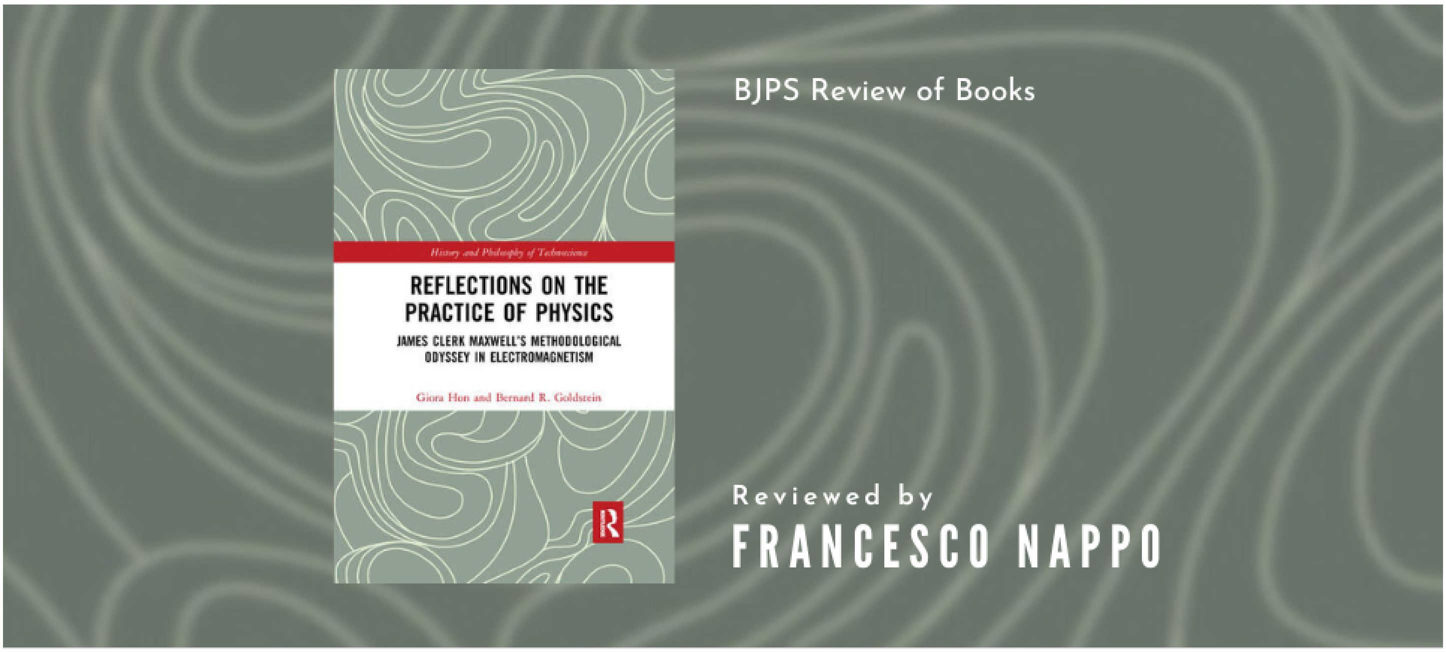

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REFLECTIONS ON THE PRACTICE OF PHYSICS

Giora Hon and Bernard R Goldstein

Reviewed by Francesco Nappo

Reflections on the Practice of Physics: James Clerk Maxwell's Methodological Odyssey in Electromagnetism
Giora Hon and Bernard R. Goldstein
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Philosophy of physics cannot be carried out considerately without a sense of the history and practice of physics. In the case of James Clerk Maxwell's scientific work, there are special reasons to pay attention. In addition to being one of the greatest and most influential physicists of all time, Maxwell regularly accompanies his papers with copious remarks on scientific methodology, epistemology, and metaphysics. This rare sensitivity to philosophical questions raised by physical research makes his texts a true 'gold mine for philosophers', as Achinstein ([1991], p. 158) once put it.

Reflections on the Practice of Physics has two admirable aims: on one hand, to contribute to a comprehensive historical understanding of Maxwell's approach to physical inquiry; on the other, to extract philosophical lessons from the story of Maxwell's astounding scientific breakthroughs. In line with an established tradition in scholarship (for example, Achinstein [1991]; Siegel [1991]; Harman [1998]), the authors defend the view that the method of 'physical analogy' that Maxwell first presented in the introductory section of his 'On Faraday's Lines of Force', and continued to invoke throughout his later physical works, was in fact many different methods. The authors deserve praise for bringing new life to the narration of Maxwell's alleged twists in methodology, merging historical and philosophical perspectives to defend it. In what follows, I will elaborate on some of the book's main strengths and weaknesses, in the spirit of pursuing a constructive critical discussion.

History

We read in the opening chapter: 'our point of departure is the scientific text, namely, the historical data of scientific discourse rather than a philosophical doctrine. We seek to remain faithful to the data as we search for the critical features of scientific methodologies' (p. 3). After an exciting second chapter on Maxwell's intellectual debt to Faraday, Chapter 3 aims at tracing the rest of the cultural background of Maxwell's methodological reflections and their audience. The authors discuss the methodological perspectives of Thomson, Stokes, and Rankine, among others, contrasting their approaches to Maxwell's. As a minor problem, I note here the omission of figures such as J. D. Forbes, Maxwell's mentor at Edinburgh. As several historians have discussed (for example, Harman [1998]), Maxwell's relation to his Scottish background is important for understanding the methodological and philosophical distinctiveness of his mature approach to scientific inquiry.

Chapters 4 to 7 defend the thesis of the 'methodological odyssey'. By extensively quoting Maxwell, the discussion has the virtue of bringing to the attention of philosophers of science passages from his electromagnetic works that have a direct bearing on contemporary issues in the epistemology of physics. However, some limitations remain. First, a thematic one: In considering the different methods that Maxwell allegedly embraced during his scientific journey, the authors bracket the evolution of his work in thermodynamics (for example, his 1860 essay, 'Illustrations of a Dynamical Theory of Gases'). This is a debatable choice to make for Maxwell ([1890b], p. 751), who was an advocate and practitioner of the 'cross-fertilization of the sciences'. As a result, the discussion is somewhat lacking with regard to the use of physical analogy in 'Illustrations of a Dynamical Theory of Gases', and the echoes and reverberations between his thermodynamic and the electromagnetic works (cf. Achinstein [1991]).

A second limitation has to do with the authors' use of the primary sources. As an illustrative example, here I will focus on their reconstruction of a central thread in Maxwell's work that runs from his 1856 paper, 'On Faraday's Lines of Forces', to his 1861–2 paper, 'On Physical Lines of Force'. Siding with a tradition that goes back to Siegel ([1991]), Hon and Goldstein perceive a stark change in the approach taken in these two papers: whereas in 'On Faraday's Lines', Maxwell had used a system of tubes containing an incompressible fluid as a mere analogy to electrical forces, in 'On Physical Lines' he boldly advanced a hypothesis about the mechanism underlying electromagnetism, namely, the theory of molecular vortices. However, unlike Siegel ([1991]), who aimed at grounding this discontinuity thesis on elements of Maxwell's physical reasoning, Hon and Goldstein argue for the existence of the discontinuity by drawing mostly from Maxwell's language.

The problem is that Maxwell's comments can often be read in multiple ways. For instance, the authors highlight this passage from 'On Physical Lines': 'I propose […] to determine what tensions in, or motions of, a medium are capable of producing the mechanical phenomena observed. If, by the same hypothesis, we can connect magnetic attraction with electromagnetic phenomena and those of induced currents, we shall have found a theory' (Maxwell [1890a], p 452). For Hon and Goldstein, the 'shift from analogy to causes' (p. 100) is made clear by his use of the words 'hypothesis' and 'producing' here. On closer inspection, however, things are not so straightforward. In fact, Maxwell's 'hypothesis' does not refer to the molecular vortices model of 'On Physical Lines' (which he is yet to introduce), but to the assumption that the condition of the imaginary medium is in a state of stress. This way of proceeding, by 'assuming certain conditions of motion' and '[tracing] out the consequences' (Maxwell [1890a], p. 156) with the help of a common model, is the method of analogy that Maxwell had advocated for in his 'On Faraday's Lines' paper. Although 'On Physical Lines' aims to devise and study a mechanical model capable of 'producing' the phenomena, the whole passage can be read as implying adherence to the approach of 'On Faraday's Lines'.

Pursuing their argument for discontinuity, the authors highlight the use of 'system' in the 'On Physical Lines' passage: 'We have now shewn in what way electro-magnetic phenomena may be imitated by an imaginary system of molecular vortices' (Maxwell [1890a], p. 451). Here is Hon and Goldstein's comment: 'the term "system" […] makes clear that the hypothesis is not, in fact, an analogy at all' (p. 101). Again, the sceptical reader will not be convinced. Among other things, the term 'system' was already used in 'On Faraday's Lines' to refer to the fluid model (Maxwell [1890a], pp. 161, 169, 187)—a model that, by Hon and Goldstein's lights, did not constitute 'a hypothesis at the micro-level that has a deductive, causal relation to the macro-level of phenomena' (p. 100). Also, the view whereby 'On Physical Lines' marks a shift from the method of analogy seems to downplay Maxwell's use of 'imitated' and 'imaginary' in the above passage. This choice of words is consistent with the idea that 'On Physical Lines' introduces a mechanically conceivable system solely as an analogy to the physics of electromagnetism. The discussion would have benefitted from considering these problems in more depth, instead of relegating dissenting voices (for example, Hesse [1974]; Nersessian [2008]) to cursory endnotes (p. 244).

Underplaying interpretative difficulties is a problem that arises again when the authors confront the well-known quotation from Maxwell's ([1956], p. 432) *Treatise on Electricity and Magnetism*: 'The attempt which I then made [in 'On Physical Lines'] to imagine a working model of this mechanism [namely, the molecular vortices model] must be taken for no more than it really is, a demonstration that mechanism may be imagined capable of producing a connexion mechanically equivalent to the actual connexion'. Based on Maxwell's use of 'working model', Hon and Goldstein comment: 'Our analysis [...] indicates that Maxwell changed his view [...] In fact, in [*Treatise*] Maxwell transformed the methodology of hypothesis, recasting it as a "working model", and then applied it retrospectively to ['On Physical Lines']' (p. 236). However, a simpler—and not necessarily more naïve—reading is that in the *Treatise* passage, Maxwell is reporting the aims of his previous electromagnetic work in 'On Physical Lines' precisely as they had been intended and pursued originally. Such a reading would be strongly favoured by those who resist thinking of Maxwell's scientific journey as merely a series of unplanned methodological twists and turns.

Arguably, the book's most valuable contributions occur when the authors go off the beaten path. Chapter 6 contains a novel analysis of the role of the 'flywheel analogy' in Maxwell's 'A Dynamical Theory of the Electromagnetic Field'—an article not treated at length by either Siegel ([1991]) or Achinstein ([1991]). In brief, Maxwell's ([1890a], p. 469) idea is to exploit the fact that two electric currents in a field interact with one another in a way that 'resembles rather the reduced momentum of a driving-point of a machine as influenced by its mechanical connexions'; for, if the analogy is correct, 'both induction of currents and electromagnetic attractions may be proved by mechanical reasoning' ([1890a], p. 471). As Hon and Goldstein correctly note, 'Maxwell showed that he did not divorce himself completely from the use of analogy' (p. 130). The chapter's only defect lies with failing to consider the possibility that Maxwell never—not even in 'On Physical Lines'—divorced himself from the use of analogy. But the idea that the method in 'On Physical Lines' was analogical is not one that the authors seem willing to entertain.

Philosophy

The concluding Chapter Eight offers philosophical reflections on Maxwell's journey through electromagnetism. In line with the preceding historical reconstruction, Hon and Goldstein praise Maxwell's alleged opportunism, that is, his attitude to modifying existing methodologies to suit the specific goals of his investigations. Readers who have not been persuaded by the 'methodological odyssey' narrative may still find in this final chapter some useful remarks concerning the necessity for the practicing physicist to develop a form of methodological awareness on top of their subject specialism. In this respect, the authors' message is important and well taken. In other ways, however, the elaboration of philosophical themes from Maxwell's works would have benefitted from some clarification and sharpening. In what follows, I will consider this weakness with regards to the treatment of one topic of philosophical attention: the role of analogy in physics.

It is controversial whether analogies between physically distinct domains function merely as heuristic tools in physics, as aids to discovery, or whether they can sometimes be the source of non-negligible inductive support to hypotheses about as yet unknown targets (see, for example, Hesse [1963]; Fraser [2019]; Norton [2021]). Maxwell's ingenious use of analogy would appear to be an excellent case study for evaluating this long-standing dispute. However, Hon and Goldstein's treatment emerges as somewhat vague and evasive. In the introduction, they distinguish between 'weak' and 'strong analogies' in Maxwell's work. Yet exactly what these terms mean, and whether they are exclusive, is never quite clear (to my knowledge, these are not expressions that Maxwell ever uses). For instance, the description that in strong analogies 'inferences drawn in one domain are applied in another' (p. 19) is clearly ambiguous between the merely heuristic and the inductive use of analogy.

If the authors intended to allow for an inductive use of 'strong' physical analogies, one would expect from them an epistemological account that addresses the question: in virtue of what sorts of facts can a 'strong' physical analogy possess an evidential role? But such an account appears to be missing from the discussion. The authors' claim that in order for something to be a 'strong analogy', it 'must maintain consistency—it is logically bound' (p. 19) is hardly sufficient. Among other things, physical analogies may 'maintain consistency' and yet fail to provide non-negligible inductive support to hypotheses about the as yet unknown. Maxwell himself noted this possibility in the introduction to 'On Faraday's Lines', while discussing the example of the analogy between refracting light and the motion of 'a particle moving through a narrow space'. While self-consistent, 'this analogy [...] extends only to the direction, and not to the velocity of motion [...] we still find it useful in the solution of certain problems, in which we employ it [...] as an artificial method' (Maxwell [1890a], p. 156).

In their concluding remarks, Hon and Goldstein seem to express reluctance to drawing a distinction between the heuristic and the inductive (p. 241). In doing so, however, they may overlook passages in Maxwell's work that suggest that a distinction is sought. Their gloss of Maxwell's 1871 paper 'On the Mathematical Classification of Physical Quantities' is that in it 'Maxwell introduced some of the mathematical techniques that he later put to use in [the *Treatise*]' (p. 165). This is puzzling, since the distinction between scalars and vectors, forces and fluxes, rotational and linear in 'On the Mathematical Classification' had already been both drawn and used in 'On Faraday's Lines' and 'On Physical Lines'. Moreover, if it is true that 'On the Mathematical Classification' aimed at introducing formal techniques to use in the *Treatise*, it is not clear why it would not introduce the Lagrangian and Hamiltonian formulations of dynamics, but only some rather elementary distinctions in statics. The authors' further discussion is unclear and evasive. A brief suggestion is made that the 'mathematical methods' introduced in 'On the Mathematical Classification' are 'more fundamental for Maxwell than the Lagrangian and the Hamiltonian' (p. 167). This is not only vague, but in unresolved tension with the authors' further claim that the Lagrangian framework allowed Maxwell to 'deduc[e] the main structure of [his] theory from purely *dynamical* considerations' (p. 168, my emphasis).

On another reading of 'On the Mathematical Classification', Maxwell's aim is not to introduce basic mathematical tools but to illustrate that (a) physical quantities emerging from the most disparate physical sciences come into stable 'mathematical classes' and (b) an epistemological distinction can be drawn between a quantity's merely 'being describable' by a mathematical class and a quantity's 'really belonging' to that class. On this view (roughly in line with Hesse [1974]; Bokulich [2015]), 'On the Mathematical Classification' serves to explicate the criterion of 'correctness' for physical analogies that Maxwell formulated in his address to the British Association for the Advancement of Science: 'The correctness of [a physical analogy]', Maxwell ([1890b], p. 219) wrote, 'depends on whether the two systems of ideas [...] are really analogous in form, or whether, in other words, the corresponding physical quantities really belong to the same mathematical class. When this condition is fulfilled, the illustration is not only convenient for teaching science [...] but the recognition of the formal analogy between the two systems of ideas leads to a knowledge of both, more profound than could be obtained by studying each system separately'.

Concluding Remarks

Reflections on the Practice of Physics addresses a theme of great relevance for historians and philosophers of science. The extensive quotations from Maxwell and his contemporaries makes it a useful reference for those who are newly approaching the topic of Maxwell's scientific methodology. On the negative side, the case provided in support of the 'methodological odyssey' narrative often seems lacking in a secure textual basis. Moreover, dissenting arguments from the secondary literature are not adequately engaged with. As a result, the authors' insistence on their narrative sometimes seems prey to precisely that 'blindness to facts and rashness in assumption' that, as Maxwell ([1980a], p. 156) contended, the inquirer of any discipline is subject to when attempting to verify their 'favourite hypothesis'. Nevertheless, it is to be hoped that the book will generate a new wave of historical and philosophical interest in the early and middle years of electromagnetic science.

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