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**Brigitte Falkenburg (Ed.), Between rationalism and empiricism. Selected Papers in the Philosophy of Physics; Erhard Scheibe, Springer, Berlin, ISBN 0-387-98520-4, 2001 (627pp. Euro 88.76).**

This book contains a representative selection of Erhard Scheibe's writings on the philosophy of physics. It encompasses eight sections, with 38 papers, distributed as follows: (I) Between Rationalism and Empiricism (five papers from 1969 to 1994); (II) The Philosophy of the Physicists (five papers from 1988 to 1995); (III) Reconstruction (four papers, from 1979 to 1988); (IV) Laws of Nature (five papers, from 1989 to 1998); (V) Reduction (five papers from 1973 to 1995); (VI) Foundations of Quantum Mechanics (six papers from 1985 to 1993); (VII) Spacetime, Invariance, Covariance (four papers from 1982 to 1994), and (VIII) Mathematics and Physics (four papers from 1977 to 1997).

The subjects go from general philosophy (such as "Remarks on the concept of cause", in Section I) to more technical (although philosophically oriented) developments, such as "Three remarks concerning Bell's inequality" (Section VI). In this review we cannot do justice to this really wide range of subjects, so we choose to treat some of the author's views that are related to our own recent work. Thus, we shall focus on the structure of physical theories and on some connected topics.

The goal of the discussion of the structure of physical theories lies in what Scheibe calls *reconstructionism* (cf. pp. 157–159). "Reconstructionism is a methodology of logical empiricism according to which in epistemology and philosophy of science 'one should not describe the real process of obtaining knowledge in its concrete constitution but rather give a rational reconstruction of its formal structure' ", says Scheibe quoting Carnap. So, the aim is to translate scientific texts into "a logically impeccable language" aiming at clarity and precision. This methodology was criticized in the 1960s mainly for its "lack of real life in the reconstructions" (p. 157), which made the theories, as observed by Kuhn, unrecognizable as science (p. 157).

Scheibe defends reconstructionism in physics against its opponents (mainly Kuhn and Feyerabend); according to Kuhn and Feyerabend, reconstructionism in physics fails to accommodate the actual development of scientific theories. The price to be paid is that without reconstruction one doesn't have a determined formal framework in terms of which scientific practice is to be understood. Scheibe tries to provide a middle ground between these two extremes, articulating a formal framework that is still sensitive to the historical development of scientific theories. Reconstructionism becomes a relative enterprise, depending on the particular reconstruction that is chosen, which makes a particular subject or piece of science assume "such and such shape" (p. 157). In Scheibe's opinion, there is no foundation for the criticism which says that the use of logic, e.g., which is the most important tool in the reconstruction of theories, would keep the resulting reconstruction far from true science. Scheibe admits that historical research and logical analysis may diverge and, as we cannot accuse historians dealing with a particular subject of not having paid attention to formal details, we also should not accuse logicians of not considering detailed historical aspects in their "logical reconstruction". However, "logic is itself a historical subject and not isolated from science, mathematics and their history" (p. 158). Scheibe's own formal approach to the philosophy of physics shows his acquaintance with the technical subjects, as well as argues its historical and philosophical perspectives.

Having argued that reconstruction does not necessarily entail isolation from historical aspects of science, Scheibe insists that it has an important role in preparing the grounds for investigations of intertheoretic relations which play a central role in the development of physics. So, in the paper III-11, "On the structure of physical theories", he analyses the elaboration of an adequate concept of a physical theory. According to him, physical theories are to be reconstructed as structures in the sense of Bourbaki (1968, Chapter 4). In this respect, Scheibe follows Ludwig (1990), who axiomatized non-relativistic quantum mechanics as a species of structures, extended by some extra-logical concepts to cover the relations between theory and experience (in our opinion, Ludwig's fundamental work is of outstanding importance in the philosophy of science). In fact, Ludwig formulates a general view of the nature of physical theories. Since Ludwig's approach does give a good idea of the structure of theories, but since there are also rival approaches (such as those in terms of logically closed sets of sentences, classes of models, etc.), the conclusion, we believe, is that there are various legitimate and alternative conceptions of a physical theory; they capture different significant aspects of theories.

Inspired by the work of Ludwig, Scheibe insists on the approach to theories as species of structures. But, contrary to Ludwig, he does not restrict his analysis to a purely syntactical approach, typical of Bourbaki. (As it is well known, for Bourbaki to do mathematics is, roughly speaking, to write symbols on paper according to certain specified rules, described by him in his book on set theory; in principle without any commitment to semantic interpretations (Bourbaki, 1968).) Instead, Scheibe tries to show in what sense a species of structures can be viewed as a physical theory, thus relating it to "reality". His insights can be regarded as quite original and relevant for the philosophy of science. As Scheibe says, physicists know certain kinds of structures from their knowledge of mathematics, such as vector fields, groups, topological spaces and the like. The problem is to link them with physical theories. This is done, in brief, by observing that those (and others) species of structures can be recognized in the informal mathematics of physical theories. As an example, Scheibe recalls that in Newton's mechanics we find the topology of the Euclidean space as well as other species of structures. He concludes that this suggests that physical theories (like Newtonian mechanics) are themselves combinations of species of structures (a combination of structures is itself a structure).

Seeing physical theories as structures, Scheibe makes a comparison between two important and recent approaches to theories (paper III.12, "A comparison of two recent view of theories", pp. 175–194): the semantic view (termed "S-program", where the "S" reminds us of Suppes, one of the forerunners of the semantic approach to theories (Suppes, 2002)) and the syntactic view (or "L-program", the "L" coming from Ludwig). It is interesting to note that Scheibe's essential point is not generally acknowledged by philosophers of science, namely, that such a comparison can be adequately treated if "the concepts have been presented [...] in an incontestable form", that is, subjected to a rigorous mathematical presentation (p. 159). In other words, in comparing the two approaches and in showing that they are equivalent (and Sneed and Stegmüller's "structuralism" also enters in the discussion, being subsumed under the "S"-program), Scheibe makes use of metatheoretical argumentation, as it should be, but his arguments also satisfy the standard levels of rigor usually found in logic and mathematics. From all of this, we learn that a purely informal philosophical discussion of the structure of physical theories is philosophically sterile since the involved concepts are not put within an adequate mathematical framework. This is an important feature of Scheibe's way of doing philosophy of science: he provides us with the necessary technical tools in logic, mathematics and science for the understanding of the problems, a clear signal of a good philosophy.

In a first approximation, we may find in a physical theory at least three main aspects (paper III.11, pp. 160–174):

(i) its mathematical structure,
(ii) its physical interpretation, and
(iii) its intended and actual applications.

A physical theory is not only a mathematical structure, for "a physical theory that deserves its name has empirical implications that simply transcend the possibilities of pure mathematics'' (p. 161). In fact, the use of terms like ''particle'', ''field'', ''space'', etc., already indicate this. The analysis of the connections between the mathematical structures that underly physical theories and the use of physical terms is ''perhaps the most difficult part in an attempt to give an adequate reconstruction of the nature of physical theories'' (p. 161). It is important to point out that Scheibe's use of the term ''physical interpretation'' does not yet include the actual or possible *referents* of a theory, but is confined to whatever is necessary to make contact with the intended referents by physical means, e.g., by measuring instruments (p. 161). Furthermore, according to Scheibe, there is no uniform use of the term ''theory'' clearly distinguishing (i)–(iii); he argues, for example, that in Kepler's theory, perhaps the three aspects can be detected, including well-defined referents. In Newton's gravitational theory, ''the first two aspects ... come to mind'' (p. 161), while the presentations of general quantum theory are restricted to (i).

Concerning aspect (i) above, which is Scheibe's main target, and which constitutes the logical part of the program of reconstruction, it is important to recall that for him mathematics is *the* science of abstract structures. Scheibe then turns to the question of how we can know which kind of mathematical structures can be used to characterize the physical theories as such (p. 162). The problem may be summarized as follows (cf. pp. 162–163):

(a) given a particular physical theory, like non-relativistic quantum theory of the hydrogen atom or classical Hamiltonian mechanics, can we point out a kind of mathematical structures and claim that it is characteristic for the given theory in the sense that a different physical theory would have another kind of species of structures not equivalent to the first? In other words, can a physical theory be distinguished from another one by means of certain kind of (species of) structures, which would be ''typical'' of that physical theory?
(b) are there one or more kinds of mathematical structures characteristic of a physical theory (in the sense of question (a)) that are responsible for the underlying physical theory to be a theory at all?

The way to answer these questions, the author says, is to be found in the analysis of the mathematical structures that underly physical theories; he regards the task of answering them quite difficult, for none of the most frequently found structures in standard books are able to individualize a physical theory in the sense of (a) (cf. p. 163). For instance, groups (or other common structures) cannot be used to distinguish between classical mechanics and quantum mechanics, but, as he writes, there are reasons to suppose that other kinds of structures do solve the problem, which requires combinations of species of structures under which the standard ones are subsumed. Here is where the concept of set-theoretical predicate is relevant. This concept was introduced by Suppes and collaborators (Scheibe also mentions the structuralist approach of Sneed and Stegmüller as achieving similar results). This methodological stance is claimed by the author to be equivalent to that used by Ludwig and himself.

Scheibe thinks that the set-theoretic approach and the approach via (formal) species of structures are equivalent, when he affirms that both concepts "are set-theoretical versions of the concept of an axiomatized theory" (p. 163); while the Suppesian approach uses informal set theory, the other uses the concept of a formalized theory. We think that there are at least two points to note here. The first is that although Suppes has written that his approach makes use of informal set theory, it is clear that, if necessary, he could make explicit the formal details, by making explicit the underlying formal set theory, for instance Zermelo–Fraenkel set theory (ZF). But we should recall that this is precisely what Suppes wishes to avoid. The second point is that the identification between set-theoretical predicates and species of structures is not immediate. Actually, there are qualifications to be made, which we cannot discuss here; a detailed comparison may be found in da Costa and Chuaqui (1988). Anyway, once the details are spelled out (which are technical and not too important for the philosophical approach), the equivalence works quite well. Just to give the reader an idea, an important detail is that a set-theoretical predicate is just a formula of the language of set theory, but it is easy to show that not all formulas define species of structures (da Costa & Chuaqui, 1988). In addition, the axioms of a species of structures are supposed to be transportable (in the sense of Bourbaki (1968)), which is not generally true for Suppes predicates. However, we believe that any significant Suppes predicate can be translated into an appropriate combination of species of structures (this condition, maybe, could be taken as the characteristic trait of the former notion).

It is important to emphasize that Scheibe argues that in physics the concept of species of structures, formulated in adequate extensions via definitions of ZF, is not restricted to a purely syntactic concept, as in Bourbaki's approach. Scheibe insists on the relevance of a semantic counterpart of physical theories (see paper III.11; some minor inaccuracies should be corrected here. For example, the use of the word "model" is not satisfactory, since it is not clear what the author understands by a model of Zermelo–Fraenkel set theory—cf. p. 164).

Scheibe's strong commitment to the importance of the mathematical counterpart of a physical theory suggests that we should look at his subtle analysis of the richness of the mathematical structures used in physics, structures that, according to some authors, give raise to mathematical ontological commitments which sometimes may seem foreign to the physical theories they serve to formulate. Briefly speaking, we can pose the question as follows: "to what extent have we took our theories so rich in mathematical aspects that the resulting mathematical ontology is stronger than what is needed to formulate their physical content?" This is the central question of paper VIII.38, "The mathematical overdetermination of physics".

The author considers the issue of reformulating theories without using full set theory, which is linked to his conception of species of structures as the tool to axiomatize physical theories. Then he analyses the possibility of reformulating a theory to avoid the mathematical ontological commitment of its original (full set theoretical) version. An example in which numbers are eliminated in terms of certain relational statements on the concrete entities is given. Another richer example is provided by replacing coordinate formulations of Euclidean geometry by synthetic geometry using congruence and betweenness. Even so, as he says, sometimes the reformulation may still be committed to too much mathematical ontology. There are also cases where the formulation of the theory without such "surplus" mathematical structure can be achieved, but in which the resulting reformulation ends up to be so complex as to be confusing.

It could be recalled that this subject has also been treated by other authors and maybe it would be interesting to expand the scope of the discussion in order to relate to them; for instance, Redhead and Teller (1992) have also discussed "mathematical surplus structures" caused by the standard formulation of quantum mechanics in terms of Hilbert spaces. A mathematical framework apparently more adequate for expressing some physical ideas, in particular regarding quantum mechanics, was pointed out by Manin (1976); he looked for adequate axioms for treating collections of elementary particles, which due to their indistinguishability would not satisfy, say, the Zermelo–Fraenkel axioms. Dalla Chiara and Toraldo di Francia (1993) have also discussed similar questions. Anyway, it is patent that the subject is important and connected with recent discussions in the philosophy of mathematics, such as those related to the indispensability arguments (Colyvan, 2003; Field, 1980). In this respect, Scheibe's option is to follow partially Ludwig's position, "at least as it includes an honest attempt to *clarify* the role of mathematics in physics" (p. 573).

Invariance, in all fields of science, is a fundamental concept. For example, Kronecker asserted that

> The search for invariants is a beautiful, indeed the most beautiful, aim of mathematics. More than this, it is also its unique objective. Furthermore, this is yet not sufficient. It is the only task of all sciences in general.[1]

One of Scheibe's most important contributions to the philosophy of physics is related to his analysis of the notions of invariance and covariance in physics. These concepts appear constantly in this field and, in general, it is difficult to disentangle their exact meaning from their use both by philosophers and by physicists.

Since a theory is to be basically viewed as a species of structures, there are two classes of defining conditions involved in its rigorous formulation. The first class describes the structures—that is, its possible models—and are strictly set-theoretic; the second consists of the axioms characterizing the special traits of these specific structures. For Bourbaki, the axioms of a species of structures must be transportable, i.e., invariant by isomorphisms. There are several reasons to justify such restriction, and Scheibe discusses this question, presenting arguments in favor of its acceptance. In mathematics, transportability constitutes a natural condition, and it is also satisfied by all physical theories. In fact, such a condition, for him, is a proper part of the notion of physical theory. So, there is the most general principle of invariance, which is identified to the norm of transportability: if $M$ is a set-

[1]"Das Aufsuchen der Invarianten ist eine schöne, ja sogar die schönste Aufgabe der Mathematik, aber noch mehr, es ist sogar ihre einzige Aufgabe. Und auch damit ist es noch nicht genug: es ist einzig Aufgabe aller Wissenschaften überhaupt."

theoretic *model* of a theory $T$, then any other structure isomorphic to $M$ is also a *model* of $T$. So, any theory has to be invariant under isomorphisms. Several examples confirm this, for example classical quantum mechanics.

However, as Scheibe notes, there are other cases of invariance in physics. For instance, those connected not only with theories or species of structures, but dependent on their models. Covariance, then, is treated from the point of view of the interplay between models and theories: it is linked to coordinate systems, which is in agreement with Einstein's use of the term.

Nonetheless, there remain some other types of invariance not covered by Scheibe's discussion. He mentions the case of gauge invariance as an outstanding example. Scheibe's investigation of invariance is surely a basic contribution to the philosophy of physics of today.

It seems that for Scheibe classical logic and classical mathematics are the formal basis of physics. We wouldn't in fact need any other kind of logic or mathematics. However, there are reconstructions of some physical theories which are based on non-classical logic and non-classical mathematics. An instance of the application of heterodox logic in physics may be found in the field of quantum mechanics and its logic; similarly, intuitionistic logic and topos theory were recently employed in cosmology (Kalamara, 2000). Moreover, strictly speaking, general relativity is incompatible with quantum mechanics, and usually physicists employ simultaneously incompatible theories, such as in plasm theory that combines, for instance, quantization, classical mechanics and electrodynamics. Is it possible to overcome these and analogous problems by means of classical logic alone or do we need new logical systems?

It is a pity that Scheibe did not treat such topics but, of course, he could not discuss in one book all extant questions in the philosophy of physics.

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