Transitions of Physics: Rationalism and Empiricism

Dennis V. Perepelitsa

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The moral and social conceits of Victorian England well reflected the mood of the scientific community at the time: descriptions of physical phenomena, like rules of ettiquette and human interaction, were vast systems mired in legacy, weight, contradiction and deference, the constant justification and reassertion of which was a monumental task. The picture of the classical physicist at the time was of a man who not only placed stock in the empirical verification of theoretical ventures, but who substituted those same methods of verification for the ventures themselves. Natural philosophy was to him a system of rules and laws that existed insofar as they could be seen, heard, felt, or otherwised observed. That is, they had a firm footing in human experience, and even the classical physicist's choice of mechanical modeling as a pedagogical tool reflected this, as did his psychological desire for explanations of the natural world that were entirely mechanical. The Industrial Revolution was in full force, and just as the value of an economy was measured by its production capacity, labor power and capital investment, discussions of physics were validated by the meter stick, weight scale, and watch. But just as this era in England's history would give way to the crisis of Modernism after a few short decades, this physicist was slowly being replaced with another breed. This new physicist placed his faith in rational explanations, championed pure mathematics as his tool, and quickly left behind that desperate reliance on familiar, Newtonian systems. The differences were significant and fundamental.

The first and most obvious source of dissent between the two generations of physicists was the means by which physics was done. The older generation were staunch empiricists, and their reputation preceeded them: even Einstein's "On the electrodynamics of moving bodies" was muted in homage to the positivist point of view. He spoke less of events, and more of their observation. He attempted to highlight the context of human experience by presenting within the paradigm of a conscious measurement-sampler.To the classicists, it is the sum of information that validates hypotheses and leads to laws, whether or not they elegantly fit within the body of previously set forth law. In the eyes of staunch empiricist Ernst Mach, theory had no inherent value outside of how it pertained to, and could be placed in the context of, human experience. The newer generation preferred to formulate their view of the universe with intuitive, rational methods. So despite this deference, the topics in Einstein's paper were an example of *a priori* deduction (something anathema to the physicist's then professed views) a method of reasoning he and other physicists of the new generation eventually became comfortable with over the coming decades. If one discovered the universal truth of the universe, natural law would flow unimpeded. There was a hint of romanticism in this notion of elegance and beauty in the fundamental description of natural phenomena. It was the "great simplification of the theoretical basis of physics as a whole"[1] that caused to Einstein to stand firmly with his general relativity, even when confronted with attacks and data (later shown to be erroneous) to the contrary. Soon enough, the development of general relativity and, later, quantum theory, would empower rationalism to challenge empiricism as the sole philosophy through which physics proceeded.

To these ends, both groups of physicists formed tools and explanatory guides dictated by their character and approach to physical investigation. The classical physicists used mechanical models not only as pedagogical analogies of the physical world, but as expressions,

[1] Gerald Holton, "Mach, Einstein and the search for reality," in Gerald Holton, *Thematic Origins of Scientific Thought: Kepler to Einstein*, 2nd ed. (Cambridge: Harvard University Press, 1973 [1988]), 237-277, on 254.

or “likenesses”, of the actual mechanics by which the natural world functioned. Indeed, Maxwell spoke stirringly of the mechanist’s desire to connect his physical theory to the real world; if, as according to Berkeley’s idealism, all physical phenomena could be broken down to pure motion, then using mechanical models as a guide with which to deduce the actual nature of universe was valid. As Hunt notes, the mechanists “could hope that a carefully chosen mechanical model might truly depict the nature of reality.”[2] The rationalists, on the other hand, utilized the elegant and lightweight power of mathematics. Einstein’s breaktrough presentation of special relativity needed no such model. It immediately stated his two central tenets, and quickly delved into the mathematical details. In only the third paragraph of “Electrodynamics”, Einstein writes off the need for a lumineferous aether simply because his theory simply makes one superfluous.[3] Mathematical intuition trumped mechanism - no strange contraptions were necessary to convey the elegance and intuitive validity of the idea. This power of mathematical expression was already beginning to be known at the time in Maxwell’s formulations of his theory of electricty and magnetism: the great machinist Heaviside was “usually content to simply to use Maxwell’s equations.”[4] Gradually, mathematics was adopted as the language and lifeblood of physics.

Finally, there was, in the classical physicist, an almost a desperate desire to place physics in the context of tangible human experience. In Einstein’s words, Mach and the rest of the empiricists “more or less believed science to consist of a mere ordering of empirical material”.[5] Mach was concerned with the measure of time, distance, and weight, and the extrapolation thereof to a natural law in accordance with what felt natural to human bodies. A theory was especially excellent if it could be *felt*: that a physicist could visualize a gas as a mass

[2]Bruce J. Hunt, *The Maxwellians* (Ithaca: Cornell University Press, 1991), 76

[3]Albert Einsten, “On the electrodynamics of moving bodies”, translated and reprinted by Arthur I. Miller, *Albert Einstein’s Special Theory of Relativity: Emergence (1905) and Early Interpretation (1905-1911)* (Reading: Addison-Wesley, 1981), 392

[4]Hunt, *Maxwellians*, 103

[5]Holton, “Mach, Einstein”, 249

of colliding particles was paramount. The rationalist, on the other hand, was able to escape this parasitic connection to a hard, empirically measured, deterministic world. Relativity theory, the crown jewel of rationalist thought, completely left behind the antiquated notions of an absolute temporal and physical reference frame. In his 1873 *Treatise on Electrity and Magnetism*, Maxwell takes care to provide a list of references to the strong expiremental and historical basis of his theory, and at one point even gently implores the reader to investigate the solid collection of data available to validate his work.[6] Thirty-two years later in "Electrodynamics", Einstein does no such thing; he is happy to make claims that, while still expecting experimental confirmation, have no empirical basis. Fellow rationalist Planck echoed this separation of the world of reality from the world of experience. He sought "the complete liberation of the physical picture from the individuality of separate intellects."[7] This ability to abandon old principles and make huge intuitive leaps, was one that would later reward the new generation of physicists with the prize of quantum mechanics.

The classical physicists had done much for the field: everything between Newton's formulation of a rigorous series of laws of mechanics and Maxwell's and Faraday's publication of a full-fledged theory of electricity and magnetism was their achievement. But just as the Victorian Period in England was later replaced and rebuilt, so was the legacy of the classicists. They were crippled by an insistence on empiricism, a distaste of pure, contextless mathematics, and the desire that physical phenomena be explained in ways intuitive to human beings. As a consequence, classical physics had exhausted itself, and, striving for new ideas, was continuously coming up lacking. Reliance on instantly testable results rooted in the world familiar to human experience had made it incapable of making truly revolutionary leaps forward. It "[could not] give birth to anything living, it [could] only exterminate" the

[6] James Clerk Maxwell, *Treatise on Electricity and Magnetism*, 3rd ed (Oxford: Clarendon, 1892), vol 1, xi

[7] Holton, "Mach, Einstein", 245

"harmful vermin" of bad theories[8], and the field gave way to men who viewed rational leaps in theory as valid, relied heavily on mathematics as a formal description of physics, and were happy to throw out and rewrite all established thought to reach a purer understanding of the truth. The advent and validation of special relativity not only brought the new generation's approach to physics to the forefront, but sealed the fate of the methods of the old. Classical physics was banished to the world of faded history it was familiar with: one black and white, empirically conceived and confirmed - an ultimately lacking, crude simulacrum of the colorful truth of our own.

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[8] Holton, "Mach, Einstein", 258