Teleology and Immaterial Substance after the Physico-Chemical Turn in the Life Sciences

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The present paper sets out to achieve two objectives. The first is to argue that the two primary features of the vitalist philosophy remain after the physico-chemical paradigm overtakes it. These features are: 1) the notion that there is an immaterial substance that plays a central role in the physical goings-on of material bodies, and 2) the teleological aspect material goings-on. In the vitalist philosophy, the immaterial substance manifests itself in varying ways, depending on the particular philosopher, but the mark of the immaterial substance is dualism. For the purposes of this paper, though many had not used the appellation, "entelechy" will be used to refer and indicate this notion. It is this immaterial substance that drove material substances toward some telos. The teleological aspect is preserved in the physico-chemical paradigm, by way of the fact that the principle of least action (PLA), the principle first discovered by Maupertuis (thus, Maupertuis' principle) and touted as his "dissertation on final causes," entails teleology.[1] This segues into the second objective of the paper, which is to assess and analyze Helmholtz' thinking in employing the PLA, being that he played a major role in stitching together his conservation of energy with PLA. In this, one finds a philosophical objective that motivates the historical objective. To make clear the centrality of Helmholtz' role in shifting from a vitalist, or vitalism-like, view of life science, Timothy Lenoir puts it as follows:

> [Physiologists of a mechanical bent] had defined the critical theoretical problem confronting the advance of physiology in the 1840s as need for a general analysis of the conditions of material exchange. The solution of this problem, they had argued, would eliminate the role of a special vital force and place physiology on the sound theoretical and empirical foundations of physics and chemistry required

[1] Terrall, Mary. *The Man Who Flattened the Earth: Maupertuis and the Sciences in the Enlightenment*. Chicago: The University of Chicago Press, 2002. p. 273

> for its future advance. Helmholtz had solved that problem by establishing the conservation of energy…[2]

The final analysis will entail two follow up considerations, subsequently. The first is that, in looking back to Kant's doctrines that inspired *Naturphilosophie*, there arises an interesting consequence of Helmholtz' work with respect to those doctrines. In merging teleology, by way of PLA, with Helmholtz' strategic tool used in establishing reduction (i.e., conservation of energy), any good Kantian will acknowledge Helmholtz' work as effectively giving teleology a life that it never had for Kant. What I mean by that is that Kant took true science to be undergirded by mathematics, and so replacing the teleology of *Naturphilosophie* with the teleology —imbued with mathematics— of the PLA means supplying teleology with a status it never possessed in Kant, that is, a real ontological status that necessarily transcends mere teleonomy. The other consideration, building off the first, is that there is still a move that the philosopher can make in avoiding extending the change in ontological status just proposed, which is to deny mathematical realism. This requires a fundamental rejection of Kant's thinking that what makes a science a science is a mathematical bone structure, so to speak, as he espouses in the *Metaphysiche Anfansgrunde der Natur Wissenschaft*. This paper begins with the philosophical objective, and then move into the historical discussion of Helmholtz.

The history of vitalism and the physico-chemical turn affirms a piece of wisdom that John Passmore espoused: '…throw metaphysics into the fire, and science goes with it, preserve science from the flames and metaphysics comes creeping back.'[3] If the changing tides of nineteenth-century life science's conceptual framework could be characterized succinctly, such a characterization would entail the desire of scientists to reduce the framework to strictly the

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[2] Lenoir, Timothy. *The Strategy of Life: Teleology and Mechanics in Nineteenth-Century Biology*. Chicago: University of Chicago Press, 1982. p. 228-9

[3] Passmore, John. *A Hundred Years of Philosophy*. New York City: Pelican, 1978. p. 392

physico-chemical terms, thus eliminating metaphysics from the picture. Theodor Schwann's work, for one, signifies this tide-changing. Armed with an education in metaphysics, mathematics, and physics, he began to peel back the metaphysics (e.g., non-material aspects) of biological explanation.[4] As Lenoir suggests,

> Schwann's presentation of the cell theory is typically hailed as starting from the complete rejection of vitalism —by which is understood as a rejection of the vitalism of Schelling, Oken and the Naturphilosophen— and placing biological research on a reductionistic framework of physics and chemistry.[5]

In Schwann's scientific texts, he strips purposiveness of its metaphysical import by regarding it as 'teolonomic rather than strictly mechanical.'[6] That is, the purposiveness lacks causal efficacy, only existing in name, only, and a product of something like Kant's reflective judgment. The strategy seen in moving toward the physico-chemical turn was one of eliminating the metaphysical components, such as the dualistic, immaterial substance in vitalism, and then relegating teleology to an in-name-only ontological status, where "teleonomic" would suffice as a description of anything purposive, rather than extending teleology a positive ontological status. This metaphysical underwriting can be seen clearly in the history, if one keeps a lookout for those features of scientific explanation that do not admit any further analysis, for that is where the metaphysics hides. This is the key task of the historian-philosopher in "keeping the field in front of them," à la the *façon de parler*. Therefore, even in historiographical texts, when one sees comments, such as 'For [Johann Reil] "form," conceived as the order among constituent elements, was the source of function. When he used it in the sense, *Lebenskraft* was not taken to

[4] Frédéricq, Léon. "ASketch of Theodor Schwann." *Popular Science Monthly* 37 (1890): 257-64. http://en.wikisource.org/wiki/Popular_Science_Monthly/Volume_37/June_1890/Sketch_of_Theodor_Schwann.
[5] Lenoir, Timothy. *The Strategy of Life: Teleology and Mechanics in Nineteenth-Century Biology*. Chicago: University of Chicago Press, 1982. p. 124
[6] ibid. p. 125

be the constitutive cause of this order. It was a term expressing a causal complex incapable of further analysis,'[7]

Section on PLA:

Before going any further, a brief introduction to the principle of least action is necessary.

The PLA is the regularity found in nature that refers to the minimization of a quantity in physics, called "action." In terms of unit analysis, action may be thought of as the product of time and energy, as its units are just that. The minimization of this quantity manifests in numerous ways, depending on the context of inquiry and the form of physical behavior examined. For instance, Maupertuis' original formulation of the principle, which dealt with light passing through a prism, asserted that the distance of light traveled would be minimized. Later formulations, such as Fermat's principle and Lagrange's form,[8] would assert that time is minimized. While all of these, contexts considered, are correct, the quantity, now called "action," is, in the broadest and most generalized, the physical quantity that is being minimized. The generalized form entails integration of a function over a time interval. For completeness, though the technical details are not crucial to understanding PLA for the present endeavor, the function is called the Lagrangian ($L(x,\frac{dx}{dt})$).[9] It is by virtue of how this quantity is minimized that makes it teleological, even before theologico-metaphysical assertions are thrown into the conversation, as Maupertuis had it. In order for the quantity of action to be minimized, the end

[7] ibid. p. 159
[8] von Helmholtz, Hermann. "Ueber die physicalische Bedeutung des Princips der kleinste Wirkung." *Journal für die reine und angewandte Mathematik* 1887, no. 100 (January 1, 1887): 137-66. OneStart@IU. p. 137
[9] Siburg, Karl Friedrich. *The Principle of Least Action in Geometry and Dynamics*. New York City: Spinger, 2004. p. v

state, the telos, must be, in a manner of speaking, known, in order for the calculation to be carried out. The action integral is the integral:[10]

$$A = \int_a^b L\left(\mathrm{x}, \frac{dx}{dt}\right) dt$$

Being that this equation denotes the action of any arbitrary physical system, the principle of least action requires just that, that the *variation* of the path (difference between "path" integrals), as represented by the integral, be zero.[11] That is:[12]

$$\delta A = 0$$

What may or may not follow intuitively from this is that the integrals and the difference are wholly dependent upon the fixed points of the integral path.[13] Looking to history, Helmholtz described the PLA in virtually the same fashion. He said,

> Das Princip der kleinsten Wirkung kann dann so ausgesprochen werden: *Der für gleiche Zeitelemente berechnete Mittelwerth des kinetischen Potentials ist auf dem wirklichen Wege des Systems ein Minimum (beziehlich für längere Strecken ein Grenzwerth) im Vergleich mit allen anderen benachbarten Wegen, die in gleicher Zeit aus der Anfangslage in die* ***Endlage*** *führen.* [emphasis added][14]

[10] It should be noted that 'A' is being used to denote action, though it is the standard convention in the physics literature to denote action as 'S'.

[11] "Path" should be understood in a conceptual sense, for while the word is apt in representations of mechanical systems, these "paths" are just as well applied to optimization of differential rates of reactions among chemical compounds, which was an interest of Helmholtz'. "Variation" is also emphasized in allusion to the fact that the calculus of variations underpins minimization of action, in the sense that it is the method by which minima are found.

[12] Feynman, Richard. *The Feynman Lectures on Physics*. Vol. 2. Reading, MA: Addison Wesley Publishing Company, 1977. Ch. 19 p. 6

[13] ibid. Ch. 19 R.P. Feynman provides excellent pictorial examples of how varying initial point and, more importantly for this discussion, the endpoints of the function completely alter the optimal (i.e., minimized) path.

[14] von Helmholtz, Hermann. "Ueber die physicalische Bedeutung des Princips der kleinste Wirkung". p. 139 Helmholtz' formulation refers to Hamilton and Lagrange's mathematically codified versions of the PLA, which employ the difference between kinetic and potential energy, as entailed, for example, by the Lagrangian.

It is in this "*Endlage*" that the trouble for the Newtonian-minded mechanist arises, as the minimization of action is contingent upon the particular (foreknown) end state, the telos, and it is the end state that determines the dynamic evolution of the physical system. There would be infinitely many possible paths for the scientist to integrate over, if there were no mathematical tricks of the trade, and so it seems only reasonable to suppose that Nature, in not blindly attempting non-optimal dynamical unfoldings, accounts for some end state from the outset of physical processes that are governed by the principle.[15] James Gleick depicts the teleological nature of the PLA in science thus:

> It is almost impossible for a physicist to talk about the principle of least action without inadvertently imputing some kind of volition to the projectile. The ball seems to *choose* its path. It seems to *know* all the possibilities in advance. The natural philosophers started encountering similar minimum principles throughout science. Lagrange himself offered a program for computing planetary orbits. The behavior of billiard balls crashing against each other seemed to minimize action. So did weights swung on a lever. So, in a different way, did light rays bent by water or glass. Fermat, in plucking his principle of least time from a pristine mathematical landscape, had found the same law of nature.[16]

It is this "*volition*" that so strongly correlates with nineteenth-century biological notions, such as Blumenbach's "*bildungstrieb*," the "developmental *urge*."[17] With an understanding of how the PLA preserves teleology, we briefly move our attention to energy.

Especially from the retrospective standpoint of twentieth-century physics, which acknowledges the dual nature of matter-energy, the project of the proponents of the physico-

[15] Margeneau, Henry. *The Nature of Physical Reality: A Philosophy of Modern Physics*. Woodbridge, CT: Ox Bow Press, 1977. p. 185
[16] Gleick, James. *Genius: The Life and Science of Richard Feynman*. New York City: Vintage Books, 1993. p. 60-1
[17] Gliboff, Sander. *H.G. Bronn, Ernst Haeckel, and the Origins of German Darwinism: A Study in Translation and Transformation*. Cambridge: MIT Press, 2008. p. 32-5

chemical turn in nineteenth-century biology are faced with a troubling reality: in eliminating explanations that featured an immaterial vitalistic entity, energy, an immaterial entity, took over that central role. Apropos the retrospective standpoint, why exactly does energy need to be regarded as something like the immaterial substance and, thus, correlated with entelechy? Well, matter is a material substance whose alternative form is immaterial, and it has the added feature of governing (refer, for example, to the technical description of the Lagrangian above), restricting, and affording the capacity for motion.[18] In predicating these descriptive words, governing motions, restricting motions, and affording the capacity for motion, to a conceptual entity which is posited to be immaterial, there is suddenly a striking correlation between energy and something like the entelechy. It begs the question of how it was that efforts of reductionists could have allowed this to happen. With the philosophical terms (e.g., adjectives) all on the table, clearly placed in plain sight, the history reveals what was at stake and how (why) this came to be. It was the dualistic aspect of vitalist notions, seemingly descended from scholastic philosophy of the soul and Cartesian philosophy's *cogito*, that thinkers like Ernst Haeckel were trying to abrogate.[19] The implicit collective thinking seems to have been: do away with dualism of any variety, and the principle of causality will do away with teleology. If this was the implicit thought, then it wouldn't be such a mystery as to how energy was, over time, swapped in the stead of the vitalists' immaterial substance. Further support is lent by the fact that monism, from Schelling —influenced in this way by Spinoza— to Haeckel, was a common intellectual commitment.[20]

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[18] Fernflores, Francisco. "The Eqivalence of Mass and Energy." Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/entries/equivME/.
[19] Gliboff, p. 195
[20] Bowie, Andrew. "Friedrich Wilhelm Joseph von Schelling." Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/entries/schelling/.

There also exists an historical link between energy and the entelechy, albeit somewhat tenuous —though when referents, in their conception are altered and are assigned different names, some ambiguity follows, hence, the tenousness. It is somewhat peculiar, though, that the vital force would be conflated by nineteenth-century German biologists with the living force, which was originally Leibniz' conception. That Leibniz is involved is even more interesting, being that '[R]eturned to the topic [of teleology] with an almost obsessive regularity,' and had in fact formulated the qualitative precursor to Maupertuis' principle, called the "most determined path principle."[21] Additionally, '[I]n the *Specimen* [*Dynamicum*], he [Leibniz] tells us that "primitive [active] force (which is nothing but the first entelechy) corresponds to the *soul or substantial form* [of the scholastics]" while "the *primitive force of being acted upon* or of *resisting* constitutes that which is called *primary matter* in the schools."[22] In other words, Leibniz even claims that *vis viva* and the force associated with the soul in medieval scholasticism are of the same metaphysical class. That *vis viva* would comingle in Liebig's (and others') "vitalistic language," as Yehuda Elkana calls it, with "*lebendige kraft*" is not too surprising, supposing that at least some of the nineteenth-century life scientists maintained some sort of association —maybe an overlap, to some degree— between the concepts. The ultimate reasoning behind Helmholtz' transition from force, "*kraft*," to energy, "*energie*," is not clear to me, but what seems difficult to comprehend is that he would have been thinking of conservation of *vis*, as Elkana claims.[23] The reason, after all, for thinking that force might be conserved was Leibniz' thinking, which dealt with conservation of living force (modern kinetic energy, minus

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[21] McDonough, Jeffrey K. "Leibniz on Natural Teleology and the Laws of Optics." *Philosophy and Phenomenology Research*78, no. 3 (May 2009): 505-44.
[22] McDonough, Jeffrey K. "Leibniz' Philosophy of Physics." Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/entries/leibniz-physics/.
[23] Elkana, Yehuda. "Helmholtz' Kraft: An Illustration of Concepts in Flux." *Historical Studies in the Physical Sciences* 2 (1970): 263-98. p. 270

the coefficient of one-half), not Newton's notion of force. All in all, I feel compelled to side with Maupertuis' opinion of the conception of force as being 'more a "confused feeling" than a clear idea,'[24] and it was probably an idea that became clear during the period around and following (i.e., in reflecting upon) the publication of *Die Erhaltung der Kraft* (1847), which may have been quite a lengthy process of conceptual clarification. At any rate, there seems to be a tenuous chronological and morphological link between what the vitalists referred to as "entelechy" and what mechanists would come to call "energy" —and if there was anything even *loosely like* vital materialists, then they would have almost assured intermingled "*lebendige kraft*" and "*vis viva*" to the point of confusion, or near enough. In some respects, it seems like concepts were slid out from one linguistic label, reshuffled, and merged with another. That both linguistic labels existed at the same point in time is not a matter, for just 'as the problems change, so, often does the standard that distinguishes a real scientific solution [or notion] from mere **metaphysical speculation**, **word game**, or mathematical play' (emphasis added).[25]

The focus now shifts to Helmholtz. The question is why it was that Helmholtz brought the conservation of energy and the PLA together, as well as how he thought about this tandem and the PLA, in general, given that Maupertuis and others acknowledged the PLA as being teleological in nature.[26] Helmholtz properly understood Maupertuis to maintain the opinion the PLA is a universal principle, in the sense that all physical phenomena could be described in terms of some minimized quantity; and Helmholtz further understood that, in opposition to such

[24] Terrall, p. 284
[25] Kuhn, Thomas. *The Structure of Scientific Revolutions*. 3rd ed. Chicago: The University of Chicago Press, 1996. p. 103
[26] If Leibniz can be extended any sort of priority, being that he formulated, at least, the qualitative version of the PLA, then it can be said that the principle was twice formulated with a view to teleology, once qualitative and once quantitatively (by Maupertuis). Others at the time (e.g., Mach) likewise acknowledged the teleology inherent to the principle —Mach calling it conception having come out of "theological dross" (see *The Science of Mechanics*).

an opinion, contemporary (to Helmholtz) evidence contradicted this "metaphysical speculation" advanced by the Frenchman. Helmholtz says,

> Daraus ergiebt sich schon jetzt, dass der Gültigkeitsbereich des Princips der kleinsten Wirkung weit über die Grenze der Mechanik wägbarer Körper hinausgewachsen ist, und dass *Maupertuis'* hoch gespannte Hoffnungen von seiner absoluten Allgemeingültigkeit sich ihrer Erfüllung zu nähern scheinen, so dürftig auch die mechanischen Beweise und so widerspruchsvoll die **metaphysischen Speculationen** waren, welche der Autor selbst für sein neues Princip damals anzuführen wusste. (emphasis added)[27]

Helmholtz goes on to point out that the irreversibility of processes in thermodynamics is illustrative of this contradiction. Some of Helmholz' interests in chemistry[28] had to do with the degree of employability of the PLA —and he was interested in the electrodynamic[29] and thermodynamic[30] aspects of chemistry, seeking similar employability in said branch of physics.[31] In this, one finds Helmholtz general disposition toward Maupertuis, namely, that Maupertuis overreached, being given to metaphysical assertions which, supposedly, had no place in physical processes. Though outside the intentions of this paper, the way in which Maupertuis meant "universal" is worthy of some consideration. At any rate, Maupertuis was as much a metaphysician as a scientist: he studied mechanics under a Cartesian,[32] and he even called his project of grounding mechanics "metaphysical mechanics."[33] As Maupertuis formulated the

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[27] von Helmholtz, Hermann. "Ueber die physicalische Bedeutung des Princips der kleinste Wirkung". p. 142
[28] Patton, Lydia. "Hermann von Helmholtz." Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/entries/hermann-helmholtz/.
[29] von Helmholtz, Hermann. In *Physical Memoirs Selected and Translated from Foreign Sources*, Translated by Physical Society of London. London: Taylor and Francis, 1888.
[30] von Helmholtz, Herman. "On the Thermodynamics of Physical Processes." *Berlin Academy* (1882).
[31] Schiemann. p. 211
[32] Terrall, Mary. *The Man Who Flattened the Earth*. p. 20
[33] ibid. p. 271

PLA, he did so on metaphysical grounds of a prior heuristic (immaterial moving planes), which needed fixing, in the sense that a metaphysical supplement was required to remove a problem:

> Maupertuis formulated the principle of least action as a mathematical version of the metaphysical principle that nature acts as simply as possible: "Whenever there is any change in nature, the quantity of action necessary for that change is the smallest possible."[34]

And so, there is a sense in which the passage in which Helmholtz mentions Maupertuis, in fact, says more about Helmholtz than it does Maupertuis, insofar as Helmholtz' outlook, approach, and general methodology is concerned. It supports a claim I will further advance, shortly, that Helmholtz was a very close (and very modern) reader of Kant and maintained a commitment to 'scientific Kantianism,' let's call it —more on this later.

Helmhotz rejected Maupertuis' motivation and his teleology, despite whatever opinion may have existed between the eighteenth and nineteenth centuries.[35] '[Maupertuis] saw this work as the direct outgrowth of his earlier papers on statics and refraction, now more fully integrated into the framework that tied extremum mechanics to a mathematically based proof for the existence of God.'[36] What is interesting about such works by Helmholtz as *Ueber die physicalische Bedeutung des Princips der kleinste Wirkung* is that the oft-waxing philosopher felt no compulsion to even discuss these issues of teleology. He did distance himself from a firm commitment to the PLA through mitigating language. Why might this be? I should like to argue that part of it was Helmholtz' metaphysical and philosophical commitments, and part of it was true motivations, which largely fed into the reasoning for his former commitments.

[34] ibid. p. 272
[35] Schiemann. p. 221 Special thanks to Jutta Schickore for pointing me toward this resource.
[36] Terrall, p. 272

What is striking about Helmholtz' biography is the unanticipated degree to which Immanuel Kant's impacted Helmholtz and was responsible for forming so many of his opinions.[37] With some understanding of Kant's critical project, this begins to make quite a bit of sense out of Helmhotz' physiological epistemology, as Lydia Patton refers to it.[38] Kant's scientific project if built out of the *Kritik der reinen Vernunft*, in the sense that what strikes the senses, literally, comes under the sway of the pure concepts, and so experience conforms to knowledge in this way. It is for this reason that Helmholtz does so much of his work in physiology on sensations (e.g., auditory tone). In this way, there are stark comparisons to be made, but that will largely be foregone here, such as the proto-positivisitic flavor of Helmholtz' approach to science, beginning where he understands metaphysics to end. As Heimann points out, Helmholtz supposed a firm grounding of physics through his establishment of energy conservation, because he believed that the metaphysical foundation for his way of doing science was also firm —and the metaphysical foundation happened to be, in essence, Kant's.[39] It is no wonder then, with this understanding in mind, why Helmholtz viewed mathematics and analogies within science as he did, in particular, 'to preoccupy himself with analogies as an "entirely rational" way of doing science'[40] and with thought in mind that mathematics in physics is structurally similar to physics.[41] With respect to analogies, Kant's "analogies of experience" explain the former thinking, and the status of "science" being predicated to an endeavor of sufficient formal mathematical scaffolding inherent to it. This is what was meant earlier by "scientific Kantianism." In fact, Lenoir says that

[37] Meulders, Michel. "Helmholtz: From Enlightenment to Neuroscience." Translated by Laurence Garey. Cambridge: MIT Press, 2010. p. xvi
[38] Patton.
[39] Heimann, P.M. "Helmholtz and Kant: The Metaphysical Foundations of Uber die Erhaltung der Kraft." *Studies in the History of Philosophy of Science* 5, no. 3 (1974): 205-38. p. 237-8
[40] Schiemann. p. 219
[41] Schiemann p. 217

> Helmholtz, for instance, reflected long and deeply on the sections on space and time as well as the deduction of the categories in Kant's *Kritik der reinen Vernunft*. He also devoted considerable attention to Kant's *Metaphysische Anfangsgründe*. These works were frequent objects of discussion in Helmholtz' writings and his own careful study of Kant led him to claim that he was an even better Kantian than Kant himself, for he had worked out the implications of Kant's work for the natural science in a manner more consistent with the "spirit" of the system than Kant had succeeded in doing.[42]

This brings us to why it was likely the case that Helmholtz didn't see it necessary to say much explicitly in contradiction to the teleological aspect of the PLA, simply dismissing it without much more said.

My claim is that Helmholtz did not actively seek to undermine the teleology of the PLA, because he was keeping with the Kantian commitment to the "*als ob*," withholding any possibility of positive ontological status that one, such as Maupertuis, might wish to extend to it; and this is indicated by Helmholtz' reference to the PLA 'als heuristisches Princip und als Leitfaden.'[43] However, there is a problem that Helmholtz, maybe, never addressed, which is the fact that the upshot of the PLA's mathematical nature, in conjunction with Kant's definition of a science as being inherently mathematical, is that all perceived teleology would be reified in a way that can no longer be mitigated by Kant's *als ob*. On this ground, Helmholtz could dismiss the criterion Kant laid out for what constitutes a science; but, if not, he would have to reject mathematical realism, the thinking that what is mathematically understood about the world is epistemic, not the way the world is ontologically. There is some evidence that suggests that

[42] Lenoir, p. 242
[43] von Helmholtz, Hermann. "Ueber die physicalische Bedeutung des Princips der kleinste Wirkung". p. 143

Helmholtz did spurn mathematical realism, employing mathematics for which he could supply no mechanical model to explain the math.[44]

In the preceding, one sees that immaterial substance and teleology survive the chemico-physical turn, and that, furthermore, Helmholtz did not have much reason to feel threatened by ostensible remaining teleology. The fact remains that, when cashing out the concepts and their labels, prior to and after the physico-chemical turn in the life science, the names have changed but the concepts remain remarkably intact. Part of the reason this occurred without any remark for so long simply seems to be that methodological commitments were the focus of various life scientists, such that the "terms and conditions" of the concepts they used were often ambiguous. This should not at all be surprising: numerous definitions for a single term indicate the ambiguity of what is meant by them, and if focus is on objectives and cashing terms out under a particular approach, such as reductionism, some of the conceptual heritages (e.g., teleology and immaterial substance) are lost in the scientific process. Helmholtz' philosophical commitments, which represent the type of methodological thinking that went into his work, provide an example of how the aforementioned concepts can metamorphose, be relabeled, and missed in terms of their heritage among concepts of previous research programs.

[44] Schiemann. p. 236