

Texts and Monographs in Physics

Series Editors: R. Balian W. Beiglböck H. Grosse E. H. Lieb
N. Reshetikhin H. Spohn W. Thirring

Texts and Monographs in Physics

Series Editors: R. Balian W. Beiglböck H. Grosse E. H. Lieb
N. Reshetikhin H. Spohn W. Thirring

From Microphysics to Macrophysics

I + II Methods and Applications of
Statistical Physics By R. Balian

Variational Methods in Mathematical

Physics A Unified Approach
By P. Blanchard and E. Brüning

Quantum Mechanics:

Foundations and Applications
3rd enlarged edition By A. Böhm

The Early Universe

Facts and Fiction 3rd corrected
and enlarged edition By G. Börner

Operator Algebras and Quantum

Statistical Mechanics I + II 2nd edition
By O. Bratteli and D. W. Robinson

Geometry of the Standard Model
of Elementary Particles

By A. Derdzinski

Scattering Theory of Classical
and Quantum N-Particle Systems

By J. Dereziński and C. Gérard

Random Walks, Critical Phenomena,
and Triviality in Quantum Field

Theory By R. Fernández, J. Fröhlich
and A. D. Sokal

Quantum Relativity

A Synthesis of the Ideas of Einstein
and Heisenberg

By D. R. Finkelstein

Quantum Mechanics I + II

By A. Galindo and P. Pascual

The Elements of Mechanics

By G. Gallavotti

Local Quantum Physics

Fields, Particles, Algebras
2nd revised and enlarged edition

By R. Haag

Supersymmetric Methods in Quantum
and Statistical Physics By G. Junker

Elementary Particle Physics

Concepts and Phenomena

By O. Nachtmann

Inverse Schrödinger Scattering
in Three Dimensions

By R. G. Newton

Scattering Theory of Waves
and Particles 2nd edition

By R. G. Newton

Quantum Entropy and Its Use

By M. Ohya and D. Petz

Generalized Coherent States
and Their Applications

By A. Perelomov

Essential Relativity Special, General,
and Cosmological Revised 2nd edition

By W. Rindler

Path Integral Approach
to Quantum Physics An Introduction
2nd printing By G. Roepstorff

Advanced Quantum Theory
and Its Applications Through Feynman
Diagrams 2nd edition

By M. D. Scadron

Finite Quantum Electrodynamics

The Causal Approach 2nd edition
By G. Scharf

From Electrostatics to Optics

A Concise Electrodynamics Course
By G. Scharf

Large Scale Dynamics of Interacting
Particles By H. Spohn

General Relativity and Relativistic
Astrophysics By N. Straumann

The Mechanics and Thermodynamics
of Continuous Media By M. Šilhavý

The Dirac Equation By B. Thaller

The Theory of Quark and Gluon
Interactions 2nd completely revised
and enlarged edition By F. J. Ynduráin

Relativistic Quantum Mechanics and
Introduction to Field Theory

By F. J. Ynduráin

Jan Dereziński Christian Gérard

Scattering Theory of Classical and Quantum N -Particle Systems

With 15 Figures



Springer

Jan Dereziński

Department of Mathematical Methods
in Physics, Warsaw University
Hoża 74
PL-00-682 Warsaw, Poland

Christian Gérard

Centre de Mathématiques
Ecole Polytechnique
F-91128 Palaiseau Cedex, France

Editors

Roger Balian

CEA
Service de Physique Théorique de Saclay
F-91191 Gif-sur-Yvette, France

Nicolai Reshetikhin

Department of Mathematics
University of California
Berkeley, CA 94720-3840, USA

Wolf Beiglböck

Institut für Angewandte Mathematik
Universität Heidelberg
Im Neuenheimer Feld 294
D-69120 Heidelberg, Germany

Herbert Spohn

Theoretische Physik
Ludwig-Maximilians-Universität München
Theresienstraße 37
D-80333 München, Germany

Harald Grosse

Institut für Theoretische Physik
Universität Wien
Boltzmanngasse 5
A-1090 Wien, Austria

Walter Thirring

Institut für Theoretische Physik
Universität Wien
Boltzmanngasse 5
A-1090 Wien, Austria

Elliott H. Lieb

Jadwin Hall
Princeton University, P. O. Box 708
Princeton, NJ 08544-0708, USA

Library of Congress Cataloging-in-Publication Data

Dereziński, Jan, 1957–

Scattering Theory of Classical and Quantum N-Particle Systems / J. Dereziński, C. Gérard.
p. cm. – (Texts and monographs in physics, ISSN 0172-5998) Includes bibliographical references.
ISBN 978-3-642-08284-9 ISBN 978-3-662-03403-3 (eBook)

DOI 10.1007/978-3-662-03403-3

1. Scattering (Physics) 2. Scattering (Mathematics) 3. Quantum theory. 4. Mathematical
physics – Asymptotic theory. I. Gérard, Christian, 1960–. II. Title. III. Series.

QC20.7.S3D47 1997 539.7'58'0151–dc21 96-46757 CIP

ISSN 0172-5998

ISBN 978-3-642-08284-9

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag.

Violations are liable for prosecution under the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1997

Originally published by Springer-Verlag Berlin Heidelberg New York in 1997

Softcover reprint of the hardcover 1st edition 1997

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: Camera-ready copy from the authors

Cover design: *design & production* GmbH, Heidelberg

SPIN: 10481305

55/3144-543210 - Printed on acid-free paper

*We dedicate this book to our beloved
Ida, Line, Marion, Michał and Pierre*

Acknowledgments

One of us (Jan Dereziński) would like to express his gratitude for the hospitality and the financial support of the following institutions: Centre de Mathématiques of Ecole Polytechnique, Schrödinger Institute, Aarhus University, IHES, Institute for Mathematics and its Applications at the University of Minnesota, Mittag Leffler Institute, Université Paris Sud, Caltech, Université Paris VII. He also acknowledges grants from Komitet Badań Naukowych.

Both of us profited from discussions with our colleagues working on scattering theory. We use this opportunity to express our gratitude to all of them, in particular to V. Enss, R. Froese, V. Georgescu, G. M. Graf, G. Hagedorn, I. Herbst, H. Isozaki, A. Jensen, S. Nakamura, E. Mourre, P. Perry, I. Sigal, E. Skibsted, A. Soffer, X. P. Wang, D. Yafaev, K. Yajima and L. Zieliński.

Contents

0. Introduction	1
1. Classical Time-Decaying Forces	5
1.0 Introduction	5
1.1 Basic Notation	11
1.2 Newton's Equation	13
1.3 Asymptotic Momentum	14
1.4 Fast-Decaying Case	15
1.5 Slow-Decaying Case I	20
1.6 Slow-Decaying Case II	26
1.7 Boundary Conditions for Wave Transformations	31
1.8 Conservative Forces	33
1.9 Gauge Invariance of Wave Transformations	35
1.10 Smoothness of Trajectories	46
1.11 Comparison of Two Dynamics	50
1.12 More Examples of Modified Free Dynamics	53
2. Classical 2-Body Hamiltonians	57
2.0 Introduction	57
2.1 General Facts About Dynamical Systems	60
2.2 Upper Bounds on Trajectories	62
2.3 The Mourre Estimate and Scattering Trajectories	65
2.4 Non-trapping Energies	69
2.5 Asymptotic Velocity	72
2.6 Short-Range Case	74
2.7 Long-Range Case	77
2.8 The Eikonal Equation	88
2.9 Smoothness of Trajectories	89
3. Quantum Time-Decaying Hamiltonians	93
3.0 Introduction	93
3.1 Time-Dependent Schrödinger Hamiltonians	97
3.2 Asymptotic Momentum	98
3.3 Fast-Decaying Case	104

3.4	Slow-Decaying Case – Hörmander Potentials	106
3.5	Slow-Decaying Case – Smooth Potentials	115
3.6	Dollard Wave Operators	118
3.7	Isozaki-Kitada Construction	120
3.8	Counterexamples to Asymptotic Completeness	124
3.8.1	Adiabatic Evolution	124
3.8.2	Counterexample Based on the Adiabatic Approximation	125
3.8.3	A Sharper Counterexample	127
3.9	Smoothness of Wave Operators in the Fast-Decaying Case	129
3.10	Smoothness of Wave Operators in the Slow-Decaying Case	132
4.	Quantum 2-Body Hamiltonians	135
4.0	Introduction	135
4.1	Schrödinger Hamiltonians	143
4.2	Weak Large Velocity Estimates	145
4.3	The Mourre Estimate and Its Consequences	148
4.4	Asymptotic Velocity	151
4.5	Joint Spectrum of P^+ and H	161
4.6	Short-Range Case	164
4.7	Long-Range Case	167
4.8	Dollard Wave Operators	174
4.9	Isozaki-Kitada Construction	176
4.10	Counterexamples to Asymptotic Completeness	181
4.10.1	The Born-Oppenheimer Approximation – an Abstract Setting	181
4.10.2	The Born-Oppenheimer Approximation for Schrödinger Operators	183
4.10.3	Counterexample to Asymptotic Completeness	186
4.11	Strong Large Velocity Estimates	190
4.12	Strong Propagation Estimates for the Generator of Dilations	193
4.13	Strong Low Velocity Estimates	196
4.14	Schrödinger Operators as Pseudo-differential Operators	198
4.15	Improved Isozaki-Kitada Modifiers	199
4.16	Microlocal Propagation Estimates	203
4.17	Wave Operators with Outgoing Cutoffs	207
4.18	Wave Operators on Weighted Spaces	209
5.	Classical N-Body Hamiltonians	215
5.0	Introduction	215
5.1	N -Body Systems	219
5.2	Some Special Observables	226
5.3	Bounded Trajectories and the Classical Mourre Estimate	236
5.4	Asymptotic Velocity	243
5.5	Joint Localization of the Energy and the Asymptotic Velocity	247
5.6	Regular a -Trajectories	249

5.7	Upper Bound on the Size of Clusters	252
5.8	Free Region Scattering	255
5.8.1	Short-Range Free Region Case	256
5.8.2	Long-Range Free Region Case	257
5.9	Existence of the Asymptotic External Position	258
5.9.1	Asymptotic External Position in the Short-Range Case	259
5.9.2	Asymptotic External Position in the Long-Range Case	259
5.9.3	External Position for Regular α -Trajectories	262
5.10	Potentials of Super-Exponential Decay	262
6.	Quantum N-Body Hamiltonians	265
6.0	Introduction	265
6.1	Basic Definitions	274
6.2	HVZ Theorem	276
6.3	Weak Large Velocity Estimates	280
6.4	The Mourre Estimate	281
6.5	Exponential Decay of Eigenfunctions and Absence of Positive Eigenvalues	289
6.6	Asymptotic Velocity	297
6.7	Asymptotic Completeness of Short-Range Systems	306
6.8	Asymptotic Separation of the Dynamics I	309
6.9	Time-Dependent N -Body Hamiltonians	315
6.10	Joint Spectrum of P^+ and H	319
6.11	Asymptotic Clustering and Asymptotic Absolute Continuity	326
6.12	Improved Propagation Estimates	328
6.13	Upper Bound on the Size of Clusters	333
6.14	Asymptotic Separation of the Dynamics II	345
6.15	Modified Wave Operators and Asymptotic Completeness in the Long-Range Case	347
A.	Miscellaneous Results in Real Analysis	353
A.1	Some Inequalities	353
A.2	The Fixed Point Theorem	356
A.3	The Hamilton-Jacobi Equation	360
A.4	Construction of Some Cutoff Functions	367
A.5	Propagation Estimates	368
A.6	Comparison of Two Dynamics	369
A.7	Schwartz's Global Inversion Theorem	372
B.	Operators on Hilbert Spaces	373
B.1	Self-adjoint Operators	373
B.2	Convergence of Self-adjoint Operators	376
B.3	Time-Dependent Hamiltonians	379
B.4	Propagation Estimates	383

B.5	Limits of Unitary Operators	386
B.6	Schur's Lemma	386
B.7	Compact Operators in $L^2(\mathbb{R}^n)$	387
C.	Estimates on Functions of Operators	389
C.1	Basic Estimates of Commutators	389
C.2	Almost-Analytic Extensions	390
C.3	Commutator Expansions I	392
C.4	Commutator Expansions II	394
D.	Pseudo-differential and Fourier Integral Operators	397
D.0	Introduction	397
D.1	Symbols of Operators	399
D.2	Phase-Space Correlation Functions	400
D.3	Symbols Associated with a Uniform Metric	401
D.4	Pseudo-differential Operators Associated with a Uniform Metric	403
D.5	Symbols and Operators Depending on a Parameter	407
D.6	Weighted Spaces	410
D.7	Symbols Associated with Some Non-uniform Metrics	410
D.8	Pseudo-differential Operators Associated with the Metric g_1	412
D.9	Essential Support of Pseudo-differential Operators	414
D.10	Ellipticity	416
D.11	Functional Calculus for Pseudo-differential Operators Associated with the Metric g_1	418
D.12	Non-stationary Phase Method	421
D.13	FIO's Associated with a Uniform Metric	422
D.14	FIO's Depending on a Parameter	425
D.15	FIO's Associated with the Metric g_1	425
	References	433
	Subject Index	443