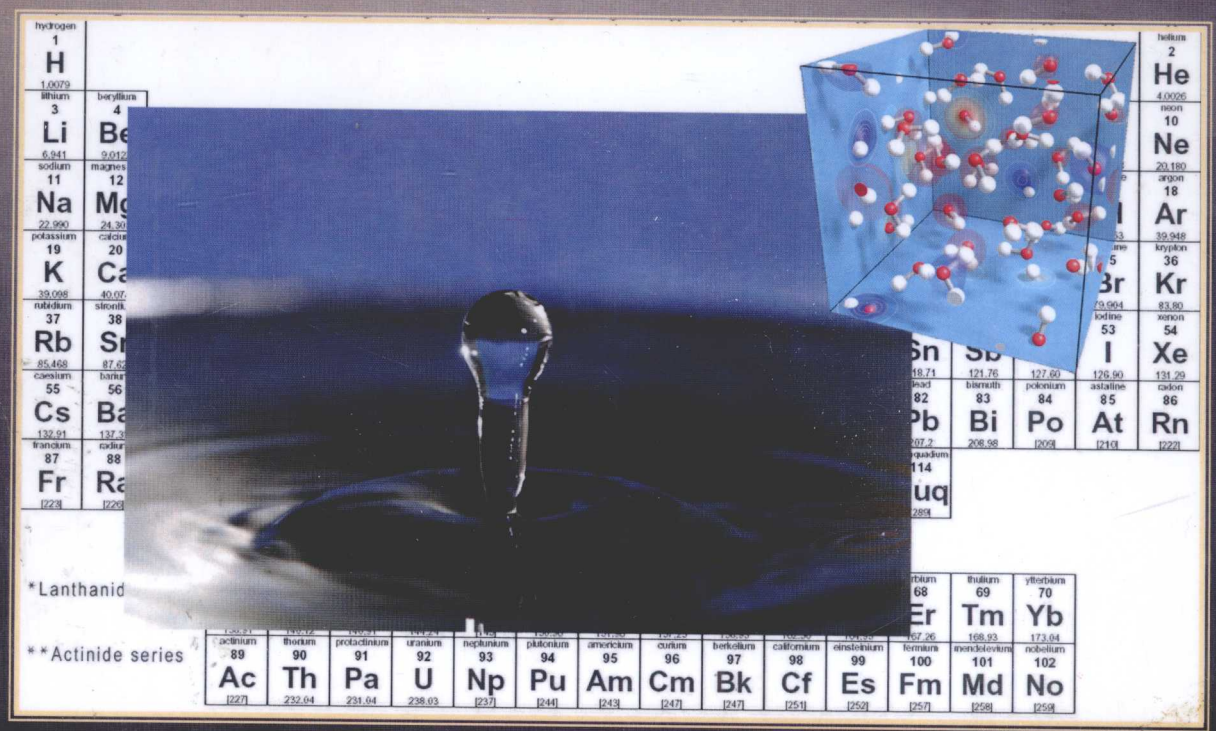
Handbook of
THE PHILOSOPHY OF SCIENCE

General Editors: DOV M. GABBAY, PAUL THAGARD, AND JOHN WOODS

PHILOSOPHY *of* CHEMISTRY



Edited by Andrea I. Woody, Robin Findlay
Hendry *and* Paul Needham

Handbook of the Philosophy of Science
Volume 6
Philosophy of Chemistry

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Philosophy of Chemistry

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GENERAL PREFACE

Dov Gabbay, Paul Thagard, and John Woods

Whenever science operates at the cutting edge of what is known, it invariably runs into philosophical issues about the nature of knowledge and reality. Scientific controversies raise such questions as the relation of theory and experiment, the nature of explanation, and the extent to which science can approximate to the truth. Within particular sciences, special concerns arise about what exists and how it can be known, for example in physics about the nature of space and time, and in psychology about the nature of consciousness. Hence the philosophy of science is an essential part of the scientific investigation of the world.

In recent decades, philosophy of science has become an increasingly central part of philosophy in general. Although there are still philosophers who think that theories of knowledge and reality can be developed by pure reflection, much current philosophical work finds it necessary and valuable to take into account relevant scientific findings. For example, the philosophy of mind is now closely tied to empirical psychology, and political theory often intersects with economics. Thus philosophy of science provides a valuable bridge between philosophical and scientific inquiry.

More and more, the philosophy of science concerns itself not just with general issues about the nature and validity of science, but especially with particular issues that arise in specific sciences. Accordingly, we have organized this Handbook into many volumes reflecting the full range of current research in the philosophy of science. We invited volume editors who are fully involved in the specific sciences, and are delighted that they have solicited contributions by scientifically-informed philosophers and (in a few cases) philosophically-informed scientists. The result is the most comprehensive review ever provided of the philosophy of science.

Here are the volumes in the Handbook:

Philosophy of Science: Focal Issues, edited by Theo Kuipers.

Philosophy of Physics, edited by Jeremy Butterfield and John Earman.

Philosophy of Biology, edited by Mohan Matthen and Christopher Stephens.

Philosophy of Mathematics, edited by Andrew Irvine.

Philosophy of Logic, edited by Dale Jacquette.

Philosophy of Chemistry, edited by Robin Hendry, Paul Needham, and Andrea Woody.

Philosophy of Statistics, edited by Prasanta S. Bandyopadhyay and Malcolm Forster.

Philosophy of Information, edited by Pieter Adriaans and Johan van Benthem.

Philosophy of Technology and Engineering Sciences, edited by Anthonie Meijers.

Philosophy of Complex Systems, edited by Cliff Hooker.

Philosophy of Ecology, edited by Bryson Brown, Kent Peacock and Kevin de Laplante.

Philosophy of Psychology and Cognitive Science, edited by Paul Thagard.

Philosophy of Economics, edited by Uskali Mäki.

Philosophy of Linguistics, edited by Ruth Kempson, Tim Fernando and Nicholas Asher.

Philosophy of Anthropology and Sociology, edited by Stephen Turner and Mark Risjord.

Philosophy of Medicine, edited by Fred Gifford.

Details about the contents and publishing schedule of the volumes can be found at http://www.elsevier.com/wps/find/bookseriesdescription.cws_ home/BS_ HPHS/ description

As general editors, we are extremely grateful to the volume editors for arranging such a distinguished array of contributors and for managing their contributions. Production of these volumes has been a huge enterprise, and our warmest thanks go to Jane Spurr and Carol Woods for putting them together. Thanks also to Lauren Schultz and Derek Coleman at Elsevier for their support and direction.

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CONTENTS

Part 1

Introduction

INTRODUCTION

Robin Findlay Hendry, Paul Needham, and Andrea I. Woody

1 WHAT IS THE PHILOSOPHY OF CHEMISTRY?

Chemistry is a scientific discipline with a particular subject matter and history of development, and these have endowed the science with a characteristic range of concepts, theories, and methods. Philosophy of chemistry is the systematic critical study of these concepts, theories, and methods, and of the inter-relations between them. This involves reflection on the ways in which they are related to, and potentially distinct from, the concepts, theories, and methods of other sciences.

Since the late eighteenth century, chemists have investigated the composition of chemical substances in terms of a growing list of elements, which constitute the building blocks of chemical composition. Yet elemental constitution is insufficient for composition, because isomers like ethanol (CH_3CH_2OH) and dimethyl ether (CH_3OCH_3) are distinct compounds that contain the same elements in the same proportions. The distinction between isomers demands a notion of chemical structure, and with the notion of structure comes the concept of the chemical bond. The chemical bond has been a central explanatory concept in chemistry for the last century. Bonds are invoked to account for the properties of substances, and the breaking and forming of bonds serve as the framework for making sense of transformation between substances. Yet serious questions remain for any satisfying metaphysics of the chemical bond. Although they are central explanatory devices within chemistry, chemical bonds are themselves explained by appeal to physical theory. Ionic bonding turns to theories of electric charge and covalent bonding turns to non-relativistic quantum mechanics. But as the essays in this volume will attest, the relationships between chemical theory and physical theory are complicated and certainly do not provide the neat reductive relation that has often been presupposed by philosophers and even many scientists. For example, it has been argued that according to quantum mechanics a molecule is not the sort of thing that has a determinate shape, let alone isolated chemical bonds. Philosophy of chemistry aims to provide robust analyses of chemical concepts and to characterize accurately the theoretical relations between chemistry and other sciences, and as a result, to challenge and refine philosophical accounts of, among others, theory reduction, emergent properties, and pluralism.

Philosophy of chemistry also includes investigations into the diverse methods of chemistry, especially those that derive from laboratory practice. The sophisticated

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methods of analytic chemistry, already evident in the precise techniques and specialized equipment of Lavoisier, have been joined in the twentieth century by powerful resources of spectroscopic instrumentation. Such reliance on sophisticated instrumentation raises a host of philosophical questions concerning the relations between data and theory in chemistry, and attendant issues concerning the role of observation and empiricism more generally. At the same time, the synthetic goals of chemistry, intertwined as they are with industrialization and Western capitalism, yield new methodological questions as chemists develop rational methods for producing new substances with specified properties, and explore automated search procedures to identify viable reaction pathways for chemical synthesis. Philosophy of chemistry encompasses all such issues. This volume presents significant work to date, but much more remains to be done.

2 HISTORY OF THE PHILOSOPHY OF CHEMISTRY

Philosophy of chemistry is a relatively new subdiscipline within contemporary philosophy of science. It lacks the long history and depth that characterizes twentieth-century philosophy of physics, and falls short of the energetic development of philosophy of biology during the past few decades. Yet throughout the history of philosophy, chemical concepts and theories have appeared in the work of philosophers, both as examples and as topics of discussion in their own right, and scientists themselves have often engaged with theoretical, conceptual and methodological issues that fall within what we would now recognize as philosophy of chemistry. Consider for instance Aristotle's discussion of mixtures and mixing, Frege's metaphorical use of the notion of unsaturatedness in explanation of his distinction between concept and object, or the late 19th-century debates about the status of atomism. In contemporary philosophy there are the extended discussions of 'water' stemming from Putnam's twin earth thought experiment, and Kripke's claim that it is necessary that gold has the atomic number 79. These traditions constitute the history of the philosophy of chemistry, and we have sought to provide glimpses of this history in Section 2 of this volume.

Chapter 2.1, Jaap van Brakel's "Prehistory of the Philosophy of Chemistry," offers a summary of the history of philosophy of chemistry since Kant, alongside a critical examination of *why* chemistry has been relegated to the sidelines so frequently in recent philosophy of science. This history offers a unique vantage point from which to consider the interests and assumptions, often implicit, that underlie 20th-century philosophy's view of what science is or perhaps should be. These include the inheritance of logical positivism and empiricism, with its particular focus on theories expressed in the language of mathematics and understood as axiomatic systems, and the widespread acceptance of reductionist views of theoretical explanation. Against this background, much of chemistry disappears. Being perhaps too grounded in laboratory and experimental practice, and often practical in its aims and correspondingly pragmatic in its methods, chemical science seldom resembles an orderly top-down enterprise from fundamental theoretical principles.

Many of its central 'theories,' like molecular structure, are expressed in systems of visual representation rather than mathematical equations. Worse yet, once chemistry is 'freed' from such 'defects,' what remains can seem to the untutored eye like little more than borrowed physics. Recent work in philosophy of chemistry, as evidenced throughout this volume, brings into sharp relief the shortcomings of such a perspective. Understanding why these discussions are so recent is itself significant.

The remainder of Section 2, Chapters 2.2 to 2.15, is devoted to brief discussions of historical individuals, both chemists and philosophers, whose work is relevant for contemporary philosophy of chemistry. We could not hope for completeness: while we think that the significance of each individual included here cannot be denied, there are undoubtedly others whose contributions also merit serious attention by philosophers. This format is distinct among volumes in the Handbook series and is thus perhaps worthy of comment. As with all volumes in the Handbook series, one goal of this book is to encompass, in some appropriate manner, the significant projects within philosophy of chemistry. Given the relative scarcity of contemporary work, this goal could not be met in any reasonable way without covering the work of historical individuals, many who are scientists, some who are philosophers, and some who are clearly both. Another intended function for this volume is to encourage and support increased research within philosophy of chemistry. We hope that the historical resources in this volume are useful also in this way. Among these brief essays one can find conceptual articulations, methodological principles, and theoretical perspectives that contemporary philosophers might fruitfully mine for future work. A final reason for including the historical section is a shared belief that history of science is of central relevance to the philosophy of science, a belief based on the contemporary commitment to explore science not just in theory, or in the abstract, but also in practice and in detail. Doing so requires philosophers to be closely connected to the history and ongoing developments of particular sciences and to explore the philosophical implications of the modern multiplicity of scientific disciplines.

There is a corresponding caveat: our restriction to discussions of individuals somewhat obscures the deeply social nature of modern science. This restriction was a pragmatic one, based on practical constraints and our knowledge that (i) issues concerning the social nature of science would arise within several of the main philosophical essays in this volume, (ii) the discussions of historical individuals often mention the social contexts in which they were embedded, and (iii) social epistemology remains relatively underdeveloped within contemporary philosophy of science, making it unclear how best to offer historical resources for contemporary philosophical investigation along these lines. Nevertheless, much can be gained from research in the history of science that explores the development of cohesive research traditions, the formation and splintering of scientific disciplines, and the embedding of science in wider social and political contexts. Within chemistry, a plethora of philosophically relevant developments comes to mind: of atomism and energeticism in the nineteenth century, the interactions between chemistry and