From Sacred to Profane: Helmholtz's Mechanization of Physiology

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In his *The Application of the Law of Conservation of Force to Organic Nature*, Helmholtz strives to convince scientists in general, but physiologists in particular, that all living beings are subject to the laws of physics just like machines are, that there is no need for the mythical living force of "vis visa". Doing so allows him to influence the direction of future physiological research away from vitalist theories. Ultimately, this paper represents one step in Helmholtz's attempt to recast physiology firmly upon a materialist foundation.

Helmholtz presented this address to the Royal Society of London, a group populated with legitimate scientists, but also, those who were more willing to believe than to question. No doubt one of his greatest obstacles in advocating for a materialist-based physiological research was separating people from their enormous set of mental prejudices and prejudgements regarding how the human body, and indeed, the very universe, function. This must be done before logical arguments about experimental evidence can occur. In other words, Helmholtz faced a much greater challenge when trying to discuss his research with other scientists precisely because his research cut so close to home. A materialist understanding of human physiology dramatically undercut both prevailing religious and societal notions but also personal assessments about what it meant to be human. Such research challenges people not only in their logical beliefs, but in their most cherished notion of their own identity. If one believes that he lives and breathes because he is imbued with the life breath of his creator, then a materialist physiology threatens his entire world view.

Helmholtz's speech goes to great lengths to deal with this problem. In addition to a clear, logical, step by step presentation of his argument, he uses several other rhetorical techniques. In particular, because the conclusions are so profoundly unsettling, he tries to mitigate the novelty of his ideas by using simple, common, everyday objects as examples. People don't feel threatened when thinking about how bullets or furnaces work, so this practice psychologically prepares them for the later ideas suggesting humans work according to the same principles as well as provides a basis for later analogy. In fact, Helmholtz delights in building chains of analogies, constructing an argument incrementally in small steps, trying to keep everyone on board at all times since he knows that any gap at all, no matter how insignificant, will be seized upon as a basis to reject the theory. I'll review the address point by point, mapping out the logical structure of his argument while explaining how that structure furthered the goal of communicating his message to what must have been a difficult audience.

He begins his address by claiming that the most important scientific understanding of this century is what we know as the law of the conservation of energy. This is followed by a brief explanation of the law and how to apply it, using examples of gravity and chemical reactions. He also takes time to deconstruct several misconceptions about the law early on in the talk. This reflects both an overall goal of ensuring the presentation is as logically consistent as possible and the fact that his audience probably is not as intelligent as it like to believe. The Royal Society had enough members with little or no scientific aptitude and a very limited exposure to this type of reasoning that the time spent debunking incorrect preliminary notions was almost certainly time well spent.

In a similar vein, it is interesting that Helmholtz claims that "some special examples will enable you better to understand the law than any general theories" (110). He had good reason to shy away from a more theoretical presentation. For beginners, such a presentation would face much more opposition from established religious and cultural beliefs. It is far more difficult to argue with objective facts and experimental data regarding physiological energy consumption than it is with a theory that on its face contradicts closely held personal, religious, and cultural beliefs. Moreover, he may have been wary of scaring away experimentalists, who were far more likely to be scientists of note. Such experimentalists undoubtably heard great a deal of unworkable, impractical theories from their less scientific colleagues and were used to turning a deaf hear to presentations that didn't lead with sufficient experimental evidence.

Casting preliminaries aside, Helmholtz enters into the meat of his argument by expounding on gravity powered machines like watermills and clocks with which his audience must have been intimately familiar. He uses these examples to illustrate the notion that mechanical energy can be readily transferred to motivate any machine, no matter the source, saying "every machine can be put into motion and by these motive powers every sort of work can be done which can be done by any machine" (110). From there, Helmholtz introduces the notion of velocity as a motive force, or, in modern terms, kinetic energy. He does so with the example of a bullet, and, in preparation for later arguments, claims that vis viva, the living force, is the same thing as kinetic energy. He says "the velocity of any body, if it is producing work, is called the vis viva" (111). This is a brilliant rhetorical move; by appropriating the theory of vis viva as his own, he makes his new theory far more familiar and less threatening. In effect, Helmholtz takes advantage of the fact that the vitalists have overreached, attempting to describe simple things like bullets with the theory of vis viva. This gives him an opening to attack them with Occman's Razor.

At this point, Helmholtz uses the example of the pendulum to visually convince his audience that gravitational energy and kinetic energy are interchangeable, saying "these two are equivalent" (111). He then proceeds with several mechanical analogies involving springs, including watch coils and crossbows. Both technologies would be familiar to his audience and they are both "reservoirs of mechanical power" (111). This choice of examples allows him to further build the image of universality of energy by explaining very different phenomena in the same vocabulary. Having established the previous examples, Helmholtz analogies from compressed solids (springs and bows) to compressed fluids (air) opining that elasticity is the key to energy storage. He makes the analogy practical by comparing the crossbow to the air gun.

Springing from the analogy to compressed solids, Helmholtz claims that the same elasticity in compressed gases underlies the power of the steam engine. Heat and mechanical power are thus interchangeable. He ascribes the conversion factor between the two to Joule, making it seem less radical. Helmholtz claims that "heat cannot be a ponderable matter, but must be a motive power" (112). The steam engine power comes from heat, but heat comes from combustion, so energy comes from "chemical forces of the fuel and in the oxygen with which the fuel combines" (112). Ergo, chemical forces can produce work. Chemical forces can be understood as attraction, just like gravitational attraction, further cementing the analogy between chemical and gravitational work. Moreover, Helmholtz states that the amount of work done by a chemical process depends only on the reactants and products. He also boldly asserts that the energy of every force in nature can be measured in foot-pounds, implicitly arguing that all energies found in nature are ultimately equivalent.

From that theoretical notion, Helmholtz takes a brief detour into cosmology, arguing that since energy is conserved, the total amount of energy in a closed system must be constant. Having convinced his audience that energy is equivalent, he goes on to claim that all activity on the Earth's surface is due to energy from the sun, making use of his previous points that wind is simply air with kinetic energy and that heat can (indirectly) produce kinetic energy. This argument prepares the audience for a critical point: the notion that plants generate "inflammable matter" using energy from the sun. Helmholtz then discusses work involving the conservation of vis viva and the impossibility of perpetual motion machines. While not directly relevant to his argument, it serves to remind his audience of how the scientific consensus regarding vis viva and perpetual motion evolved over time. He no doubt hopes to elicit a similar evolution in the thinking regarding the conservation of energy in animate beings.

Helmholtz now enters the core of his argument, claiming that the steam engine is a good model for living organisms. Both take in hydrocarbons and oxygen and produce carbon dioxide and motion, as well as heat. Moreover, he argues that both the steam engine and a resting animal produce equivalent amounts of heat for the same amount of hydrocarbons. Based on further experimental work, Helmholtz concludes that a human being produces a great deal more useful work than the best steam engines given the same amount of energy to start with. At this point, he has transitioned from saying that steam engines are a good model for animal physiology to saying that humans are steam engines. The former point is much harder to reject out of hand while the latter is much easier to accept once the former has been accepted.