

Cambridge University Press
0521019680 - Electron-Atom Collisions
Ian E. McCarthy and Erich Weigold
Frontmatter
[More information](#)

This book is a comprehensive introduction to electron–atom collisions, covering both theory and experiment. The interaction of electrons with atoms is the field that most deeply probes both the structure and reaction dynamics of a many-body system. The book begins with a short account of experimental techniques of cross-section measurement. It then introduces the essential quantum mechanics background needed. The following chapters cover one-electron problems (from the classic particle in a box to a relativistic electron in a central potential), the theory of atomic bound states, formal scattering theory, calculation of scattering amplitudes, spin-independent and spin-dependent scattering observables, ionisation and electron momentum spectroscopy. The connections between experimental and theoretical developments are emphasised throughout.

Graduate students and researchers in atomic, molecular, and chemical physics will find this text a valuable introduction to a subject of central importance.

Cambridge University Press
0521019680 - Electron-Atom Collisions
Ian E. McCarthy and Erich Weigold
Frontmatter
[More information](#)

**Cambridge Monographs on Atomic, Molecular,
and Chemical Physics 5**

General editors: A. Dalgarno, P. L. Knight, F. H. Read, R. N. Zare

ELECTRON-ATOM COLLISIONS

Cambridge University Press
0521019680 - Electron-Atom Collisions
Ian E. McCarthy and Erich Weigold
Frontmatter
[More information](#)

*Cambridge Monographs on
Atomic, Molecular, and Chemical Physics*

1. R. Schinke: *Photodissociation Dynamics*
2. L. Frommhold: *Collision-induced Absorption in Gases*
3. T. F. Gallagher: *Rydberg Atoms*
4. M. Anzinsh and R. Ferber: *Optical Polarization of Molecules*
5. I. E. McCarthy and E. Weigold: *Electron-atom Collisions*

Cambridge University Press
0521019680 - Electron-Atom Collisions
Ian E. McCarthy and Erich Weigold
Frontmatter
[More information](#)

ELECTRON-ATOM COLLISIONS

IAN E. McCARTHY

The Flinders University of South Australia

ERICH WEIGOLD

Australian National University



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
0521019680 - Electron-Atom Collisions
Ian E. McCarthy and Erich Weigold
Frontmatter
[More information](#)

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521413596

© Cambridge University Press 1995

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 1995
This digitally printed first paperback version 2005

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data

McCarthy, I. E. (Ian Ellery), 1930–
Electron–atom collisions / Ian E. McCarthy, Erich Weigold.
p. cm. – (Cambridge monographs on atomic, molecular, and
chemical physics; 5)

Includes bibliographical references.

ISBN 0 521 41359 1

1. Electron–atom collisions. I. Weigold, Erich. II. Title.
III Series.

QC793.5.E628M3 1995

539.7'57 – dc20 94-16810 CIP

ISBN-13 978-0-521-41359-6 hardback

ISBN-10 0-521-41359-1 hardback

ISBN-13 978-0-521-01968-2 paperback

ISBN-10 0-521-01968-0 paperback

Contents

	<i>Preface</i>	xi
1	Introduction	1
2	Experimental techniques for cross-section measurements	4
2.1	Concept of cross sections	5
2.2	Measurement of total and integral cross sections	8
2.3	Measurement of differential cross sections	14
2.4	Ionisation	22
2.5	Polarised electrons	32
2.6	Polarised atom sources	39
2.7	Electron–photon correlation experiments	45
3	Background quantum mechanics in the atomic context	50
3.1	Basic mathematical constructions	50
3.2	Physical interpretation	58
3.3	Angular momentum	61
3.4	The Pauli exclusion principle	71
3.5	The Dirac equation	77
4	One-electron problems	81
4.1	Particle in a cubic box	81
4.2	The Schrödinger equation for a local, central potential	82
4.3	Bound states in a local, central potential	82
4.4	Potential scattering	87
4.5	Integral equations for scattering	98
4.6	Resonances	104
4.7	Relativistic electron in a local, central potential	111

viii	<i>Contents</i>	
5	Theory of atomic bound states	115
5.1	The Hartree–Fock problem	116
5.2	Numerically-specified orbitals	120
5.3	Analytic orbitals	123
5.4	Frozen-core Hartree–Fock calculations	125
5.5	Multiconfiguration Hartree–Fock	126
5.6	Configuration interaction	128
5.7	Perturbation theory	133
5.8	Comparison with spectroscopic data	135
6	Formal scattering theory	139
6.1	Formulation of the problem	139
6.2	Box-normalised wave-packet states	142
6.3	Integral equation for the box-normalised collision state	143
6.4	The physical limiting procedure : normalisation	144
6.5	Transition rate and differential cross section	145
6.6	The optical theorem	146
6.7	Differential cross section for scattering	147
6.8	Differential cross section for ionisation	148
6.9	The continuum limit : Lippmann–Schwinger equation	149
6.10	The distorted-wave transformation	152
7	Calculation of scattering amplitudes	156
7.1	Antisymmetrisation	157
7.2	Reduced Lippmann–Schwinger equations	164
7.3	Potential matrix elements	168
7.4	The complete set of target states	178
7.5	The optical potential	179
7.6	Alternative methods for restricted energy ranges	190
8	Spin-independent scattering observables	199
8.1	Collisional alignment and orientation	200
8.2	Hydrogen	212
8.3	Sodium	225
8.4	Two-electron atoms	230
9	Spin-dependent scattering observables	235
9.1	Origin of spin-dependent effects	236
9.2	Combined effects of several polarisation mechanisms	241
9.3	One-electron atoms	247
9.4	Closed-shell atoms	252

<i>Contents</i>		ix
10	Ionisation	261
10.1	Formulation of the three-body ionisation problem	263
10.2	Inner-shell ionisation	274
10.3	Ionisation near threshold	275
10.4	Excitation of autoionising resonances	279
10.5	Integrated cross sections	283
10.6	Total ionisation asymmetry	288
11	Electron momentum spectroscopy	289
11.1	Basic theory	289
11.2	Examples of structure information	300
11.3	Excited and oriented target states	307
	<i>References</i>	310
	<i>Index</i>	321

Preface

The advancement of knowledge of electron–atom collisions depends on an iterative interaction of experiment and theory. Experimentalists need an understanding of theory at the level that will enable them to design experiments that contribute to the overall understanding of the subject. They must also be able to distinguish critically between approximations. Theorists need to know what is likely to be experimentally possible and how to assess the accuracy of experimental techniques and the assumptions behind them. We have aimed to give this understanding to students who have completed a program of undergraduate laboratory, mechanics, electromagnetic theory and quantum mechanics courses.

Furthermore we have attempted to give experimentalists sufficient detail to enable them to set up a significant experiment. With the development of position-sensitive detectors, high-resolution analysers and monochromators, fast-pulse techniques, tuneable high-resolution lasers, and sources of polarised electrons and atoms, experimental techniques have made enormous advances in recent years. They have become sophisticated and flexible allowing complete measurements to be made. Therefore particular emphasis is given to experiments in which the kinematics is completely determined. When more than one particle is emitted in the collision process, such measurements involve coincidence techniques. These are discussed in detail for electron–electron and electron–photon detection in the final state. The production of polarised beams of electrons and atoms is also discussed, since such beams are needed for studying spin-dependent scattering parameters. Overall our aim is to give a sufficient understanding of these techniques to enable the motivated reader to design and set up suitable experiments.

Theorists have been given enough detail to set up a calculation that can be expected to give a realistic description of an experiment. For scattering this level of detail is only given for methods that take into account the whole space of reaction channels, which is necessary in general to describe

experiments. These are mainly the recently-developed momentum-space methods, based on the solution of coupled integral equations, which have given an excellent account of experiments in a sufficient variety of cases to support the belief that they are generally valid and computationally feasible. Calculations of ionisation have not in general reached this stage of development, although kinematic regions are known where reactions are fully understood within experimental error. These reactions are extremely sensitive to the details of atomic structure and constitute a structure probe of unprecedented scope and sensitivity.

While reactions are the subject of the book, an essential ingredient in their understanding is the calculation of atomic structure. There is a chapter describing many-body structure methods and how to obtain the results in a form suitable for input to reaction calculations. This aims at an understanding of the methods without giving sufficient detail to set up calculations.

There is a chapter summarising background quantum mechanics from the undergraduate level and developing aspects such as angular momentum, second quantisation and relativistic techniques that are not normally taught at that level.

For certain mathematical functions and operations it is necessary for the physicist to know their context, definition and mathematical properties, which we treat in the book. He does not need to know how to calculate them or to control their calculation. Numerical values of functions such as $\sin x$ have traditionally been taken from table books or slide rules. Modern computational facilities have enabled us to extend this concept, for example, to Coulomb functions, associated Legendre polynomials, Clebsch–Gordan and related coefficients, matrix inversion and diagonalisation and Gaussian quadratures. The subroutine library has replaced the table book. We give references to suitable library subroutines.

We would like to acknowledge the help of Dmitry Fursa, Jim Mitroy and Andris Stelbovics in reading and criticising parts of the manuscript, Igor Bray and Yiajun Zhou for special calculations, and particularly Win Inskip for her patience, good humour and expertise in typing.

Ian McCarthy
Erich Weigold