of their professor. Even if 'life force' was not actually used as explicitly and emphatically as du Bois-Reymond claimed, it was, without doubt, the basis of contemporary notions of the organism, either implicitly or as a placeholder concept.

But this, for all the polemics against it, was not the 'obstacle of thought' hindering the breakthrough of the law of the conservation of energy. It was, rather, the theory of an imponderable matter of heat, called 'calorique' by its inventor, Lavoisier. Mayer emphasized that the "greatest truth" of his discovery of 1842 was the fact that, "[t]here is no such thing as immaterial matter."[7] For the concept of energy, three of Mayer's findings were essential: *Firstly*, he recognized the amount of heat as a further force in addition to kinetic and potential energies. *Secondly*, Mayer proved that heat ("this third force, upon whose effects our century looks with admiration") can be converted into other forms of energy.[8] In doing so, he abstracted from the question of what certain forms of energy were or how their 'metamorphoses' were interrelated and concentrated on purely quantitative questions. By investigating combustion processes within the human body, Mayer succeeded in reformulating Lavoisier's 'calories' as the quantitative measure of the mechanical heat equivalent (365 kpm = 1 kcal). In 1843, almost simultaneously but independently of Mayer, Joule, who was concerned with increasing the efficiency of combustion engines, was able to calculate the heat equivalent with even greater methodological precision. From the production of heat through mechanical motion Joule concluded that heat itself must *be* mechanical motion. *Thirdly*, Mayer put forward the hypothesis that the sum of all forms of energy in a closed system is constant. Mayer related his new law to other, especially physiological processes (work performance of muscles, fever, respiration, etc.) and developed the idea that the living body is a kind of machine converting the chemical energy of food into equivalent amounts of mechanical energy and heat. With these conceptual advances, differences in the way human and animal bodies function were rejected.

In the physical community, however, Mayer was denied scientific recognition for his discovery for quite some time, as it was in part philosophically and deductively explained. Instead, it was Helmholtz who went down in the history of science as the first, in 1847, to mathematically formulate the *"principle of conservation of force"* and to establish its function in physics: *"The sum of the existing living forces and the forces of tension […] is constant."*[9] Here, 'living force' (following the term *vis viva* as defined by Leibniz) corresponded to kinetic energy while the 'force of tension' corresponded to potential energy. Helmholtz concluded:

> *"It follows thence that the total quantity of all the forces capable of work in the whole universe remains eternal and unchanged throughout all their changes.* All change in nature amounts to this, that force can change its form and locality without its quantity being changed. The universe possesses, once for all, a store of force which is not altered by any changed of phenomena, can neither be increased nor diminished, and which maintains any change which takes place on it."[10]

7 "Es gibt keine immateriellen Materien," as quoted from Robert Mayer: "Die Mechanik der Wärme," in: *Ostwalds Klassiker der exakten Wissenschaften*, vol. 37, Frankfurt a.M. 2003, p. 33, translated by A. S.

8 Ibid., p.14.

9 Hermann von Helmholtz: "Über die Erhaltung der Kraft (1847)," in: *Ostwalds Klassiker der exakten Wissenschaften*, vol. 1, Frankfurt a. M. 2011, pp. 5–62, here p. 16, translated by A. S.

10 Hermann von Helmholtz: "On the Conservation of Force

III. MECHANICAL WORK AND CAPITALIST ECONOMY

For Helmholtz, the concept of 'mechanical work' was fundamental to his theory of energy conservation: "All forces of nature can be reduced to the measure of force in which the activity of machines is measured: The concept of mechanical work."[11] Helmholtz, the 'first modern theorist of labor' (Rabinbach), equates the 'quantity of force' with the more popular concept of the 'magnitude of work.' Against the backdrop of the Industrial Revolution, a fundamental metaphorical shift occurred: Nature is no longer thought of as a clock, but as a working machine.[12] The law of energy becomes part of a world view in which all natural forces are attributed to mechanical movements.

While in English physical 'work' is clearly distinguished from economic 'labor,' the identical terms in German and French (Arbeit and Arbeitskraft; travail and travail d'une force) can be used interchangeably. The term travail mécanique was first used by French polytechnicians (Gustave-Gaspard de Coriolis, Jean-Victor Poncelet) at the end of the 1820s as a measuring unit for human and animal (living or organic) activity and then transferred to machines as a measuring unit for the efficiency of steam engines. The standard of the new measure was the vertical lifting of bodies (kilogram-meters, watts, horsepower).[13] The entanglement of physical and social aspects becomes evident in the following statement: "We have unproductive stress for free, but the force or the so-called kilogram meter always costs money."[14] The concept of work was thus constituted at the interface between man and machine. 'Travail mécanique' had initially been an economic quantity, while 'work,' in the original meaning of toil, had only become an economic term in the second half of the eighteenth century. And in turn, implications from the human concept of work were projected onto machines. Whereas only humans had, until then, known 'fatigue' through work, Poncelet coined the word 'material fatigue' in 1839 and compared it to the slackening of human muscles. By incorporating the concept of work into physics, Helmholtz had created a category that, from its linguistic genesis alone, could be traced back directly to social conditions.

The ubiquitous comparisons between the law of the conservation of energy and the concepts of exchange, value creation, and, in particular, work, show how strongly the establishment of 'energy' was linked to the rise of capitalism. Industrial capitalism fueled the search for the laws of thermodynamics and they, in turn, were projected back into social thought: "Thermodynamics changed the concept of work decisively, modernizing it according to the principles of the new industrial technology of steam power and at the same time naturalizing it in accordance with the laws of physics."[15]

Lavoisier had already conceived an abstract concept of work in the course of his investigations into oxygen consumption:

"We can determine, for example, what weight must be lifted to correspond to the work performed by a man giving a speech or a musician playing an instrument. We can even calculate the mechanical effort in the work of a philosopher when he thinks, a writer when he writes, and a musician when he composes […]. There is therefore a good reason why the French language, under the common definition of 'travail,' combines the efforts of the mind with those of the body, the 'travail' of the mental activity and the 'travail' of the hired servant."[16]

While Helmholtz, in his 1847 paper *Über die Erhaltung der Kraft* (On the Conservation of Force), argues largely from a physical perspective, his lectures of the

(1862/63)," in: *Scientific Papers. Physics, Chemistry, Astronomy, Geology*. The Harvard Classics, vol. 30. Cambridge 1904–1914, line 102, available online: https://www.bartleby.com/30/125.html, accessed 05.07.2020.

11 Hermann von Helmholtz: "Ueber die Erhaltung der Kraft (1862/63)," in: *Vorträge und Reden*, vol. 1, 5th edition, Braunschweig 1903, p. 227, translated by A. S.

12 See Breger: *Die Natur als arbeitende Maschine* (note 6), p. 155.

13 Anson Rabinbach: "Ermüdung, Energie und menschlicher Motor," in: Philipp Sarasin/Jakob Tanner: *Physiologie und industrielle Gesellschaft. Studien zur Verwissenschaftlichung im 19. und 20. Jahrhundert*, Frankfurt a. M. 1998, pp. 286–312.

14 Robert Mayer to Karl Friedrich Mohr, 28. April 1868 as quoted in Robert Mayer: *Kleinere Schriften und Briefe*, Stuttgart 1893, p. 419, translated by A. S., see also: Philipp Felsch: "Nach oben. Zur Topologie von Arbeit und Ermüdung im 19. Jahrhundert," in: Thomas Brandstetter/Christof Windgätter (eds.): *Zeichen der Kraft. Wissensformationen 1800-1900*, Berlin 2008, pp. 141–169.

15 Maria Osietzky: "Körpermaschinen und Dampfmaschinen. Vom Wandel der Physiologie und des Körpers unter dem Einfluß von Industrialisierung und Thermodynamik," in: Philipp Sarasin/Jakob Tanner: *Physiologie und industrielle Gesellschaft. Studien zur Verwissenschaftlichung im 19. und 20. Jahrhundert*, Frankfurt a. M. 1998, pp. 313–346, translated by A. S.

16 Lavoisier: *Mémoire*, as quoted in Ruth Moore: *Die Lebensspirale*, Stuttgart 1967, pp. 26–27, translated by A. S.

same name in 1862/63 develop the problem from a practical, especially economic, perspective. Helmholtz relates the refutation of perpetual motion to the process of value formation, which, he says, is only achieved by machines to which energy is supplied: "Work is money."[17] Monetary value itself is reduced to its purely physico-mechanical function. Helmholtz himself illustrates how such physical categories are based on socially generated abstractions.

"Both the arm of the blacksmith, who strikes heavy blows with the mighty hammer, and the violinist, who knows how to entertain the slightest alteration of sound, and the hand of the embroiderer, who performs her delicate work with threads that lie at the limit of the visible: they all receive the force that moves them in the same way and through the same organs, namely the muscles located in the arm."[18]

What drives the organic machine (its motive power), according to the analogy between man and machine, are the muscles, including their capacity for fatigue or exhaustion.

This broad conception of energy can also be found in Marx's thought, insofar as he too conceives work as abstracted from qualitative or concrete forms.

"It was a tremendous advance on the part of Adam Smith to throw aside all limitations which mark wealth-producing activity and [to define it] as labor in general, neither industrial, nor commercial, nor agricultural, or one as much as the other. […] The indifference to the particular kind of labor corresponds to a form of society in which individuals pass with ease from one kind of work to another, which makes it immaterial to them what particular kind of work may fall to their share. Labor has become here, not only categorically but really, a means of creating wealth in general and is no longer grown together with the individual into one particular destination. This state of affairs has found its highest development in the most modern of bourgeois societies, the United States. It is only here that the abstraction of the category 'labor,' 'labor in general,' labor *sans phrase*, the starting point of modern political economy, becomes realized in practice."[19]

When Marx speaks of 'human labor,' he too means machine labor and distinguishes it from the expenditure of human labor. He too adopts the physical quantification of work (quoting an English popularizer of the concept of energy, William Robert Grove).[20] At the same time, however, he places it within a different framework by embedding it in a specific societal form, namely the capitalist production of surplus value. Philip Mirowski, an American economist and historian of science, has even attempted to prove that all basic concepts of economics in use today owe their existence to the translation of basic concepts in physics and machine theory in the nineteenth century.[21]

This emphasis on work can also be observed in the emergence of work physiology, where energy served to legitimate the practice of measurement and optimization. While du Bois-Reymond had already made the law of conservation of energy the basis of his physiological research, the physiologist and hygienist Max Rubner proved the validity of the law of conservation for living beings in the 1890s.[22] He no longer considered only subsystems of the organism but the transformation processes of the whole organism. Rubner initiated a paradigm shift in physiology, which he wanted to change from a metabolic to an energetic basis. In his view, the conversion of energy did not have to examine the chemical qualities of the nutrients, but their chemical energy. With this, he was the first to express food value in calories.

17 Helmholtz: "Über die Wechselwirkung der Naturkräfte und die darauf bezüglichen neuesten Ermittelungen der Physik (1854)," in: *Vorträge und Reden* (note 11), S. 48–83, here p. 53, translated by A. S.

18 Hermann von Helmholtz: "On the Conservation of Force (1862/63)," in: *Scientific Papers,* line 10 (note 10)

19 Karl Marx: "Production, Consumption, Distribution, Exchange," in: *A Contribution to the Critique of Political Economy*, translated from the second German edition, Chicago 1904, p. 298, 299.

20 Karl Marx: "Das Kapital," in: *Marx Engels Werke (MEW)*, volume 23, Berlin 1956–1990, pp. 634–635, translated by A.S.

21 Philip Mirowski: *More Heat than Light. Economics as Social Physics, Physics as Nature's Economics*, Cambridge University Press 1989; and Philip Mirowski: *Machine Dreams: Economics becomes a Cyborg Science*, Cambridge 2002.

22 Max Rubner: "Die Quelle der thierischen Wärme," in: *Zeitschrift für Biologie* 30 (1894), pp. 73–142; see Anson Rabinbach: *Ermüdung, Energie und menschlicher Motor* (note 13).

IV. ENERGEIA AND ENERGY AS CONCEPT IN THE NINETEENTH CENTURY

The new concept of energy, inspired by English physicists, did not become established until the 1850s. As Ernst Mach said: “For the indestructible something the measure of which is mechanical *work*, the name *energy* has gradually come into use.”[23] In 1851, William Thomson (later Lord Kelvin) proposed to replace ‘mechanical work’ with ‘mechanical energy,’ and William Rankine made the term generally accepted in *On the general law of the transformations of energy* (1853). ‘Energy’ clarified the term ‘force,’ which until then had been used in Newton’s sense both for the temporal change of momentum and to describe heat and energy in all of their idiosyncratic forms.

‘Energy,’ which had been assimilated from the French ‘énergie’ in the early eighteenth century, was indeed already being used as a technical term. Its use, in fact, dates back to Aristotelian philosophy in which ‘énergeia’ had two meanings: a) realization or activity of a property (vs. ‘dynamis’ as mere property, lat. potentia, vis), b) as completed activity (e.g. happiness), which is distinguished from ‘process’ (kinesis).[24] In this sense, ‘energeia’ had been employed in Galileo’s physics.

In everyday language, energy was used to denote strength and power, especially as a human quality or ability (will, character, feeling, etc.). In Zedler’s words, ‘energeia’ means “effect or pressure, power of a thing, especially of its lifeforce and blood.”[25] In moral terms, energeia was willpower or vigor, the ability to prove one’s will forcefully through action. This positive everyday meaning is also found underlying ideological debates based on the physical concept of energy. For a long time, however, such meanings were registered in encyclopedias under the entries ‘power’ or ‘conservation of energy’ – not under ‘energy’ itself.[26]

Beyond their continued everyday meaning and before they were established as physical terms, ‘energeia’ and ‘energy’ were being used in the German language in other disciplinary contexts. In the eighteenth century, ‘energy’ was an aesthetic basic concept for Herder and Sulzer. Sulzer understood energy to be an “exquisite force, not only in speech, but in all other things accessible to taste.”[27] Both objects and words could have energy, both, after all, moved people and stirred their emotions. More prominently, however, was Wilhelm v. Humboldt’s *linguistic* use of ‘energeia’ and ‘ergon’ (Greek εργον, ‘static structure’) as the two poles of determination of human language. According to the Aristotelian tradition, he defined language as energeia, as an act, an *“eternally generating”* and changing dynamic force. Language is activity (energeia), not a completed work (ergon).[28] Energeia, according to Humboldt, revealed itself in human speech and in the act of articulating sounds to express a thought.

In 1826, Johannes Müller formulated as the “fundamental idea” of physiology that “the energies of the light, the dark, the colored, are not immanent in the external things, the causes of excitation, but in the substance of the sense of sight itself, that seeing cannot be affected without being active in its inborn energies of the light, dark, colored.”[29] The ‘law of the specific nerve energies’ in which Müller assumed an energy – inherent in every type of nerve and inaccessible to physical description – was later often understood in the modern, physical sense, but it is still fully committed to the Aristotelian program.

V. THE CONCEPT OF ENTROPY

In 1850, the physicist Rudolf Clausius investigated the ability of heat to transform into work based on the newly formulated law of conservation of energy.[30] In doing so, he drew on Sadi Carnot’s work on circulation processes in heat machines, as set out in his treatise *Réflexions sur la puissance motrice du feu et*

23 Mach: *Über das Prinzip der Erhaltung der Energie* (note 3), p. 168, translated by A. S.
24 “dynamis, energeia und kinesis,” in: Christoph Horn/Christof Rapp: *Wörterbuch der antiken Philosophie*, Munich 2002.
25 Johann Heinrich Zedler: *Grosses vollständiges Universal-Lexicon Aller Wissenschafften und Künste*, Halle/Leipzig 1731–1754, vol. 8, p. 620, translated by A. S.
26 See, for example, “Energie,” in: *Meyers Konversations-Lexikon*, 4th edition, 1885–1892, vol. 5, p. 620.
27 Johann Georg Sulzer: “Von der Kraft (Energie) in den Werken der schönen Künste (1765),” in: idem: *Vermischte philosophische Schriften*, vol. 1, Leipzig 1773, pp. 122–145, translated by A. S.
28 Wilhelm von Humboldt: “Über die Verschiedenheit des menschlichen Sprachbaus und ihren Einfluß auf die geistige Entwicklung des Menschengeschlechts (1830-1835),” in: idem: *Werke in fünf Bänden, vol. 3: Schriften zur Sprachphilosophie*, Darmstadt 1988, p. 418.
29 Johannes Müller: *Zur vergleichenden Physiologie des Gesichtssinns des Menschen und der Thiere nebst einem Versuch über die Bewegungen der Augen und über den menschlichen Blick*, Leipzig 1826, p. 44, translated by A. S.
30 Rudolf Clausius: “Über die bewegende Kraft und die Gesetze, welche sich daraus für die Wärmelehre selbst ableiten lassen (1850),” in: *Ostwalds Klassiker* (note 7).

sur les machines propres à développer cette puissance (1824). Carnot had presumed that where there was a temperature difference, moving force could be generated, as hot states always strove toward cold states. Furthermore, he had already observed that in steam engines heat was never completely convertible into mechanical work. Both Clausius and Rankine reflected on these findings within the context of what was known about thermodynamics and formulated a second law. It stated that heat cannot pass from a cold to a warmer body without additional changes to the energy budget. A 'perpetual motion machine of the second kind' was thus also refuted: It is impossible to transform thermal energy equally distributed in space into energy driving a machine without using additional energy. In 1865, Clausius named the variable for the transformability of heat and technical work. In coining this new term, 'entropy' (from entrepein = to transform and tropé = potential for transformation), he based his neologism on the term energy.

The realization that energy conversions tend to be irreversible and only unfolded in one direction of time was hardly compatible with classical models of mechanical physics, which only described reversible phenomena. By introducing statistics into thermodynamics in the 1870s, the Austrian physicist Ludwig Boltzmann attempted to reconstruct the reversibility problem within mechanical physics. In this interpretation, the disorder or dispersion of particles in a system was only their most probable behavior.

Few scientific findings or theories have caused such fascination as well as controversy as the law of conservation of energy and the law of entropy.[31] Since 'entropy' is one of the most complex and abstract concepts in physics, its disciplinary transfers always producing semantic surplus, its spread throughout disciplines and knowledges was assured.[32] And yet, the theorem of entropy, formulated around 1850, developed its greatest impact on philosophy, literature, and the arts much later, between the fin de siècle and the 1920s. Here, the concept of energy implied both the optimistic nineteenth century understanding of progress and its gradual fading into pessimism, legitimated naturalistically, not socially. 'Entropy,' on the other hand, became a projection surface for grasping the trajectory of cosmic development including human society but also for imagining the course of history without humans as living or spiritual beings. The idea of entropy could only become meaningful embedded within a world view that drew its legitimation from the infinity of progress. If heat, which had so fascinated nineteenth century scientists, was no longer associated with life but with death, this meant a radical reversal of the symbolic order.

In Germany, the cultural discussion on entropy was spurred on by Helmholtz's essay *Über die Wechselwirkung der Naturkräfte und darauf bezüglichen Ermittlungen der Physik* (1876). Physics could replace, as it were, the philosophy of history: "Physical-mechanical laws are like telescopes of our mental eye; they penetrate into the distant night of the past and future."[33] Together with Darwin's theory of evolution, the natural sciences now seemed capable of replacing one of the most speculative areas of philosophy, namely the philosophy of history. At almost the same time as evolution testified to the historicity to nature on Earth, a law was discovered that refuted the uniformity of this history. Earth, rather, was itself subject to a unique process. Based on the laws of energy conservation, scientists designed comprehensive cosmological narratives in which human history was but one episode. While popular accounts of biological evolution implied a directionality of the process that coincided with the concept of progress, the concept of entropy (or heat death) suggested decay and end. For Boltzmann, the "general struggle for existence of living beings" is a "struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold earth."[34]

Helmholtz predicted the

"complete standstill of all natural processes […]. [T]he life of plants, animals, and humans cannot con-

31 Kassung: *EntropieGeschichten* (note 5).

32 The German poet and cartoonist Wilhelm Busch serves as a prime example of how deeply the energy/entropy discourse penetrated popular culture in 1883:
Hier strotzt die Backe voller Saft; /
Da hängt die Hand, gefüllt mit Kraft. /
Die Kraft, infolge der Erregung, /
Verwandelt sich in *Schwingbewegung.* /
Bewegung, die in schnellem Blitze /
Zur Backe eilt, wird hier zur *Hitze.* /
[…]
Ohrfeige heißt man diese Handlung, /
Der Forscher nennt es *Kraftverwandlung.* /
Wilhelm Busch: "Balduin Bählamm der verhinderte Dichter," in: idem: *Werke. Historisch-kritische Gesamtausgabe*, vol. 4, Hamburg 1959, pp. 42–53, 52.

33 Helmholtz: *Ueber die Wechselwirkung* (note 17), p. 80, translated by A. S.

34 Boltzmann: "Der zweite Hauptsatz der mechanischen Wärmetheorie," as quoted in Kassung, *EntropieGeschichten,* (note 5), p. 188.

tinue to exist if the sun has lost its high temperature and its light, and if all parts of the earth's surface have closed the chemical bonds. In short, the universe will from then on be condemned to eternal rest."[35]

Clausius echoed this apocalyptic scenario when he described the consequences of energy dissipation in 1863. The universe, he said, was gradually approaching a state in which forces were no longer capable of generating new movements and in which temperature differences no longer existed. The entropy maximum is the heat death of the world. By characterizing lower heat, that is heat not able to perform productive work, as a less valuable form of energy, Clausius evokes the anthropomorphic perspective resonating in thermodynamics. But resistance to such fatalistic interpretations also existed in physics. Boltzmann, for instance, proposed that in addition to sub-worlds approaching the entropy maximum, there must always be areas in which these more probable (disordered) states change into less probable (ordered) ones. In this reinterpretation, the phenomena of life, the transformation of energy into work required to stay alive, are consequences of statistical fluctuations of cosmic proportions. Scientists also repeatedly put forward theories that aimed to 'outsmart' entropy. James Clarke Maxwell's demon who sorted fast and slow molecules in order to reduce entropy (1871) and Erwin Schrödinger's theory of life as so-called neg-entropy (1951) are just the most famous examples.

Outside of physics, the aversion to idealism and the devotion to scientifically oriented world views may actually have turned many away from the concept of entropy. It was enthusiastically welcomed by theologians as it negated one of the standard arguments against religion, namely that the world was eternal and without biblical beginning or end. The entropy theorem thus became a central element in the debate between materialism and theology.[36] Theorists as different as Friedrich Nietzsche, Friedrich Engels, or Ernst Haeckel were unified, though they agreed on little else, in their support of the first and in their rejection of the second law of thermodynamics. Nietzsche's 'eternal recurrence,' for instance, referred directly to the first law of thermodynamics while ruling out the second: "The law of the existence of energy demands *eternal return*."[37] Similarly, Friedrich Engels, a scientifically literate follower of the notion of progress, doubted whether entropy was true at all. For him, given the law of conservation of energy, entropy was conceivable without contradiction only within the framework of a theory of the creation of movement, matter, and work.[38]

VI. ENERGETICS: DISPUTES BETWEEN NATURAL SCIENCES, HUMANITIES, AND SOCIAL SCIENCES

In Helmholtz's popular lectures, the law of conservation of energy served to justify the methodological separation of the natural sciences and the humanities, which were just being established. However, because the limits of its validity were so fluid, energy became a highly disputed term – both in the natural sciences *and* in the humanities. How far could the concepts of energy and entropy be extended beyond physics?

One tightly patrolled borderline in thermodynamics' intellectual terrain was psychology. In his *Elements of Psychophysics* (1860), Gustav Theodor Fechner based the psychophysical parallelism on energetics. Transferring potential energy as 'tension' to the field of mental activities, he proposed psycho-physiological processes were always associated with some form of motor processes.[39] The law of the conservation of energy served to establish this psychophysical parallelism. Therefore, when the psychophysical parallelism was attacked by philosophers and fellow scientists such as Wilhelm Wundt and Carl Stumpf in the 1890s, the law of conservation of energy played a major role.[40] Carl Stumpf advocated, for instance, a relationship of reciprocal interaction (i.e. causality) between the physical and the psyche but assumed the existence of a separate *psychic* energy.[41]

35 Helmholtz: *Ueber die Wechselwirkung* (note 17), p. 67, translated by A. S.

36 See, for example, Ludwig Dressel: "Der anthropologische Gottesbeweis auf Grund des Entropiesatzes," in: *Stimmen aus Maria-Laach* 76 (1909), pp. 150–160.

37 Friedrich Nietzsche: "Nachgelassene Fragmente," in: *Kritische Studienausgabe in 15 Bänden*, edited by G. Colli and M. Montinari, vol. 12, München/New York 1980, p. 205.

38 Friedrich Engels: "Dialektik der Natur. Notizen und Fragmente," in: *MEW* (note 20), volume 20, p. 545, translated by A.S.

39 Gustav Theodor Fechner: *Elemente der Psychophysik*. Leipzig 1860. See also *Historisches Wörterbuch der Philosophie* (note 4), vol. 9, p. 1295.

40 See, for example, Mai Wegener: "Der psychophysische Parallelismus," in: *NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* 17, (2009), issue 3, pp. 277–316.

41 Carl Stumpf: *Eröffnungsrede zum 3. Internationalen Kongress für Psychologie in München 1896*. Acten des dritten internationalen Congresses für Psychologie in München

In contrast, Sigmund Freud initially advocated the biophysical paradigm of his teacher Ernst Brücke. Many problems of psychology were reformulated in the terms of energetics around 1900. The 'forces' changed, as it were, from biology to psychology; they became 'unconscious forces' of the living soul, opponents of the conscious will. Freud famously used metaphors from thermodynamics (the principle of the conservation of energy, hydraulic figures of classical mechanics, drive theory according to the steam boiler model, etc.) to formulate the field of psychoanalysis scientifically. For instance, he understood the drives as energetic forces, the libido corresponding to life energy.[42] Furthermore, concepts such as the 'work of mourning' were designed according to energetic ideas. And in *'Civilized' Sexual Morality and Modern Nervous Illness*, Freud modeled the sublimation of sexual energies into cultural goals on the transformation processes of energy. He emphasized that from a psychoanalytical point of view the libido, like entropy, cannot be completely sublimated: "The effort of shifting away can certainly not be continued indefinitely, just as the conversion of heat into mechanical work in our machines" could not be continued indefinitely.[43] After 1906, Freud, however, used other pictorial sources such as theories on myths.

The transfer of energies between people in situations of collective interaction was also the subject of the emerging mass psychology around 1900 (from Gabriel Tarde to Theodor Geiger and Gustave le Bon to Elias Canetti). Around 1900, the notion of a human crowds as historically powerful agents was closely connected with the concept of energy.[44] The comparison of impulsive movements of human crowds with thermodynamic processes was striking, as was the idea of a 'trigger' (and catalytic effect), which Robert Mayer first discussed as a principle of nature when reflecting on the law of conservation of energy.[45]

A radical and highly controversial expansion of the concept of energy was undertaken by the chemist and Nobel Prize winner Wilhelm Ostwald and by Georg Ferdinand Helm.[46] Their doctrine, known as energetics, regarded energy and the principle of conservation of energy as the basis of all sciences. According to them, even substances are only a special form of primary energy. Helm, mathematician and professor at the Technical University of Dresden, publicized the energetics movement particularly assertively. Ostwald and Helm demanded (against Boltzmann amongst others) an ideological monism that was to overcome scientific materialism and its mechanically imagined world of particles in motion. All areas of human and cultural life should be examined for their energetic basis. Drawing on the works of the Belgian chemist and sociologist Ernest Solvay (*Questions d'énergétique sociale*, 1884-1910), Ostwald and Helm understood energetics as an important contribution not only to describing society but also to designing it. Ostwald thus sought to counter the second law with his "guideline of cultural development."[47] Through pedagogy and art, 'lower' physical energies could be transformed into 'higher' mental and intellectual forms. For economics, Helm postulated that money was the economic equivalent of low entropy.[48] It was in these debates, which often read like techno-optimistic ecological manifestoes, that key notions were conceptualized that would later become fundamental for the contemporary Anthropocene discourse.

Ostwald's energetic sociology was read far beyond physics. Max Weber, for instance, reviewed Ostwald's and Solvey's work with furious derision, saying the account showed "which changelings are produced when purely scientifically trained technologists rape

1896. München, pp. 3–16. See also Ludwig Busse: "Die Wechselwirkung zwischen Leib und Seele und das Gesetz der Erhaltung der Energie (1900)," in: *Philosophische Abhandlungen. Christoph Siegwart zu seinem Sechzigsten Geburtstag gewidmet*, Tübingen 1900, pp. 89–125. Henri Bergson: "Hirn und Denken. Eine philosophische Illusion," in: idem, *Die seelische Energie*, Jena 1928.

42 See Günter Gödde: "Der Kraftbegriff bei Freud. Physiologische und psychologische Verwendungen," in: Thomas Brandstetter/Christof Windgätter (eds.): *Zeichen der Kraft* (note 14), pp. 228–246. Sigmund Freud: "Die 'kulturelle' Sexualmoral und die moderne Nervosität (1908)," in: *Gesammelte Werke vol. VII*, Frankfurt a. M. 1999, pp. 141–167; Sigmund Freud: "Entwurf einer Psychologie (1895)," in: *Gesammelte Werke, Nachtragsband*, pp. 373–486.

43 Sigmund Freud: "Die 'kulturelle' Sexualmoral und die moderne Nervosität (1908), " in: idem: *Das Unbehagen in der Kultur und andere kulturkritische Schriften*, Frankfurt a. M. 1997, pp. 109–132, here p. 117, translated by A S.

44 See Michael Gamper: "Masse als Kraft. Energetische Konzepte des Sozialen," in: Barbara Gronau (ed.): *Szenarien der Energie*, p. 28. Joseph Vogl: "*Masse und Kraft*," in: Brandstätter, Windgätter, *Zeichen der Kraft* (note 14), pp. 187-197.

45 Robert Julius Mayer, "Über Auslösung," in: *Bes. Beilage d. Staatsanzeigers für Würtemberg* (1876), issue 7, pp. 104–107.

46 Wilhelm Ostwald: *Energetische Grundlagen der Kulturwissenschaft* (Philosophisch-soziologische Bücherei, XVI), Leipzig 1909.

47 Max Weber: "Energetische Kulturtheorien," in: idem: *Gesammelte Aufsätze zur Wissenschaftslehre*. Tübingen 1909, pp. 400–426, here p. 402–403, translated by A. S.

48 Georg Helm: *Lehre von der Energie*, Leipzig 1887.

'sociology.'"[49] Whether energy was material or not also had a jurisprudential dimension around 1900. Could it be stolen or not?

Ostwald, who enjoyed a broad readership in Russia at the time, greatly influenced the Russian avant-garde (Pavel Florensky, the symbolist Andrei Bely) and visions of the godbuilders (bogostroiteli) who propagated a Marxist-religious collective consciousness (Maxim Gorky). For example, in debates on avant-garde language experiments, the popularized concept of physical energy interfered with Humboldt's linguistic energeia as well as the Russian Orthodox doctrine of equating God's name with God's energy.

The mathematician, priest, and philosopher Pavel Florensky put forward his 'principle of ectropy,' the word made flesh, and opposed it to entropy. At the same time, using the synérgeia concept of Orthodox theology, he reactivated an energetic-performative perspective of the word: "The word is synergetic: energy."[50]

Ostwald's energetic theory, which was critical of materialism, became directly relevant for Russian politics. Interpreted in the sense of Mach and the empirio-criticists (Richard Avenarius), it entered the leadership circle of the Russian SDAPR as an ideology compensating the defeat of the 1905 revolution over Alexander Bogdanov (empiriomonism) and Anatoly Lunacharsky. When Lenin, in *Materialism and Empiriocriticism* (1907), dealt with the question of whether the concept of energy disproved philosophical materialism, it was also a question of ideological hegemony.

VII. OUTLOOK

Today, the concept of energy has lost none of its significance as a key concept in social debates. However, the acute awareness that energy can neither be saved nor wasted in the strict sense of the word but can only be used by humans in different ways has given way to a popularized and naturalized term. Some debates, however, build on and have developed fin de siècle motives (e.g. Ostwald's pre-ecological plea for energy use, the apocalyptic scenario of heat death of the universe, etc.).

Ever since its formulation, the law of energy conservation has most likely never been questioned by any physicist. Nevertheless, both its scientific significance and its ideological appeal have been diluted. One reason for this is that the law of the conservation of energy is, according to the Noether theorem (1918), only the special case of a more comprehensive physical symmetry. In physics, the term symmetry is used when something can be exposed to certain operations and, afterwards, appears exactly the same as before these operations. A special case of such symmetry is when time has passed but the value of one physical quantity has not changed. This quantity is called energy.

The pervasive cultural fascination with energy and entropy shifted, in the twentieth century, to other topics in physics like the special theory of relativity and the discovery of the wave-particle dualism (1927). The complementary properties of location and momentum cannot both be measured at exactly the same moment, and this applies to energy and time also. Furthermore, the mass of a body, traditionally the measure of its passive resistance as inertia, becomes, in special relativity, the value for its energy content. The epistemic authority of the all-encompassing energy concept has suffered severe relativization.

Finally, functions that were originally associated with the concept of energy were transferred, in the twentieth century, to the concept of information. The statistical representation of entropy through categories of order/disorder allowed its reconstruction in information theory and cybernetics.[51] Thus, whereas in the nineteenth century Robert Mayer stressed the great potential of harnessing heat for the future of mankind, Norbert Wiener, in the twentieth century, placed information as a third alongside matter and energy.[52]

Translation: Anna Simon-Stickley

49 Max Weber: "Energetische Kulturtheorien," in: idem: *Gesammelte Aufsätze zur Wissenschaftslehre*. Tübingen 1909, pp. 400–426, here p. 402, translated by A. S.

50 Tatjana Petzer: "Übertragungsphantasien in der russischen Moderne," in: Barbara Gronau (ed.): *Szenarien der Energie. Zur Ästhetik und Wissenschaft des Immateriellen*, Bielefeld 2013, pp. 45–66, 54.

51 See Bernhard Siegert: "Am Ende der Kräfte. Von der thermodynamischen zur nachrichtentheoretischen Welt," in: Brandstätter/Windgätter: *Zeichen der Kraft* (note 14), pp. 273–275.

52 "Information is information not matter or energy". See Norbert Wiener, *Cybernetics or Control and Communication in the Animal and the Machine* (1948), New York 1961, p. 132.