Review of William Demopoulos' *On Theories: Logical Empiricism and the Methodology of Modern Physics*

William Demopoulos, *On Theories: Logical Empiricism and the Methodology of Modern Physics*, edited by Michael Friedman. Cambridge: Harvard University Press (2022), 272 pp., $39.95 (hardcover)

On Theories offers a novel account of the scientific method, a novel account, in particular, of the relation between a theory and its empirical evidence. According to Demopoulos, existing accounts, diverse as they may be, fail to explain how theories are actually anchored in experience and supported by it. This failure encourages a rather skeptical attitude toward scientific methodology. The heart of the new theory of theories proposed by Demopoulos is his notion of *theory-mediated measurement*, which provides theories with more robust epistemic grounding than that provided by existing accounts. Two case studies are analyzed in detail, the role of Perrin's experiments in establishing the reality of atoms and molecules and Bohr's understanding of how measurements performed on classical instruments and analyzed in terms of classical concepts can muster evidence for quantum phenomena.

Demopoulos does not deny that typically, scientific theories go beyond the directly observable and cannot be simply derived from it. As an offspring of the problem of induction, this shortcoming of theories has to be taken on board. It is the common response to this problem, however, that Demopoulos challenges. Rather than attending to the subtle relationships between theory and experience, he claims, the dominant views about theories center on the dichotomy between observational and nonobservational terms, letting the latter float freely, so to speak, above the former and leaving the reference of nonobservational terms and the truth of sentences invoking them indeterminate. Accepting this indeterminacy as fact, Demopoulos contends, is an overreaction to nonobservability.

One target of Demopoulos's critique is the deductive nomological model (and its close relative, the hypothetical-deductive method), according to which theories are confirmed by their empirical/observational consequences. Although, as a matter of logical fact, such consequences could be true while the theory is false, and although there could be other theories that entail the same observational sentences, it is still widely believed that the method of science consists of the confirmation of theories by successful predictions derived from them. Furthermore, when coupled with the inference to the best explanation or the no-miracle argument (both of which see the explanatory import of a theory as a truth-related virtue), successful predictions are taken to indicate the truth (or approximate truth) of the theories that yield those predictions. Demopoulos rejects these inferences: successful predictions, he contends, only establish the compatibility of a theory with experience; they cannot establish its truth or the truth of its existence claims. Theory-mediated measurement, however, can yield more than compatibility.

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Another family of positions that Demopoulos subjects to critique includes Carnap's partial-interpretation account and accounts based on Ramsey and Carnap's sentences. The reason for the inadequacy of these accounts, according to Demopoulos, is that they are all driven by an overstretched analogy between physics and mathematics. Specifically, the idea that the axioms of a mathematical theory constitute *implicit definitions* of the theory's primitive terms gives rise to the possibility of multiple interpretability of these terms. (The point is epitomized by the story of Hilbert's quip about *point*, *line*, and *plane* being replaceable with *table*, *chair*, and *beer mug*.) In the purely mathematical domain, multiple interpretability is often considered a merit, for it reveals the underlying structure common to different kinds of entities and relations. But when this account is carried over to physical theory, multiple interpretability becomes a problem. We expect physical theory to ascertain that certain unobserved entities—atoms, for instance—exist. It is disappointing to be told that all our best theory can tell us is that one of the legitimate interpretations of its terms, *atom*, is such and such a particle. And once more, the conception of theory-mediated measurement that Demopoulos champions in this book shows that science need not disappoint us; it can do a better job of pinning down the reference of its terms. Construing theories as implicit definitions has two further unwelcome implications. First, in this construal, a change of theory results in a change in meaning and, arguably, a change of reference of its terms. From here, it is just a short step to a Kuhn-like relativism and its different theories–different worlds metaphor. Worse, if our only contact with the theoretical entities of a theory (i.e., the entities its theoretical terms refer to) is via their definitions *by the theory*, are we not facing the danger of circularity or question-begging? To test the theory, it seems, we need access to the said entities independent of the theory under examination. That worry, too, is alleviated, according to Demopoulos, by the method he describes. A number of other positions are implicated by similar arguments, but we can stop here and turn to theory-mediated measurement and its advantages over the aforementioned accounts.

Theory-mediated measurement probes unobservable domains more directly than by conjecturing their existence and testing the observable consequences of this conjecture. Although Demopoulos does not actually define theory-mediated measurement, a number of salient characteristics can be extracted from his analysis. First, theory-mediated measurement does indeed require theoretical assumptions, but it in no way presupposes the theory (or its existence claims) that the measurements eventually confirm. Second, rather than assuming a dichotomy between the observable and unobservable, theory-mediated measurement explores the interface between them. When the interactions between entities belonging to the two domains are studied, the unobservable emerges as continuous with the observable, differing from it in degree of accessibility, not in essence. One can thus understand Poincaré's conversion from skepticism about the existence of molecules (before Perrin's experiments) to his declaration (after Perrin) that we can now actually *see* molecules (cited by Demopoulos on p. 88). Third, because theory-mediated measurement does not set out from the theory that is under examination but from more limited theoretical assumptions (that could be true even if the theory in its entirety is not), it becomes possible to approach the same phenomenon via different paths that depend on different and independent assumptions. If these different paths converge on the same empirical findings, this convergence is more significant in its evidential import than

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Whewell's "consilience of induction." The latter only means that the *same* conjecture is confirmed by a variety of empirical consequences, whereas the paths explored by theory-mediated measurement often differ in their theoretical starting points—which renders the convergence of the results more convincing. Moreover, when the unobservable entities are approached via such limited theoretical assumptions—as when we assume, for example, that certain parameters will not change their value when we observe gradually smaller entities—the meaning of such theoretical terms is already *given* and does not wait for an interpretation (or a multitude of interpretations). Finally, theory-mediated measurement facilitates an iterative process of improvement and approximation that is less available to competing methodologies.

These characteristics are exemplified by the analysis of Perrin's experiments and their bearing on the reception of the existence of molecules. To begin with, Demopoulos reminds us that as of the seventeenth century and certainly throughout the nineteenth century, atomic and molecular conceptions of matter were quite common. And yet, despite their explanatory import, atoms and molecules were mostly conceived as useful theoretical constructs rather than real particles. What made Perrin's experiments different, Demopoulos argues, was his careful employment of theory-mediated measurement. Thus, instead of using the molecular kinetic theory as his theoretical scaffolding, Perrin began by studying the observable granules of Brownian motion, describing their complicated trajectories and showing, for example, that their mean kinetic energy (at a certain temperature) is independent of their size, density, and the nature of the fluid in which they are suspended. He then conjectured that this would also be the mean kinetic energy of the molecules of the fluid. In contrast with the split between the observable and the unobservable, here, the visible granules and the invisible molecules make close epistemic and ontological contact. Guided by Einstein's papers on Brownian motion, Perrin continued to measure several other molecular parameters, the most important among them being Avogadro's number, on which several independent methods converged. By contrast with the hypothetical method, which mainly yielded qualitative explanations, Perrin's theory-mediated measurement produced quantitative results that could then be plugged into new equations and further refined.

The chapter on quantum mechanics is intriguing: it appears, at first, to shift the focus away from the scientific method, the method of theory-mediated measurement in particular, to a more general interpretation of quantum mechanics and its break with classical mechanics. (Indeed, the notion of theory-mediated measurement is hardly mentioned in this chapter.) It turns out, however, that the thesis of this chapter is crucial for understanding the theory–evidence relation in quantum mechanics and thus crucial for understanding its method. In a nutshell, Demopoulos is concerned with the following problem: although quantum mechanics is radically different from classical mechanics both in its formalism and its empirical predictions, the experiments and measurements that confirm the theory are anchored in a classical world. As Demopoulos explains, the disparity between the two is conspicuous when thinking of the notion of probability. Although the probability space of quantum mechanics is nonclassical (yielding, e.g., nonlocality by allowing more correlations between events than those allowed by the classical theory), classical probability theory is nonetheless required at some points in the construction and analysis of experiments. Demopoulos argues that this combination is coherent and

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shows in some detail how the classical evidential framework of quantum mechanics can confirm its nonclassical principles. His analysis of Bell's inequalities along these lines illustrates how theory-mediated measurement works in quantum mechanics as well. As a historical bonus, the argument suggests to Demopoulos a new interpretation of Bohr's much-deplored dictum regarding the necessary recourse (in quantum mechanics) to classical concepts. Classical concepts, in the proposed reading of Bohr, were not claimed by him to be indispensable in quantum theory but rather in its evidential framework.

Sadly, *On Theories* was not sent to the press by its author, who passed away before completing the concluding chapter of the book. Although there was no way to reconstruct this coda, Michael Friedman, the editor of the book, did a great service to readers by adding a foreword and an afterword that contextualize the work, both in terms of its place in the intellectual biography of Demopoulos and in terms of its broader historical and philosophical background. In the foreword, Friedman traces the history of the method of theory-mediated measurement in mechanics all the way back to Newton's methodology; in the afterword, he indicates the relevance of this methodology to our understanding of quantum mechanics as portrayed by Demopoulos. In shedding new light on the nature of the scientific method, *On Theories* constitutes a tremendous contribution to the field. It not only challenges some of the skeptical implications of the prevailing views but also invites us to take a fresh look at further historical episodes from the exciting perspective it provides.

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