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Jonathan Hanselman
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Hermann von Helmholtz:
Making and Promoting an Understanding of Energy Conservation

In the early and middle nineteenth century, the Industrial Revolution and growing importance of the steam engine, coupled with numerous discoveries in the areas of heat, electricity, magnetism, and chemistry, fostered the extensive study of various forms of energy. In the 1840's Herman von Helmholtz, as well as several other scientists from across Europe and from diverse fields, realized the crucial relationship between the various forms of energy, that they are interchangeable and that total energy is always conserved. Helmholtz expressed this truth as the law of Conservation of Forces. The development of this idea by Helmholtz was influenced by many factors, including his own background and training, his contemporary scientists, the Industrial Revolution and the legacy of the Romantic era. His 1854 essay "On the Interaction of Natural Forces" discussed the interchangeability of forces and the conservation of energy as developed by Helmholtz and others in the 1840's. It did not present any new scientific discoveries, but explained and promoted Helmholtz's theory to a broader audience than before. In his law of conservation of forces, and specifically in the essay "On the Interaction of Natural Forces," Helmholtz assimilated a variety of new discoveries, his own diverse background, and multiple cultural and historical influences to develop and promote a worldview including the constancy of energy in the universe.

Hermann von Helmholtz was a German physiologist and physicist of the mid-nineteenth century. He studied chemistry, clinical medicine, and physiology at the University of Berlin, ultimately focusing on physiology under the guidance of Johannes Müller (Turner, 241). At Berlin, Helmholtz was taught in the tradition af vitalism, of which Müller was a staunch supporter. However, Helmholtz was also exposed to alternative approaches to physiology. Helmholtz became a protégé of Emil du Bois-Reymond and Ernst Brücke, older students of Müller who rejected his vitalism in favor of a mechanistic explanation of physical processes. This new approach sought a physical and chemical basis for the study of organic life (242). Helmholtz became a successful physiologist, and at the time "On the Interaction of Natural Forces" was published, he was associate professor of physiology at Königsberg. Although mechanistic physiology was the dominant influence and interest in Helmholtz's career, he had a strong interest in physics as well. The interest that was present all along became most evident later in his career. He published prolifically in both physiology and physics during the 1860's (242). In 1871, he actually left his physiology post at Heidelberg to become physics chair in Berlin (243). It will be shown that the melding of physics and physiology in Helmholtz's science found its expression in his theory of the interaction and conservation of forces.

The 1854 essay "On the Interaction of Natural Forces" was not Helmholtz's first formulation of the law of conservation. This came in 1847, with the famous essay "Über die Erhaltung der Kraft," or "On the Conservation of Force." However, the former essay presents a good summary of the new understanding that was developed by Helmholtz and others in the 1840's. It did not present any new experimental evidence, nor did it contain the technical mathematical proofs Helmholtz developed in his earlier treatment (Weber, 279). It did, however, present the basic argument for the connection between all known forms of energy and promote the new theory as developed in the previous decade. The essay seems to be targeted to a broader public than may have been reached by the development of the 1840s. Helmholtz wrote in the essay that although there were still investigations to make, there was enough evidence that he had "not deemed it premature to bring the subject before even a non-scientific audience" (Helmholtz, 27). Due to his audience, Helmholtz did not need to provide the detailed logic and experimental evidence a skeptical scientist might have demanded. Instead he communicated each key point with one or two clear examples. He used a wide range of observations and thought experiments from well known phenomena, including pendula, grandfather clocks and pocket watches, water mills, and steam engines, which he expected his audience to be familiar with, to show the equivalence of different types and measures of energy. Helmholtz concluded from the equivalence of different natural forces that total force is always conserved (38). One of Helmholtz's goals in this essay seems to have been convincing the "non-scientific audience" the the conservation of force was not just a scientific concept but a fundamental and relevant principle of how the world works.

The development of Helmholtz's theory of interrelatedness and conservation of forces presented in "On the Interaction of Natural Forces" was an assimilation of many cultural, scientific, and personal influences. Both Helmholtz's background in physiology and his interest in physics were significant factors in the result of his research. Of course his interest in physics propelled him in this direction. Energy was of growing importance in physics, and Helmholtz was well aware of the other scientists doing work on forces of various kinds, including Carnot, Joule, and Lord Kelvin. He was also interested in the debate about perpetual motion, and its impossibility was an important argument for his theory (Helmholtz, 25). However, Helmholtz's early work from 1843 to 1847 was dominated by physiology, not physics, and his 1847 essay "On the conservation of forces," in which he first proposed his law of conservation of energy, was no exception. Specifically, his work in these years focused on animal heat and movement of muscles (Turner, 242). An important part Helmholtz's mechanistic physiology was to show that Müller's vital force was not necessary, and so he had to demonstrate that both heat and mechanical motion of the muscles could be explained by a transformation of chemical energy obtained in food. This was likely the primary initial motivation for Helmholtz's study of forces, and indeed in "On the Interaction of Natural Forces" Helmholtz includes animal conversion of chemical energy into heat and work as a primary example, writing, "The animal body therefore does not differ from the steam-engine as regards the manner in which it obtains heat and force" (37). Thus the study of forces for Helmholtz fell into the intersection of physics and physiology. While his interest in physics was important in equipping him to study energy, his initial motive was likely the application to physiology in refuting vitalism.

In addition to Helmholtz's education and background, there were several cultural and historic factors which influenced his work and are reflected in "On the Interaction of Natural Forces." The most notable of these, perhaps, was the Industrial Revolution. In the first half of the nineteenth century, industry and mechanization powered by steam exploded across Europe. Thomas Kuhn has argued that the "concern with engines" resulting from the growing importance of steam powered industry was a critical factor in the simultaneous discovery of the law of energy conservation by Helmholtz and his contemporaries (Kuhn, 323). Steam engines were certainly motivation for much of the energy research being done at the time, and many of those from whom Helmholtz drew results, including Sadi Carnot and Joule, worked with engines in some capacity (333). Steam engines were an important example for Helmholtz for they were commonplace and well understood examples of how chemical energy is converted to heat and then to mechanical work. In his later 1862 lecture "On the Conservation of Forces," which is a thorough explanation of the equivalence of different forms of force, Helmholtz gives a detailed description of the steam engine and the energy transformation that occurs (Helmholtz, 110). He does not devote as much time to the steam engine in "On the Interaction of Natural Forces." As has already been mentioned, he did not include as thorough explanations or descriptions in this essay. However, he still used the steam engine as the prime example of creating work from chemical energy and as a basis against which to compare the transformation of chemical energy to heat and work in animals (37). While the steam engine may not have been a central element in "The Interaction of Natural Forces," the cultural context of the Industrial Revolution and significance of the steam engine are inseparable from Helmholtz's development of the law of conservation.

Another significant historical factor evident in this essay was the work of other scientists in Europe at the time. Kuhn points out that between 1842 and 1847, four scientists, Mayer, Joule, Colding, and Helmholtz, announced the concept of conservation of energy. These discoveries were mostly independent, but Helmholtz was aware of some of the others' work. Furthermore, Carnot, Sequin, Holtzmann, Hirn, Mohr, Grove, Faraday, and Liebig had all expressed some notion of forces being connected as different forms of one universal force (Kuhn, 321). Helmholtz was clearly not alone in his studies of energy. Furthermore, Helmholtz drew heavily on the work of these other scientists, particularly for experimental evidence (Turner, 243). In "On the Interaction of Natural Forces," Helmholtz did not present any of his own experimental evidence, beyond simple observations and thought experiments. To back up his claims of the equivalence of work and heat, therefore, he referenced Joule's calculation of the "mechanical equivalent of heat," 1350 foot ponds for the heat needed to raise one pound of water one degree Centigrade (Helmholtz, 28). He also cited one of Carnot's laws in discussing unchangeable heat (29). Finally, in Helmholtz's discussion of the heat and work generated in animals, he referenced Liebig, who had previously argued that the chemical energy in food is converted to heat and mechanical forces by chemical processes (37). The work of Joule, Carnot, Liebig, and others was clearly an important factor in Helmholtz's own discovery of the interaction of natural forces. Helmholtz's reliance on the experiments and results of others in his writing is also revealing about his purpose. It demonstrates that he was not presenting new scientific facts, but rather combining and interpreting old observations and recent discoveries to promote a new theory within his mechanistic worldview.

Helmholtz reacted against the vitalism taught by Müller in Berlin, but he was not all together immune from the influence of previous scientific and philosophical trends. Helmholtz worked in the context of the end of the Romantic period, and in particular the *Naturphilosophie* movement, which among other things held that there was unity and connectedness in the universe. Helmholtz may have been influenced by thinkers like Friedrich Schelling and Hans Christian Oersted, who both maintained on philosophical grounds the notion that the observable forces were all manifestations of one universal force (Kuhn, 338). This conviction motivated both men in their scientific explorations of the connections between forces. Kuhn argues that this same mentality may have been a factor in development of the law of conservation by Helmholtz and his contemporaries (339). In addition to influence in the study of forces, Helmholtz had still further exposure to *Naturphilosophie* through his father, who was himself a romantic thinker (Turner, 241). Kuhn's proposal about the influence of the *Naturphilosophie* movement on Helmholtz and others is speculation, but there do seem to be some elements of romantic ideas in "On the Interaction of Natural Forces." The use of the term *vis vita* for the force of a moving body, for instance, which is reminiscent of Müller's "vital force," may have been indicative of the difficulty in fully abandoning romantic habits and ideas.

A further hint of *Naturphilosophie* ideas in Helmholtz's essay may be the emphasis he seemed to put on the universality of natural laws, including his own law of conservation, in the cosmos. For instance, he pointed out that the gravity that acts on earth is the same gravity that puts the planets and stars in motion, the light and heat of terrestrial bodies are not any different that of the heavenly bodies, and meteoric stones contain the same elements and minerals we find on earth (Helmholtz, 31). Helmholtz uses these universal facts to support the claim of his own laws' universal truth. furthermore, Helmholtz seems to emphasize cosmological implications of his theory in this essay, especially when compared with other works like his later lecture, "On the Conservation of Forces," in which he focused on explaining familiar processes of energy transformation. In "On the Interaction of Natural Forces," he described how the conservation of forces could help explain the formation of the solar system from a nebulous space cloud (32). He then concluded the essay with his theory's implications on the ultimate fate of the universe (43). It is as if Helmholtz wanted to promote the acceptance of the law of conservation of forces as a worldview by showing it was not just a phenomenon of steam engines and water wheels, but an all-embracing, intrinsic principle of the universe. In fact, perhaps an even bolder claim can be made. In addressing the formation of the solar system, Helmholtz referred to the earlier work of Kant and the "fundamental ideas of Newton" (31). By emphasizing the cosmological implications of his theory in the context of Newton's fundamental ideas, perhaps Helmholtz was equating the law of conservation of forces with the foundational laws of Newton in importance and intrinsic, universal character. That Helmholtz had this comparison in mind when he wrote "On the Conservation of Forces" is pure speculation, but in any case it seems clear that Helmholtz was trying to communicate the grandness and importance of conservation of forces as not merely an observed phenomenon but a deep truth about the universe.

In Herman Helmholtz's study of the conservation of energy can be seen the varied influences of Helmholtz's dual background in physiology and physics, the scientific environment in which he worked, the cultural and scientific setting of the Industrial revolution, and the legacy of the Romantic and *Naturphilosophie* movements. Helmholtz assimilated all of these factors, as well as several new discoveries of other scientists leading up to the 1840's, into a coherent theory in the framework of his mechanistic worldview. Similarly, in his essay "On the Interaction of

Natural Forces," Helmholtz integrated the concepts of interchangeability and conservation of energy he and others had developed into an understandable theory for a broader public and argued for its acceptance as a fundamental understanding about the universe. Helmholtz and his colleges were ultimately successful in promoting this view, as out of this important discovery was born the modern field of thermodynamics. The universal acceptance of the law of conservation of energy in science today demonstrates that the worldview Helmholtz was promoting was adopted, and just hints at the vast scientific and cultural influence the discovery of Helmholtz and his contemporaries has had.

Works Cited:

Helmholtz, Hermann von. "On the Conservation of Force." (1862-63). In *Science and Culture: Popular and Philosophical Essays*. Ed. David Cahan. Chicago: University of Chicago Press, 1995. pp. 96-126.

-----. "On the Interaction of Natural Forces." (1854). In *Science and Culture: Popular and Philosophical Essays*. Ed. David Cahan. Chicago: University of Chicago Press, 1995. pp. 18-47.

Kuhn, Thomas S. "Energy Conservation as an Example of Simultaneous Discovery." Critical Problems in the History of Science. Ed. Marshall Clagett. Madison, WI: The University of Wisconsin Press, 1969.

Turner, R. Stephen. "Helmholtz, Hermann von." In *Complete Dictionary of Scientific Biography*. Vol. 6. Detroit: Charles Scribner's Sons, 2007. 241-253. Gale Virtual Reference Library. Gale. BLC Massachusetts Institute Of Tech. 2. 15 Mar. 2008 <http://go.galegroup.com/ps/start.do?p=GVRL&u=camb27002>.

Weber, Alan S. *Nineteenth Century Science: A Selection of Original Texts*. Orchard Park, NY: Broadview Press, 2000.