

Cambridge University Press
0521019966 - Oscillations in Finite Quantum Systems
G. F. Bertsch and R. A. Broglia
Frontmatter
[More information](#)

This book surveys the physics of small clusters of particles undergoing vibrations, with applications in nuclear physics and the physics of atomic clusters.

The book begins with a survey of the experimental information on collective vibrations in atoms, metal clusters and nuclei. Next, the book goes on to develop theoretical tools to understand these findings. Special emphasis is placed on the Rayleigh-Ritz principle, the use of sum rules, and the quantum mechanics of mean field theory, known as “RPA”. The important vibrational modes observed in the different systems are then discussed, including the dipole mode of oscillation (important in both nuclei and metal clusters), surface modes of higher multipolarities, and the compressional mode. In the last two chapters mechanisms for the damping of vibrational modes and the effects of excitation energy on the modes are described.

This book will be of interest to experimentalists and theorists studying finite quantum systems in nuclear physics, atomic physics or physical chemistry.

Cambridge University Press
0521019966 - Oscillations in Finite Quantum Systems
G. F. Bertsch and R. A. Broglia
Frontmatter
[More information](#)

CAMBRIDGE MONOGRAPHS ON
MATHEMATICAL PHYSICS

General Editors: P. V. Landshoff, D. R. Nelson, D. W. Sciama, S. Weinberg

OSCILLATIONS IN FINITE
QUANTUM SYSTEMS

Cambridge University Press
 0521019966 - Oscillations in Finite Quantum Systems
 G. F. Bertsch and R. A. Broglia
 Frontmatter
[More information](#)

Cambridge Monographs on Mathematical Physics

- A. M. Anile *Relativistic Fluids and Magneto-Fluids*
 J. Bernstein *Kinetic Theory in the Early Universe*
 G. F. Bertsch and R. A. Broglia *Oscillations in Finite Quantum Systems*
 N. D. Birrell and P. C. W. Davies *Quantum Fields in Curved Space*[†]
 D. M. Brink *Semiclassical Methods in Nucleus–Nucleus Scattering*
 J. C. Collins *Renormalization*[†]
 P. D. B. Collins *An Introduction to Regge Theory and High Energy Physics*[†]
 M. Creutz *Quarks, Gluons and Lattices*[†]
 F. de Felice and C. J. S. Clarke *Relativity on Curved Manifolds*
 B. DeWitt *Supermanifolds, second edition*[†]
 P. G. O. Freund *Introduction to Supersymmetry*[†]
 F. G. Friedlander *The Wave Equation on a Curved Space-Time*[†]
 J. A. H. Futterman, F. A. Handler and R. A. Matzner *Scattering from Black Holes*
 M. Göckeler and T. Schücker *Differential Geometry, Gauge Theories and Gravity*[†]
 M. B. Green, J. H. Schwarz and E. Witten *Superstring Theory, volume 1: Introduction*[†]
 M. B. Green, J. H. Schwarz and E. Witten *Superstring Theory, volume 2: Loop Amplitudes, Anomalies and Phenomenology*[†]
 S. W. Hawking and G. F. R. Ellis *The Large-Scale Structure of Space-Time*[†]
 F. Iachello and A. Arima *The Interacting Boson Model*
 F. Iachello and P. van Isacker *The Interacting Boson Fermion Model*
 C. Itzykson and J.-M. Drouffe *Statistical Field Theory, volume 1: From Brownian Motion to Renormalization and Lattice Gauge Theory*[†]
 C. Itzykson and J.-M. Drouffe *Statistical Field Theory, volume 2: Strong Coupling, Monte Carlo Methods, Conformal Field Theory, and Random Systems*[†]
 J. I. Kapusta *Finite-Temperature Field Theory*
 D. Kramer, H. Stephani, M. A. H. MacCallum and E. Herlt *Exact solutions of Einstein's Field Equations*
 N. H. March *Liquid Metals: Concepts and Theory*
 L. O'Raifeartaigh *Group Structure of Gauge Theories*[†]
 A. Ozorio de Almeida *Hamiltonian Systems: Chaos and Quantization*[†]
 R. Penrose and W. Rindler *Spinors and Space-time, volume 1: Two-Spinor Calculus and Relativistic Fields*[†]
 R. Penrose and W. Rindler *Spinors and Space-time, volume 2: Spinor and Twistor Methods in Space-Time Geometry*
 S. Pokorski *Gauge Field Theories*[†]
 V. N. Popov *Functional Integrals and Collective Excitations*[†]
 R. Rivers *Path Integral Methods in Quantum Field Theory*[†]
 R. G. Roberts *The Structure of the Proton*
 W. C. Saslaw *Gravitational Physics of Stellar and Galactic Systems*[†]
 J. M. Stewart *Advanced General Relativity*
 R. S. Ward and R. O. Wells Jr *Twistor Geometry and Field Theories*[†]
 J. Fuchs *Affine Lie Algebras and Quantum Groups*

[†] Issued as a paperback

Cambridge University Press
0521019966 - Oscillations in Finite Quantum Systems
G. F. Bertsch and R. A. Broglia
Frontmatter
[More information](#)

OSCILLATIONS IN FINITE QUANTUM SYSTEMS

G. F. BERTSCH

National Superconducting Cyclotron Laboratory, Michigan State University

R. A. BROGLIA

Dipartimento di Fisica, Università di Milano and INFN Sez. Milano,
and The Niels Bohr Institute, University of Copenhagen



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
0521019966 - Oscillations in Finite Quantum Systems
G. F. Bertsch and R. A. Broglia
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/9780521411486

© Cambridge University Press 1994

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 1994
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

Bertsch, George F.
Oscillations in finite Quantum systems / G.F. Bertsch, R.A. Broglia.
p. cm. – (Cambridge monographs on mathematical physics)
Includes bibliographical references and index.
ISBN 0 521 41148 3
1. Many-body problem. 2. Oscillations. 3. Atoms. 4. Metal
crystals. 5. Nuclear physics. 6. Mathematical physics.
I. Broglia, R.A. II. Title. III. Series.
QC174.17.P7B458 1994
530.1'44–dc20 92-40596 CIP

ISBN-13 978-0-521-41148-6 hardback
ISBN-10 0-521-41148-3 hardback

ISBN-13 978-0-521-01996-5 paperback
ISBN-10 0-521-01996-6 paperback

Cambridge University Press
0521019966 - Oscillations in Finite Quantum Systems
G. F. Bertsch and R. A. Broglia
Frontmatter
[More information](#)

for Angela, Donatella, Gianandrea and Bettina–RAB

Contents

	<i>Preface</i>	page xi
1	Introduction	1
1.1	Probing the system with photons	2
1.2	A second probe of resonances: inelastic scattering	10
1.3	Energy transfer in inelastic scattering	15
1.4	Inelastic scattering with strongly interacting projectiles	19
1.5	Spin excitations	25
1.6	Excitation by heavy ions	28
2	Basic concepts	33
2.1	Vibrations of continuous systems	33
2.2	Resonance formulas	43
3	Theoretical tools	46
3.1	Operators	46
3.2	Sum rules	49
3.3	TRK sum rule and the oscillator strength	53
3.4	Photon cross section	53
3.5	Spin sum rules	58
3.6	Polarizability sum	58
4	RPA	63
4.1	Linear response	64
4.2	Matrix formulation of RPA	69
4.3	Sum rules	73
4.4	Separable interactions	74
5	Dipole oscillations	81
5.1	Dipole oscillations of electrons and the Mie theory	81
5.2	Nuclei	90

x	<i>Contents</i>	
6	Surface modes	99
6.1	Liquid drop vibrations	102
6.2	Surface oscillations of Fermi liquids	106
6.3	Nuclear quadrupole modes	109
6.4	Low frequency vibrations	119
6.5	Higher multiplicities	124
7	Compressional modes	127
7.1	Nuclear breathing mode: classical	128
7.2	Nuclear breathing mode: RPA	130
7.3	Electronic breathing mode	135
8	Spin modes	137
8.1	Isobaric analog resonance	138
8.2	Magnetic modes in nuclei	140
8.3	Gamow–Teller resonances in nuclei	142
8.4	Spin in metal clusters	146
9	Line broadening and the decay of oscillations	148
9.1	Particle escape width	150
9.2	Landau damping	154
9.3	Deformation effects	161
9.4	Optical model of configurational damping	164
9.5	Other internal degrees of freedom	167
10	Thermal effects	171
10.1	Thermal line shifts	175
10.2	Thermal line broadening	176
10.3	A general theory	181
	Appendix A: Mean field theory	187
	Appendix B: Specification of deformations	193
	Appendix C: Finite nucleus compressibility	196
	Appendix D: Nuclear surface reactions	199
	Appendix E: Numerical RPA	203
	<i>References</i>	205
	<i>Index</i>	209

Preface

One of the fascinating questions in Nature is trying to understand how the properties of macroscopic systems emerge from the quantal behavior of its constituents. For example, how many atoms does it take to make a solid? Equally interesting is to ask how the macroscopic behavior of large systems emerges as a limit point when one observes the properties of finite systems. A powerful technique, both theoretically and experimentally, to study this question is to examine the response of the system to weak external perturbations. The study of this subject is the central theme of the present monograph.

We start by surveying the experimental information on collective vibrations in atoms, metal clusters and nuclei. It will be apparent that the vibrational modes and their frequencies can reveal much about the nature of the forces acting within the system.

Following the overview, we develop the main tools to provide an understanding of these findings. We place special emphasis on the Rayleigh–Ritz principle, the use of sum rules, and the quantum mechanics of mean field theory, known as ‘RPA’.

With the various classical and quantum mechanical tools, we proceed to discuss the important vibrational modes observed in the different systems. The dipole mode of oscillation is prominent in both nuclei and metal clusters, and there are remarkable similarities between the two systems—on very different energy scales of course. Surface modes of higher multipolarity are prominent features of the nuclear response, and quantum mechanics of the many-fermion system produces a rather subtle response. The compressional mode is also important in nuclei, because it bears most closely on the properties of macroscopic nuclear matter.

In the last two chapters we discuss the mechanisms responsible for the damping of vibrational modes and the effects of excitation energy on the modes.

The book is aimed mainly toward students and experimental researchers studying finite quantum systems. We have deliberately avoided technicalities, formalism, and many details. Our emphasis is on the physics of the response of these small systems. In keeping with this spirit, we have not compiled an extensive bibliography, but we hope we have cited enough material, via other books and review articles, for the reader to find more extensive literature. Readers who are interested in carrying out numerical RPA calculations themselves may obtain free copies of relevant programs described in App. E.

We would like to thank A. Bulgac, P.F. Bortignon, D. Nocera, D. Tomanek and K. Yabana for discussions, and in addition J. Foxwell, G. Lazzari and Y. Wang for reading parts of the manuscript. We also thank O. McHarris for the figures, and G. Colò for providing figures for selected topics, and for helping to prepare one of the computer codes for distribution.