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Studies in History and Philosophy of Modern Physics 36 (2005) 576–582

Studies in History and Philosophy of Modern Physics

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# Book review

**Katherine Brading and Elena Castellani (Eds.), *Symmetries in Physics: Philosophical Reflections*, Cambridge University Press, Cambridge, ISBN 0521821371, 2003, (pp. xii + 445, £65, US$ 100, hardback).**

Symmetry considerations stand at the core of classical and quantum physics. No modern—and few older—physical theories forgo the immense services that these considerations offer. It is therefore only natural that philosophers of physics have increasingly started to study the motivations for, as well as the technical implementations and the interpretative implications of, symmetries in fundamental physics. Apart from the extraordinary foundational interest of symmetries, they provide a vehicle to study more general philosophical issues such as the relation between the physical world and its representations and between physics and mathematics. Moreover, traditional problems in metaphysics and philosophy of science such as the nature and status of laws of nature, scientific realism, and determinism naturally arise in, and enjoy substantial fertilisation from, the context of symmetries in physics.

This volume, edited by Katherine Brading and Elena Castellani, which grew out of a workshop held at Oxford in 2001, thus fulfills the felt need to collect the current philosophical debates on different aspects of symmetries in physics. The editors declare at the outset that their intention was to offer a "format that would provide a point of entry into the subject for non-experts, including students and philosophers of science in general." (p. ix) Indeed, some of the articles are clearly accessible (and relevant!) to this wider audience. A number of articles—among them some of the most interesting contributions—, however, presuppose at least a willingness on the part of the reader to engage with more technical material. Although this may partially undermine the editors' expressed intention, they need not worry, for these articles will stir the interest of the specialist. What is more, some of the contributions present splendid and truly didactical reviews of the core issues in the subject and will therefore be of great service in advanced courses in the foundations and philosophy of physics. Please join me in more extensively exploring the collection, which is divided into four parts.

Part I concerns *continuous* symmetries and constitutes the most voluminous section of the collection. After brief selections of classic texts on the subject by Weyl and Wigner, Christopher Martin sets out to survey the role and significance of continuous symmetries in fundamental physics and to introduce the philosophical

doi:10.1016/j.shpsb.2005.05.002

issues that arise in this respect. Most prominently among the latter, he critically discusses the gauge argument, i.e. the idea of inferring the existence of an interaction field from the demand of invariance under local gauge transformations. How can it be, he asks, that gauge symmetries have a deep physical meaning when the invariance under gauge transformations as understood canonically only reflects a formal redundancy in the mathematical description of the physical phenomena at stake? Martin resolves this tension by urging that the gauge argument should be regarded as an enormously successful heuristic device, rather than as a fundamental principle of physics. Next, T.A. Ryckman follows up on Martin's brief historical remarks concerning the origin of the gauge argument in Weyl's 1918 work. He identifies Weyl's philosophical motivations as originating in the transcendental phenomenological idealism of Edmund Husserl.

Brading and Harvey Brown revisit the historical context in which Noether's theorems were formulated and offer a systematic interpretation of the theorems. In their analysis, they caution against reading physical content into these mathematical results without due diligence. The physical significance of Noether's theorems, they argue, only arises in considerations which go beyond the letter of the theorems. These considerations concern the interpretation of the theorems, i.e. their *spirit*, if you will. They are physical in nature and only *they* endow the theorems with physical significance. The proper place to search for the empirical relevance of Noether symmetries, according to Brading and Brown, is in physical requirements such as the one demanding that the equations of motion of a physical system must exhibit a certain symmetry. They explicate how the second Noether theorem shows that in theories with a local Noether symmetry, we are faced with a situation where determinism apparently fails: the Euler–Lagrange equations are not independent and their solutions can thus contain arbitrary functions of the independent variables. This issue is resumed in the contributions of John Norton, Michael Redhead, John Earman, and David Wallace. In his article, Norton discusses the problem of general covariance in the general theory of relativity, of which general covariance constitutes a local Noether symmetry. The controversy, which dominates the interpretation of general relativity to this day, turns on whether the fact that Einstein's field equations retain their form under arbitrary spacetime diffeomorphisms should be interpreted as a deep physical principle observed by Nature or merely as a mathematical truth which places no restrictions on a physical theory since any theory can be cast in a generally covariant form. Norton proposes to reconcile these views by realizing that while it is probably true that we can always express a physical theory in a generally covariant form, once we fix the formalism and its interpretation, in general relativity, but not in most other theories, we must ascribe physical significance to the formal property of general covariance.

Earman proposes to cast theories which admit an action principle in the powerful constrained Hamiltonian formalism in order to analyze gauge symmetry in the context of these theories. He, too, is concerned with (and about) the underdetermination that arises in theories with local gauge symmetries. This underdetermination results because in these cases, the initial value problem does not enjoy a unique solution. In an attempt to re-establish determinism, Earman urges to interpret all solutions for the same initial data as equivalent descriptions of the same evolution. That this resolution of the threat of indeterminism is not ad hoc is assured by switching to the constrained Hamiltonian formalism, which offers a principled and rather general path to dealing with gauge symmetries. The details of this formalism are too technical to review here, but suffice it to say that Earman's wonderful contribution is convincing in its argument that the constrained Hamiltonian formalism offers a route not only to philosophical questions regarding determinism, but also to pressing issues in the foundations of physics such as the nature of observables in general relativity and the quantization of gauge theories. Wallace, who follows next, offers, in his own words, a commentary to Earman's article. He picks up the issue of relating the failure of determinism to the presence of local gauge symmetries in both the Lagrangian and the Hamiltonian formulation of mechanics. The identification of mathematically distinct evolutions of a physical system as physically equivalent in order to restore determinism, he suggests, can be done in two different ways: either by identifying the Lagrangian configurations through which a system passes in its evolution individually, or by identifying only the entire dynamical histories whenever they are equivalent. Wallace warns that this conceptually relevant distinction is lost in standard quantizations of gauge theories. This loss, however, may turn out to be an important insight on the road to a quantum theory of gravity.

General interpretational issues are addressed by Redhead in his excellent contribution on gauge symmetry. As it offers a well organized and enjoyable general introduction to the topic, I recommend that this article be read first by those interested, but not yet fluent, in the subject. Again, the focal problem is that for a physical structure, i.e. a set of physical entities and their relations, there exist in general many isomorphisms between this structure and a corresponding mathematical structure. But again, given this ambiguity of mathematical representation, how can any conventional choice of gauge, i.e. of mathematical representation, have any physical significance? Redhead identifies three principal reactions to the problem of this mathematical "surplus structure": (i) invest at least part of the surplus structure with physical reality, i.e. postulate corresponding physical structures; (ii) seek a reformulation of the theory in terms of gauge-invariant quantities; or (iii) admit non-gauge-invariant quantities of the surplus structure and introduce additional mathematical surplus structure to turn the newly admitted quantities into gauge-invariant ones. Redhead's lessons can be illustrated by the paradigm case of the Aharonov–Bohm effect. This effect is studied in detail in the contribution of Antigone Nounou. She briefly discusses, and dismisses, the three accounts of explaining the Aharonov–Bohm effect in the extant philosophy of physics literature before she moves on to propose a fourth explanation of the effect, which she dubs "topological" for good reasons. Her proposal is based on the fibre bundle approach to treating gauge theories. While her positive contribution, the topological explanation of the Aharonov–Bohm effect, convinces in its ability to account for the non-local flavour of the effect, the somewhat hasty introduction to the fibre bundle formalism does not seem to be necessary for the development of the topological explanation as given here.

Part II deals with *discrete* symmetries, most notably of course with parity and permutation symmetry. The latter is the subject of a review article by Steven French and Dean Rickles. Permutation invariance, for French and Rickles, is the mathematical expression of the fundamental indistinguishability in an ensemble of particles restricted to fermionic and bosonic subspaces of the Hilbert space. French and Rickles address both the metaphysics of permutation invariance, as well as its theoretical and experimental status. After a prelude reminding the reader of the mathematical and physical background of permutation symmetry, they survey the most important metaphysical stances taken toward permutation invariance and individuality. Naturally, a discussion of the validity of the Principle of the Identity of Indiscernibles (PII) in the light of the indistinguishability of fermions and bosons ensues. In his contribution, Simon Saunders defends a novel reading of PII which escapes both Max Black's famous counterexample to PII—a universe consisting of nothing but two identical spheres—as well as problems concerning indistinguishability arising from quantum statistics. Saunders proposes the notion of "weak discernibility", understood as holding between otherwise indiscernible objects which satisfy an irreflexive relation. He argues that an irreflexive relation such as "standing one mile apart from" is necessary if we wish to maintain that there are *two* spheres in an otherwise empty universe. Because Black's two spheres, as well as the spherically symmetric state of two indistinguishable fermions, afford such an irreflexive relation, they are weakly discernible and hence do not violate PII properly understood. Since bosons do not bear an irreflexive relation, they still endanger PII. But Saunders dismantles them as acceptable counterexamples by insisting that they be interpreted "as the discrete measure of dynamical couplings [...] between the genuine physical objects of the theory" as opposed to being fundamental objects themselves. French and Rickles dismiss Saunders's proposal of grounding the individuality of objects in their irreflexive relations as unduly awarding ontological priority to relata at the expense of relations. For them, the whole problematic issue of individuality can be eschewed once we accept permutation invariance as offering a strong motivation for a structuralist programme where relata and relations live side by side as ontologically equal partners.

Without discussing Saunders's altered PII, Nick Huggett seeks to generalise earlier results establishing the violation of PII by fermionic and bosonic states in that the latter are indistinguishable with respect to a set of properties corresponding to observables. The generalisations studied by Huggett extend the set of properties with respect to which indistinguishability should be established to all those corresponding to Hermitian operators, and include in this set not just monadic properties and binary relations, but also properties of higher order. But the most important generalisation extends the results beyond the fermionic and bosonic sector of the Hilbert space into sectors corresponding to other kinds of quantum particles (the so-called "quarticles"). Huggett convincingly shows that the violation of the traditionally interpreted PII survives all these generalisations.

Huggett's paper is followed by a review article on handedness, parity violation, and its implications for the reality of space by Oliver Pooley. What's the difference between idealised left and right hands or, more generally, between incongruent counterparts related to each other by parity symmetry? What is it to be such a "handed" object and how can such an object be of one "handedness" rather than the other? Pooley addresses these questions and by doing so defends a view according to which incongruent counterparts are intrinsically identical. He explains their different handedness as arising from their spatial relations to one another and to other material objects. Of course, his relational account must face the challenge mounted by parity violation. John Earman (1989, ch. 7) has suggested that a relationalist cannot account for the law-like asymmetry found in parity-violating processes, while the substantivalist—for whom handedness can be grounded intrinsically—can. Pooley meets the challenge Weyl-style, by suggesting that the relationalist can maintain that the first process in the universe governed by a parity-violating law is either a typical or an atypical process depending on its (in)congruence relation to the majority of subsequent similar processes. As long as such a majority is not established, there is no fact of the matter whether the first process was typical or atypical. While such a response, Pooley admits, is sufficient for descriptive purposes, it will not be satisfactory for explanatory ones. Purely relational explanations of parity-violations can be had, but only at the price of an ineliminable non-locality in the explanations offered. In his second contribution, Huggett takes issue with Pooley's notion of enantiomorphy.

The third part of the collection, with contributions by Giovanni Jona-Lasinio, Elena Castellani, John Earman, and Margaret Morrison, concerns the topic of symmetry breaking, in particular *spontaneous* symmetry breaking. The issue of spontaneous symmetry breaking is philosophically relevant because it claims to offer an account as to why many laws of physics exhibit a high degree of symmetry, understood as invariance under the action of a group of transformations, despite the manifest asymmetry that is in general found in the states of those physical systems governed by these laws. Technically, symmetry breaking means that the symmetry group of the laws at stake is reduced to one of its subgroups in the physical states behaving according to the laws. The original symmetry of the dynamical equations acting as laws is typically preserved as a symmetry of the entire set of their solutions, i.e. of the totality of the nomically admissible physical states. Clearly, the natural philosophical reaction to this state of affairs of pervasive manifest asymmetry is to question the physicists' unabated belief not only in the methodological usefulness of symmetry considerations, but also in the ontological weight that hidden symmetries seem to command at the level of fundamental physics.

In this light, the collection is particularly meritorious in including essays on symmetry breaking and in thus fostering an important but neglected discussion in the foundations of physics. Jona-Lasinio offers the first-hand account of how ideas of symmetry breaking from condensed matter physics were introduced in theoretical particle physics. Unfortunately, the account is far too brief and will only be helpful to readers who are already familiar with the topic. In her review article on symmetry breaking, Castellani asks questions as to why and how symmetries break and seeks to understand what the consequences of such breaking are. She explains the now-standard group-theoretic approach to symmetry breaking, Curie's principle, the distinctions between symmetries exhibited by the physical laws versus those exhibited by physical states and between explicit and spontaneous symmetry breaking, and works her way up to a brief discussion of Goldstone bosons and the Higgs mechanism. Her well-organised article manages to provide a very useful map to novices of symmetry breaking. Earman, who offers another deserving though decidedly more technical guide to symmetry breaking, argues that the algebraic approach to quantum field theory helps to understand and resolve puzzles concerning symmetry breaking which are notoriously difficult to tackle in the standard formulation of quantum field theory. In her overly conversational contribution, Morrison studies the issue of whether symmetries of the laws can justifiably be interpreted in a realistic manner despite their being hidden in the sense of not appearing in the physical states compliant with the laws. She claims that although symmetry breaking in quantum field theory has led to partial empirical success, some of the assumptions concerning the vacuum state are not independently testable and should thus not be invested with a realistic interpretation. In sum, part III surveys an increasingly important issue in foundations of physics and features two invaluable guides to symmetry breaking, those by Castellani and Earman. Their usefulness to the neophyte could only have been increased if they would have been given more space in order to more fully reap their rich philosophical harvest.

The last part of the book, which due to its stage-setting character should in my opinion have been the first, is devoted to general interpretative issues regarding symmetries in physical theories. It comprises excerpts from Wigner's (1967) classic *Symmetries and Reflections* as well as contributions from Jenann Ismael and Bas van Fraassen, Gordon Belot, Peter Kosso, and Elena Castellani. The tone of the section, with the exception of Belot's article, is decidedly more reflective and less technical than in the rest of the book. Ismael and van Fraassen set out to explicate how symmetries can serve as means to identifying what they call "superfluous theoretical structure".[1] They argue for the general philosophical lesson that symmetries in physics can indeed point to superfluous structure and that pertinent considerations are typically motivated by an ideal of formal simplicity rather than by philosophical predilections or physical intuitions. Unfortunately, some of the core notions relevant for their argument are not sufficiently well worked out; e.g. it remains unclear why under some (unspecified) conditions a world can undergo qualitative changes and still remain one and the same world while under other circumstances two worlds must be considered different although the only difference between them are *potential* qualitative differences which would only be actualised under suitable qualitative changes of the two worlds. Because the individuation of worlds is of paramount importance for their argument, I found it rather difficult to follow the details of the latter.

In his more technical paper, Belot offers notes which attempt to describe a common symmetry argument and illustrate it with five examples drawn from the history of physics and cosmology. The historic episodes alone make the article worth

[1] Redhead's related notion of "surplus structure" strikes me as more fortunate, because this extra-structure serves important theoretical purposes—despite the fact that it is generally thought to carry no ontological weight. It is therefore far from being "superfluous".

reading, although I wished Belot had given a more extensive account of them. In the second part of the paper, he convincingly shows how the mathematical technique of "quotienting" serves to eliminate symmetries from a theoretical structure. Belot encourages philosophers of physics to study and exploit this technique as it offers a unifying perspective on a number of issues in the field: identical particles in quantum theory, the nature of gauge freedom in general and general covariance in particular, to name just two. Next, Kosso considers the connections between symmetry on the one hand and objectivity and design on the other. While he detects a close link between symmetry and objectivity, he denies a similar connection for design. In fact, he argues, design is more conducive to symmetry breaking and thus to asymmetry rather than to symmetry. In the last article of the collection, Castellani explores how the presence of symmetries in physical theories leads to the subsumption of entities into equivalence classes carved out by the symmetry relation. In the standard interpretation of symmetries in physics, this points to the presence of empirically irrelevant elements in the theoretical description. On the other hand, equivalence classes of indistinguishable entities give rise to the freedom to choose any element of a particular equivalence class as its representative. On the last few pages of the volume, Castellani gives a masterly discussion of gauge freedom and its relation to constraints in the Hamiltonian formalism.

In sum, despite the few reservations I had here and there, I can warmly recommend this excellent collection for which the editors have assembled an impressive all-star crew of contributors. Congratulations for a job well done!

## References

Earman, J. (1989). *World enough and space-time: Absolute versus relational theories of space and time*. Cambridge, MA: MIT Press.

Wigner, E. P. (1967). *Symmetries and reflections*. Bloomington, IN: Indiana University Press.

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