How Theories Begin: Max Planck and the Genesis of Quantum Theory

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Philosophy of science has traditionally paid much attention to the multitude of processes a scientific theory goes through. How theories can be confirmed, falsified, reduced, substituted, justified, applied or communicated have been constant concerns of philosophers in the last century. These researches tend to consider theories as full- fledged, self-contained entities amenable to analysis in terms of logical relations or model concepts. Though theories are historical objects and, more importantly, are composed of parts, which are historically situated. Given this premises, it becomes obvious that the way in which scientific traditions are interpreted, rediscovered, changed, and applied by scientists to produce a scientific theory must play a role in the analysis of the epistemological problems related to science.

Lately, the issue of how a theory is created from existing traditions has started to feature prominently in philosophy of science. In a recent paper (Synthese, 162; 195-223, 2008) Olivier Darrigol has argued in favor of the “modular structure of physical theories”. Darrigol explains the unity and heterogeneity of science by claiming that theories are made of relatively stable sub-theories or theoretical units called moduli. The exportability of the moduli allows that continuity across both time and space that is so striking in the scientific development.
However, Darrigol's moduli seem to be more similar to settled textbooks chapters than to historically contingent entities. Thus, a truly historical-epistemological perspective on the construction of a scientific theory is still a desideratum. In this paper I do not have the ambition to fill this gap. I will rather confine myself to elaborate some conceptual tools that I consider useful to understand both the historical and the epistemological problems raised by science. I will do that by focusing on a well-studied episode in the story of modern physics: the path that leads from Planck's classical theory of black-body radiation to quantum theory.

The central concept I will dwell upon is the concept of 'selective adaption'. By selective adaption I mean the transfer of a conceptual resource (a model, a tool, a formal technique, an analogy, ...) from a theoretical tradition to another. In general this process involves a deep reconfiguration of the resource. First a selection is necessary because not all original aspects of the resource are usually needed to apply it to the new context. This can entail that some problems that traditionally plagued the conceptual resource are simply dismissed. Second, the adaption to the new theoretical tradition often implies a change in meaning and in function of the conceptual resource. Depending on how successful this reconfiguration is, it can lead to the epistemic isolation of the resource or rather to the emergence of some of its unexpected potentialities.

In Planck's theory we can find two relevant instances of selective adaption, both concerning conceptual resources belonging to nineteenth century statistical mechanics. Hoping to show that, contrary to the statistical view of irreversibility, heat radiation reached the equilibrium without any exceptions, Planck concentrated on a spherical cavity in which electromagnetic radiation interacted by resonance with a Hertzian oscillator placed at the center. Planck thought that the resonator would be able to cancel out the spatial differences in the distribution of the radiation intensity and thus to bring the radiation to an equilibrium state. More importantly, he believed that this process would be strictly irreversible, in the sense that the time-reversal of a solution of the problem would not satisfy the boundary conditions of the problem and thus would not be, in turn, a solution. But Planck's argument was not fully accurate.

Ludwig Boltzmann showed that such a strong notion of irreversibility could not stand: a time-reversal of the solution of an electromagnetic problem is always a solution itself.

At this point Planck's program faced a serious crisis. Planck had hoped to achieve his goal by using electromagnetism and thermodynamics only. Boltzmann's critique had destroyed this hope and now Planck had to integrate new resources to get out of the deadlock. Boltzmann's statistical mechanics provided him with the solution. Planck formulated an electromagnetic analogon of the notion of molecular chaos (hypothesis of natural radiation), which, combined with a suitable definition of electromagnetic entropy, allowed him to prove that the heat radiation tends to an equilibrium state. The adaption of resources of statistical mechanics was not without consequences, though. From the complex debate about molecular chaos in 1894-1895, Planck selected merely the aspects that were of importance for his goal and changed remarkably the role of the assumption. Whereas for Boltzmann molecular chaos was the ultimate reason to use probability theory, for Planck it became the justification to rule out entropy-decreasing processes. To achieve that Planck had to rearrange other parts of his theory. In particular, Fourier series as a representational tool for electromagnetic quantities acquired a great prominence. By means of this tool Planck could draw a line between macroscopic quantities (represented by series) and microscopic quantities (represented by the amplitudes and phases of the series). This distinction provided the conceptual space for the hypothesis of natural radiation as a bridge between micro- and macroworld.

But the reconfiguration of Planck's theory went even further. Forced to change his argument for irreversibility, Planck resorted to the concept of entropy and to an analogon of the H-theorem. The entropy function, however, was justified only by the fact that it led straightforwardly to Wien's distribution law. Thus, Planck's entire program got bound together with the fate of Wien's law, which, in 1900, was proven only approximately true. This marked the second and more famous crisis of Planck's program, which led to the adaption of Boltzmann's 1877 combinatorial procedure in radiation theory. Since this episode has been studies in details, I will confine myself to point out that the quantum hypothesis remains an unintegrated - albeit necessary - ingredient of Planc's theory. While Planck succeeded in relating some requirements of the combinatorial procedure to parts of his classical radiation theory, the quantum remained in epistemic isolation. It was only after the careful exploration of this notion by Lorentz, Einstein, Jeans, and Ehrenfest that the nonclassical potentialities of the quantum could be recognized.