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Erhard Scheibe

The Reduction of Physical Theories

A Contribution to the Unity of Physics
Part 1: Foundations and Elementary Theory

Translated by Brigitte Falkenburg · Gregg Jaeger

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...und in den Wäldern des Amazonenflusses wie auf dem Rücken der hohen Anden erkannte ich, wie von einem Hauche beseelt von Pol zu Pol nur ein Leben ausgegossen ist in Steinen, Planzen und Tieren und in des Menschen schwellender Brust.

Alexander von Humboldt to
Caroline von Wolzogen, May 14, 1806

To Carl Friedrich von Weizsäcker
in gratitude and adoration

Translators' Preface

Die Reduktion physikalischer Theorien is the *opus magnum* of the German philosopher of science Erhard Scheibe (1927–2010). For more than two decades, only fragments of this outstanding theory of reduction in physics were accessible in English, through a series of his articles with general considerations and case studies included in the collection *Between Rationalism and Empiricism. Selected Papers in the Philosophy of Physics* (2001). We are glad to present now the translation of the first volume of his comprehensive study *Die Reduktion physikalischer Theorien. Ein Beitrag zur Einheit der Physik. Teil I: Grundlagen und elementare Theorie* (1997). It explains the philosophical background and the logical foundations of Scheibe's theory of reduction. The second volume *Die Reduktion physikalischer Theorien. Ein Beitrag zur Einheit der Physik. Teil II: lnkommensurabilität und Grenzfallreduktion* (1999), the translation of which is also in preparation, deals with incommensurability and the reduction of the classical theories to special relativity, general relativity, and quantum mechanics.

Scheibe's approach focuses on reduction within physics, and it does so on a highly sophisticated formal level. Nevertheless, it is also relevant for a deeper understanding of reduction in general that takes scientific pluralism into account. As Scheibe himself emphasizes in the *Preface* to the present volume, the motivation to develop his approach was the question of how scientific progress may be understood in the face of Kuhn's and Feyerabend's attacks against Logical Empiricism and Critical Rationalism. Scheibe's answer was a rational reconstruction of the architectonics of physics based on a detailed analysis of the inter-theoretical relations between the laws of classical mechanics, special and general relativity, and quantum mechanics. This rational reconstruction aims, in particular, at clarifying the logical relations between classical mechanics and quantum mechanics, which in Scheibe's view is the hardest case of incommensurability. The inter-theoretical relations of physics show that reduction has many faces. There is no unique, all-encompassing concept of reduction. The case studies discussed in the book reveal that there are several stronger and weaker kinds of reductions—different kinds of exact reductions, approximate reductions, and partial reductions, which quite often also need to be successively combined in order to reduce a theory to its successor. The resulting theory of reduction is *synthetic* (rather than analytic) and *recursive*. It is open for adding new kinds of reduction, and it demonstrates that theoretical reduction has its limits already in physics—not to speak of the possibility to reduce higher-level sciences such as biology and chemistry to physics, for which the situation is expected to be much worse. In a certain sense, Scheibe's approach takes the disunity of science into account, which has been emphasized by Nancy Cartwright in particular, at the time when Scheibe developed his theory of reduction in physics. His approach, however, shows that the plurality of theories or theory fragments that coexist in the practice of physics is neither irrational nor arbitrary. It gives systematic access to the web of inter-theoretical relations that make up the architectonics of physics after the quantum revolution, due to which the unity of physics was lost.

Scheibe's theory of reduction differs in several respects from the predominant tendencies of philosophy of science in the second half of the twentieth century. Based on detailed case studies as well as the different conceptions of reduction presented by Nagel and other leading philosophers of science in the 1950s, Scheibe develops a pluralistic concept of reduction, which limits the prospects of a reductionist scientific worldview already from its basis in physics. He is able to reconcile Kuhn's insight into the incommensurability of theories with the rational reconstruction of their inter-theoretical relations. For the rational reconstruction, he chooses a semantic approach, which crucially differs from the contemporary empiricist attempts to reconstruct the architectonics of physics from its empirical basis. Scheibe's reconstruction of physics introduces physical objects in a very broad sense, from space-time points to electrons, as basic elements into set theory, taking up Zermelo's conception of individuals (*Urelemente*). And his formal tool is not naïve set theory, but Bourbaki's structuralism. This work illustrates clearly through its novel and detailed treatment of the reduction problem in physics, which has long served as the proving ground for understanding science in general, how the success or failure of future attempts to reduce theories meant to describe different physical scales or subject areas can be thoroughly assessed by taking into account the specific character of the theories under consideration.

In the translation, we have corrected all obvious errors we found in the German edition, relying on an extremely helpful error list provided by Johannes Mierau. For better reading and more clarity concerning cross-references between the chapters, we changed the equation numbers to consecutive numbering within each chapter. All footnotes are ours. We added them to explain Scheibe's approach and to indicate differences between the announcements made in Vol. I and the final contents of Vol. II. In the footnotes, we also make some handwritten comments available which we found in Scheibe's own copy of the book.

In the Appendix, we added the table of contents of Vol. II, which corresponds to Part II of the German edition published in 1999. It replaces Scheibe's original plan of the contents of Part II, as given in 1997 at the end of the German edition of the present book. In addition, we included Brigitte Falkenburg's memorial article *The Legacy of Erhard Scheibe*, which was first published in the *Journal for General Philosophy of Science* (2011), and the complete list of Erhard Scheibe's works taken from there.

We would like to thank Angela Lahee from Springer for supporting the overdue translation of this important book, Johannes Mierau for his careful proofreading of our translation, and Paul Busch for his engagement with the project in its early stages before his recent, untimely passing.

Berlin, Germany Brigitte Falkenburg
Boston, USA Gregg Jaeger
January 2022

Preface

My motive for considering the subject of this book was the ways in which T. Kuhn and P. Feyerabend attacked the philosophy of science of logical positivism and of Popper. Even then, in the early seventies, I myself still maintained a basically reductionist attitude, perhaps due to the early influence of my philosophy teacher C. F. von Weizsäcker. The idea of devoting an entire book to the subject emerged in the mid-eighties. From then on, I looked for opportunities to focus on this work. The first came in the form of a visiting professorship at the University of California at Irvine during the Winter semester of 1987. There, at the invitation of Prof. K. J. Lambert, I held lectures entitled "Explanation, Reduction, Progress". A second opportunity came through a 10-month fellowship at the Institute for Advanced Study of Berlin in 1987–1988. The relatively long period of exemption from teaching duties even gave hope that I would already be able to finish the book in Berlin. This by no means happened. Only two years later, at a colloquium held in Pittsburgh in honor of A. Grünbaum, could I present the main idea on which today's book is based. The research semester of 1990–1991, partly spent in Delhi as a guest of Prof. G. Pandit, further served the formation of its conception. But the detailed work had still to wait until my retirement.

Of those with whom I occasionally conversed, I would like in addition to gratefully mention J. Ehlers and H.-I. Schmidt. From the beginning and repeatedly until his death, my path brought me together with L. Krüger. With G. Ludwig, I had the exchange of ideas of most far-reaching scope and content on relevant issues. The latter made such a lasting impression on me because it took place not only in oral discussions, as is usual today, but also in large part through an extensive correspondence.

A special concession from Springer is that the book can be published in two parts—the first now and a second within a year. My colleague from Heidelberg, Prof. W. Beiglböck, has followed the progress of my work with continued interest and has arranged for the possibility of bringing my thoughts to a broader public.

The text of the book was written by me after my retirement—without a secretary and on a PC. I could not have done it if my sons had not introduced me to such a device and had not also had an impact on the production process itself.

To all named, my heartfelt thanks.

Hamburg, Germany Erhard Scheibe
September 1996

Introduction

Denn so laut er auch die
Unerschütterlichkeit seines
Systems proklamieren mochte,
gerade hinter seinen
bestimmtesten Versicherungen barg sich
der quälendste Zweifel. Alle Systeme
sind gefallen, sagte er zu sich selbst,
und vor jeder neuen Debatte beschlich
ihn die Vorstellung: wenn nun jetzt
dein Bau zusammenstürzte!

Fontane, Vor dem Sturm

This first part of this book is dedicated to the reduction of physical theories. Instead of 'reduction', one could also say the *explanation* of physical theories (through others). Because, even though one does not want to deny that this distinction can be made, it does not suggest itself in the context of the theory to be developed here. Since reductions of several theories to a single one are carried out as a unification of the former by the latter, the book is also a contribution to the unity of physics. Finally, it will matter that many examples of reductions which have actually occurred in the history of physics are at the same time examples of empirical progress in theory formation. "Reduction, Progress and Unity of Physics" would be another possible title for the book. But the emphasis of the presentation will be on the reductions themselves.

One knows them from science, first of all as the 'grand' reductions of entire disciplines, such as biology to physics, or better, as the *problems* of such reductions. These never actually manage to succeed. The pre-Socratic philosophers already established broadly reductionist theses when they claimed that the first principle of all existence is one or the other material, for example, water (Thales) or something more abstract, such as the 'indefinite' of Anaximander. These approaches do not seem to have progressed very far. Something else was already the case with the atomistic thesis, according to which all matter was built out of immutable atoms, the different positions and movements of which should explain the multiplicity of phenomena (including sensation!). This doctrine of atomism, going back to Leucippus, had already in Antiquity developed a certain tradition (Democritus, Epicurus, and others). Above all, it has been taken up again in modern times (Gassendi, Hobbes, and others). Incorporating the doctrine of primary and secondary qualities, it has led to the first large reduction program of the *mechanization* of the natural sciences.

The reduction to mechanical (and, a fortiori, geometrical) qualities in the sense of modern physics and chemistry could be atomistic, but it needn't be. Newton's mechanics had established such a stable and successful conceptual system that the mere mechanization of processes was already considered of sufficient explanatory power. This was in particular true for the nineteenth century when, especially in England, the explanatory success of mechanical 'models' was cherished. But the futile attempts to understand gravity as a mechanism and the successes of the field concept in electrodynamics, as well as the incompatibility of the latter with Newtonian mechanics, eventually led to abandoning the mechanistic program. Only the atomistic branch remained excluded, which, under Boltzmann's and Maxwell's hands, had partial explanatory success in describing the thermodynamics of gases. This development, however, proceeded through replacing classical mechanics by quantum mechanics. The latter made for the first time an atomic physics possible which complied with the methodological standards achieved in the meantime, making parts of chemistry, in particular, the periodic table of elements and chemical bonding, accessible for atomistic explanations. But to summarize these successes as a reduction of the whole of chemistry to physics would certainly still be a euphemism. Accordingly, the physicists who had achieved these successes preferred to speak of a 'fusion' of physics and chemistry, thereby leaving the intrinsic importance of the latter untouched.

The reduction of biology to chemistry and physics has also become a favored topic of discussion. In the middle of the previous century, scholars such as Helmholtz and E. Du Bois-Reymond explicitly established physiology as a scientific bridge from biology to physics. The Darwinian theory of descent was a physicalization of what had been a predominantly static perspective of biological species, an evolutionary way of thinking that was taking its place. In our century, molecular biology then contributed significantly to anchoring the physico-chemical conception of evolution and of the subject area of biology in general. Again, however, to summarize these results as a reduction of biology to physics and chemistry would serve to obscure the situation rather than to clarify it. As already in the case of the mechanization of physics, such a summary of the hard-won successes of molecular biology would again put at risk their scientific standards reached in between, bringing a reductionist terminology into play which has not yet been sufficiently thought through. It is far too unclear, in such unqualified reductive claims, what the reduction counterparts are here, not to mention what is to be understood by the respective reduction itself. Even the generalized analysis of phenomena—theory formation—is already a kind of reduction of phenomena to a theory. One can reduce languages to other languages, theories to other theories, and objects to other objects of which they are made up—all this flows uncontrolled in the general discussion of these reductions and even leaves what is at issue barely recognized.

One possibility for circumventing these difficulties, or at least diminishing them, consists in completely excluding for the time being the grandiose perspectives which are given by the reduction of chemistry to physics, biology to chemistry, or even psychology to physics. Indeed, it turns out that this does not mean that the issue of reduction itself goes overboard. Rather, the reduction business, provided one does not make it too restrictive, is already generating large revenues *within physics*, and its precise treatment is at least possible if physics is included in the undertaking as a certain *rational reconstruction*. These, in any case, are the two limitations that are made in this book if one still does not specifically add the third, which is that it will predominantly be about *theory reduction*, i.e., reductions that reduce theories to other theories. Together with the other two restrictions, the achievements regarding reduction will hence be substantially based on a reconstruction of the concept of physical theory. Whether, in this form, they throw a light on those great questions of the connections all sciences have with each other, and what light this would be, is a *cura posterior* which remains undiscussed in this book.

In this framework, restricted by content to physics and by method to reconstructionism, what is genuinely new that awaits the reader in this book is, on the one hand, a *theory of reduction* not yet found in the literature (or, to be more precise, a metatheory of reduction of physical theories) and, on the other hand, an especially detailed *exemplification of the reduction problem*. Theory and exemplification are indeed here to be seen independently, which in the two-part division of the work comes particularly to the fore. In Vol. I, the theory stands in the foreground and is introduced and explained through simple examples from physics. The explanation of the Galilean law of falling bodies by Newtonian gravitational theory is perhaps typical of the examples relied upon here. The exemplification given in Vol. I certainly receives at least quantitative support in the large number of examples provided, compared to what is usual in the philosophy of science. In Vol. I, however, first and foremost, a general theory of reduction is developed. Its novelty is as follows. It replaces the usual attempt to center such a theory around *one general* notion of reduction, which holds for all instances, by the approach of finding distinct kinds of reduction, which are as *specific* as possible and have no proper decomposition, and from which further reduction types are obtained by combing them (i.e., by composition). In this way, the analytic explication of a prior 'pre-scientific' concept of reduction is replaced by a synthetic (or, recursive) construction of the reduction concept based on the iteration of reductions. For this reduction concept, however, it must remain unclear for the time being what distinguishes its elementary, i.e., no longer genuinely decomposable reductions.

This is, in fact, already the whole idea on which this new theory is built. Its novelty comes primarily to the fore by its taking on a character different from that which a theory based on the usual explication method would take on (or has done, to the extent that it exists at all—see the literature mentioned in the introduction to Chap. 1). In particular, the analysis of the examples turns out to be much more productive because each example that is at all recognized as such immediately appears as one or the other elementary reduction, or as a combination of the two, whereas following the usual method, it would be identified as merely an instance of the general notion of reduction, just like any other example. In all remaining respects, the synthetic concept of reduction preferred here is constructed without prejudice to the general *guiding notion* that, in principle, a physical theory is made dispensable or needless or redundant by the very theory to which it is reduced.

Vol. II reverses the relationship of theory and example: The examples, now in the foreground, become independent, and it is no longer claimed that they still exemplify the theory put forward in Vol. I. In some cases, however, this is certainly still so, and the theoretical analysis of the new case studies is not passed over. Indeed, the notion of reduction, which is based on the theory developed in Vol. I, remains in principle *open*, as indicated, and we are hence free to extend the theory through new types of reduction. According to Vol. I, however, the reductions gained iteratively through a combination of elementary reductions are still linked by the requirement and its validation that they represent possible *empirical progress*. This demand will not be given up in Vol. II, but its specification and supporting evidence will move to the background. We will there consider the more difficult cases (see the announcement of planned chapters) which, in part, regard the questions of reducibility and empirical progress (in the usual sense) that still remain controversial to this day. These cases also became the starting point of attacks against the orthodox theories of the philosophy of science of logical empiricism and critical rationalism of the period from the 30s to the 50s. Under the common battle cry of 'incommensurability', Feyerabend and Th. Kuhn above all carried out such attacks. The notion of incommensurability was to emphasize the difficulties into which one falls in the attempt to reduce, for example, the Newtonian–Galilean space-time theory to the Einsteinian–Minkowskian, or Newtonian gravitational theory to general relativity, or classical mechanics to quantum mechanics. Such attempts suggested themselves for the following reason. Each second-mentioned, later of these theory pairs should be the *successor* of the first-mentioned, earlier theory. However, in the application to overlapping areas they didn't simply disagree, but rather an unpleasant contradiction appeared which according to the Kuhn–Feyerabend analysis should be a *semantic* incommensurability. It remains to be tested whether this analysis is the appropriate way to describe the situation, where the hardest test may be that of the relationship of quantum mechanics to its classical predecessors. The quantum field theories, in so far as they have classic predecessors (such as, for example, quantum electrodynamics has), are also included in this examination. It is certain that the orthodoxy has taken it too easily in all of these cases (and others).

The successor relationship between physical theories referred to above is perhaps the most important historical context for the description of the systematic notion of reduction used—unproblematically for the examples of Vol. I, but with some considerable difficulty for the examples in Vol. II. In addition to those already mentioned, the problematic cases also include the well-known type of *ontological reduction* (or micro-reduction). On the basis of the usual analysis, the reduction here is due to the objects of the reduced theory *consisting* of the objects of the reducing theory in some sense. So this is just half of the basic idea of the classical atomism, to which the claim adds that the analysis into components cannot continue indefinitely but must terminate after finitely many steps. One calls that of which something is made its parts, so the story ends just with the *indivisible* constituent parts of matter. The temporal relationship is, in this case, not so obviously captured because of the long and repeatedly stuck atomistic tradition. In addition, here we deal with a whole chain of reductions (according to the usual analysis), pervading a hierarchy of theories endowed with ever-changing responsibilities. This hierarchy is, according to the mentioned basic idea of this type of reduction, not usually given by the theories themselves, but through their objects. Today, it most often begins with the elementary particles and continues (depending on the degree of differentiation) through the layers of nuclei, atoms, molecules, cells, etc., up to (taking an extreme) human society. This hierarchy extends far beyond the scope of physics. It will concern us only in the physically relevant layers where, above all, (phenomenological and statistical) thermodynamics, continuum mechanics, and solid-state physics are treated. Here, too, the extent to which the accepted philosophical, reductionist notions of that layer structure of matter and of atomism are justified has to be examined here, as well as other anti-reductionist notions of wholeness and emergence.

So much for the preliminary clarification of the character of this book concerning its content. There remains a word to be said about the *rational reconstruction* of physics, which lays the grounds for the substantive reduction-theoretical explanations. Since the early days of logical empiricism, the rational reconstruction of an empirical science has been understood to be the in-depth, as it were, logically purified version of the original presentation given by the respective scientists themselves, achieved through extensive logico-conceptual analysis. In the present case, the substantive ideas could be presented if needed without a special reconstruction, but only out of necessity, since the task is to establish a relatively independent area not cultivated by the scientists themselves. The reconstruction could also be, even without necessity here, differently chosen than is actually done without endangering the reduction-theoretical content. These freedoms are already mentioned at the beginning, so that the degree of detail that is dedicated to the matter, despite everything, does not lead to overestimating the appearance and the special role of the chosen reconstruction. Experts initially vastly exaggerated the benefits of reconstructionism, and later those of different expertise exaggerated its disadvantages. These observations are made in the main text (1.3). The reader familiar with the practices of formal philosophy of science will anyway immediately notice that our reconstruction (like the reduction theory itself based upon it) is merely *sketched*. This should be stated in consolation to those with no familiarity with it.

In keeping with the main subject of the book, the reduction of physical theories, the reconstruction undertaken here concerns mainly the concept of a physical theory. It ultimately fulfills the ages-old claim that a science closed in content should be presented *more geometrico*, that is, given *axiomatically*. But, today, slightly more lies behind this requirement than at the time of its first survey and practice by Aristotle and Euclid. Today, it is required that a logical framework be given first for a complete axiomatization. As such, we choose here a standard first-order *set theory* with individuals. Admitting individuals (in the sense of Zermelo's 'Urelemente', i.e., objects that do not contain elements but nonetheless are not the empty set[1]) is convenient if one wants an approach that extends beyond mathematics. A set theory furthermore equipped with the usual axioms is stronger than any finite-type logic and has the advantage of uniformity in any desired application. However, it primarily recommends itself for coping with the usually high mathematical demands of physical theories. That is, in principle, in the propositional forms of the underlying language of physics, mathematical sets add as referents to physical quantities and urelements. A special case is widely known from model theory, in which the arguments of a propositional form generate a *structure*. The connection with physics is made by reconstructing its main object—the *physical system*—as one structure. To the structure, a proposition (form) is added which refers to the structure (i.e., the physical system). As an axiom of a particular theory, this proposition (form) has to be satisfied (among other, less central claims) by the systems which this very theory qualifies as physically possible. Examples are Maxwell's equations of electrodynamics or the Schrödinger equation of quantum mechanics.

For the use of the first volume of this two-part work lying before you, there is no further advice other than to read it through from cover to cover. To do so is still no golden road to the acquisition of the contents. But, by virtue of the systematic character of Vol. I, in particular, this is the quickest way to arrive at the goal. In Chap. 1, the problem will initially be informally explained: first, how the physicists saw it; then, from the perspective of philosophers of science; and, finally, how it shall be addressed here. In so far as historical material is also laid out in Chap. 1, it appears in most places not for the purposes of dispute, but rather to inform, at least so far as Vol. I is concerned. I consider the theory I present to be more powerful than others with which I have become acquainted (for an exception, see Ludwig 1990 and Scheibe 1987un), but I do not provide a proof of it. Regarding this, the reader must form his own opinion. The systematic treatment of the subject begins with 1.3, where the principles of the theory are presented. Chapter 2 serves entirely to explain the further applied concept of a physical theory. In Chap. 3, a theory of confirmation (for physical theories) is outlined. It is then used in Sect. 3.3 to form a, so-to-speak, degenerate concept of reduction, according to which a theory appears already reduced to another if, roughly speaking, its empirical successes are also always successes of this other theory. It is expected that *any* (genuine) reduction implies this empirical reduction, and this will always be examined. (In this respect, here, too, an adequacy condition in the sense of the Carnapian explanation method is employed.)

The next two chapter titles indicate what is probably the most important division of the elementary reductions: the exact versus the approximate. The neglect of approximate reductions (and explanations) was a major shortcoming of the early efforts of logical empiricism regarding the matter. Even the reduction of the Galilean law to Newton's gravitational theory only succeeds approximately. Exact reductions primarily play a role in compositions, but composite reductions are already approximate if only one of their components is. In all other respects, in the further

[1] Zermelo (1980). Scheibe identifies them with individuals in the sense of Field (1980, 9). See Notes 2 and 3 of Chap. 2 and Sect. 2.2.

subdivisions of Chaps. 4 and 5, we find a quite colorful landscape before us, bearing in mind that the combined reductions still do not yet appear at all there. However, they are just found most frequently in the applications: The classical formula for the mean energy of a harmonic oscillator in thermal equilibrium is (partially) traced back in Sect. 6.2 to quantum mechanics by six successive reductions of three different kinds.

In Chap. 6, the last of the first part, we leave the domain of reductions proper with the introduction of so-called partial reductions. Their introduction is partly a concession to a common practice of physics. It is a frequently found expression that, for example, classical mechanics has proven to be a limiting case of quantum mechanics and Newtonian gravitational theory as a limiting case of the Einsteinian, or the like. In fact, however, this normal textbook manner of speech will never be justified except through the demonstration of more or less special *deductions* (in a broad sense) from classical mechanics, respectively, of Newtonian theory, as such limiting cases. With our 'difficult cases', which we kept especially for Vol. II, one is even happy already having such partial results. In addition—and this is only a concession to human cognition—in the development of physics, one theory could be replaced by another and truly improved also *without* entirely reducing the former to the latter. The partial reductions still possible in this case, thus, form a natural transition to the second part dedicated to the problematic cases, which we will face there again.

Naturally, the book is written for those who have an interest in its subject: the unity of physics. It can be read by anyone who has studied physics and possesses mathematical knowledge and has a sense for logical order as well. Philosophical knowledge is not required. Although the issue is ultimately a philosophical one, and the very questions regarding the unity of knowledge reach back to the beginnings of Greek philosophy, the present contribution is, nonetheless, a less philosophical one and a much more physics-oriented instance of conceptual analysis. From the philosophical side, C. F. von Weizsäcker, in particular, has advocated the unity of physics in many works—most notably in his book *Die Einheit der Natur* (Weizsäcker 1971). Although I readily admit that the unity of knowledge is a worthy ideal to envision, I don't argue for it in this book—at least not directly and primarily. Instead, it's more about answering the question of what someone who feels himself reductionist would have to do *in concreto*, if he wanted to give his feeling general validity, and if he is ready to submit to certain now usual, but not too immodest standards of philosophy of science. There is, here, an intermediate realm between the physical and philosophical issues in the narrow sense, and just questions about reduction and explanation have their place here. In his not yet too old book *Dreams of a Final Theory*, Steven Weinberg, the currently most prominent physicist–spokesman for reductionism, expressed the view "that a knowledge of philosophy does not seem to be of use to physicists" (Weinberg 1992, 168). One can only agree. The esotericism of philosophy consists in the fact that it only brings benefits to the one that already comes to it with a philosophical question. When Weinberg then continues on "—always with the exception that the work of some philosophers helps us to avoid the errors of other philosophers", one can only hope that this help is only a minimum requirement. Weinberg himself is already within that intermediate realm where physics and philosophy merge into one each other when, with respect to the standard model of elementary particle physics, he says “and now we want to take the next step and explain the standard model [...] I do not understand how this can not seem to be an important task to anyone who is curious about why the world is the way it is [...]” (58). Can—one wonders—a philosopher do no more than help the physicist avoid the mistakes of other philosophers?

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Contents

Chapter 1
The Problem

This book raises a systematic claim. It involves the presentation of a theory of the reduction of physical theories to others. In connection therewith, it regards the questions of the theoretical progress of physics and its development towards a unity. These questions are closely bound up with the problem of reduction: A theory that can reduce or explain another theory is expected at least not to be worse and, usually, even better than its predecessor. It represents a step forward. And if we can reduce several theories to one and the same theory, we have achieved a unification of the former. Insofar as this is the case and generally newer theories explain or reduce their predecessors, it is about the development of physics and, thereby, the history of physics as well. But not in the way a historian sees it. In the foreground stands the question: What do we mean by theory reduction, what do we mean by the progress and unity of physics so that these concepts help to make broadly comprehensible the course of physics with hindsight? All historical details, the detours that physics has taken, external influences on its developments, the personalities and the interactions of eminent physicists, etc.—all of that is not considered here. Instead, the book is about the conceptual reconstruction of physical theories and inter-theoretic relations. In addition, it is systematic in the other sense that it does not reproduce the history of the concepts of reduction, progress, and unity as others have developed them (within and outside of physics) and is rather a self-contained presentation of the matter itself. The citations and allusions to other relevant work mentioned, although in total numerous, are not given for the purpose of supporting what is said in this book. They serve much more as indicators of sources and supplements to what is said.

A certain exception to this is made by the first chapter. It seems reasonable, as an introduction to an otherwise systematically laid out book, at least to point out the previous fate of the addressed issues, in order to make the tradition clear to which the further exposition belongs. Here, the peculiarity becomes immediately apparent that, historically, one has to distinguish two traditions that were only loosely connected with each other, even though they struggled with the same problem. On

E. Scheibe, *The Reduction of Physical Theories*, Fundamental Theories of Physics 207,
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the one hand, we have the efforts of physicists of understanding the progress of their science (Sect. 1.1). On the other hand, the philosophy of science of our century directed its conceptions, above all, toward physics and arrived, despite the absence of closer contact with the physicists, at somewhat similar and, in particular, similarly controversial conclusions as the physicists themselves in just the conceptual field of interest to us, that of reduction, progress, and unity (Sect. 1.2).

The truly controversial point is, in short, the question of how far we can push reductionism even within physics, not to mention such grandiose perspectives as the reduction of chemistry to physics or of biology or even psychology to chemistry and, thus, possibly also to physics. In other words, it regards the question of how unified our physics is in its present stage, at which it remains still composed of many theories and there exists no final clarity regarding their independence of or dependence on these theories. From the part of the history and philosophy of science, Kuhn and Feyerabend have drawn a gloomy picture, and their respective thoughts were anticipated by some physicists, in particular, by Bohr and Heisenberg. The following book starts from this situation and attempts to cope with it by a moderately reductionist tendency. Even an only nearly complete examination of physics with reductionist intentions would, however, be an undertaking which can only be described as a hybrid, especially if one takes into account that a large portion of the work must be paid to the question of which reduction concept and which notions of progress and unity one wishes to employ. Therefore, the only undertaking that currently makes sense is one that places the systematic development of a concept of reduction in the foreground (Sect. 1.3) and explains it through as many and varied examples as possible, which the abundance of theories of modern physics provides.

This is done in this book, and the underlying idea on which it is based is *new*, given that most of the recent larger attempts to cope with the situation created by Kuhn and Feyerabend undertaken in the philosophy of science have proven themselves not very helpful for the development of our own thoughts. As deserving as these works might be in one way or another, an engagement with them at this point is omitted (Stegmüller 1976; Krajewski 1977; Yoshida 1977; Spector 1978; Dilworth 1981; Niiniluoto 1984; Balzer et al. 1987). It is different in the case of the theory set out in (Ludwig 1990), by which the present study was strongly influenced but has, nonetheless, finally moved beyond (cf. especially the Appendix).[1]

1.1 The Physicists' Conception of Progress

The rapid and, in some respects, unusual development of physics since the mid-19$^{\text{th}}$ Century did not lead only to occasional comments of physicists about the peculiar way in which their discipline developed. Rather, one can speak of the gradual emergence

[1] Scheibe planned to add to Vol. II an appendix about Ludwig's approach, which however was finally not realized; see Table of Contents Vol. II at the end of this book. Scheibe (1982a) compares the approaches of Ludwig (1990) and Sneed (1971). In an unpublished lecture, Scheibe (1987un, Ch. VIII) explained Ludwig's approach in more detail.

of a proper tradition of thinking about the theoretical progress of physics. It can further be seen that, in this tradition, largely uninfluenced and unnoticed by philosophers, many important ideas that we recall from the recent philosophical controversy about the matter are anticipated in principle, i.e., with the degree of detail that one can reasonably expect of physicists. In this section, we will want next to provide an historical picture of this tradition (see Scheibe 1988a), which will only in outline be connected to the recent philosophical discussion.

The basic features of the concepts of progress of physics developed within the community of physicists were already expressed in mature form at the end of the last century. Even at that time—1895— *Boltzmann* made the following remarks in an obituary of Joseph Stefan (Boltzmann 1905, 94–95) (see also (Boltzmann 1979, 59–60, 123–124 and 207–208))—to begin with, I quote only the first part of the passage:

> The layman may have the idea that to the existing basic notions and basic causes of the phenomena new notions and causes are gradually added and that, in this way, our knowledge of nature undergoes a continuous development. This view, however, is erroneous, and the development of theoretical physics has always been one by leaps. In many cases, it took decades or even more than a century to articulate fully a theory such that a clear picture of a certain class of phenomena was accomplished. But, finally, new phenomena became known which were incompatible with the theory; the attempt to assimilate the former into the latter was in vain. A struggle began between the adherents of the theory and the advocates of an entirely new conception until, eventually, the latter was generally accepted.

It is fairly obvious that the course of development of theoretical physics here outlined by Boltzmann broadly resembles the more general model of scientific development which recently Thomas Kuhn (1970a) proposed again and carried out in more detail. After a phase of continuous development (Kuhn's normal science), the discipline runs into problems which it initially tries to master within the framework of the prevailing doctrine (Kuhn's crisis). Finally, however, there comes "an entirely new conception" which supersedes after some "struggle" (Kuhn's scientific revolution). It is here where, according to Boltzmann's text, the development makes a "leap."

But this is only half of Boltzmann's (and also Kuhn's) story. In the second part, Boltzmann specifies this discontinuity as follows:

> Formerly one used to say that the old view has been recognized as false. This sounds as if the new ideas were absolutely true and, on the other hand, the old (being false) had been entirely useless. Nowadays, to avoid confusion in this respect, one is content to say: The new way of ideas is a better, a more complete and a more adequate description of the facts. Thereby it is clearly expressed (1) that the earlier theory, too, had been useful because it gave an, if only partially, true picture of the facts, and (2) that the possibility is not excluded that the new theory in turn will be superseded by a more suitable one.

The discontinuous development of theoretical physics, which Boltzmann emphasized in principle, is thus explicitly mitigated here, and the remark that well-proven and reliable physical theories will never be completely wrong is one of the most repeated (and now largely unconsciously so) in the physics literature. Kuhn also put the scientific-revolution surviving and progressive elements together, but on the whole put more stress on the incommensurability of the new conception with the