

FELIX ALEXANDROVICH BEREZIN

# INTRODUCTION TO SUPERANALYSIS

*Edited by*  
A. A. KIRILLOV

*Translated from the Russian by J. Niederle and R. Kotecký*

*English translation edited and revised by Dimitri Leites*



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# Introduction To Superanalysis

**Sergio Cecotti**



## Introduction To Superanalysis:

**Introduction to Superanalysis** F.A. Berezin, 2013-04-09 TO SUPERANALYSIS Edited by A A KIRILLOV Translated from the Russian by J Niederle and R Kotecky English translation edited and revised by Dimitri Leites SPRINGER SCIENCE BUSINESS MEDIA B V Library of Congress Cataloging in Publication Data Berezin F A Feliks Aleksandrovich Introduction to superanalysis Mathematical physics and applied mathematics v 9 Part I is translation of Vvedenie v algebru i analiz s antikommururushchimi peremennymi Bibliography p Includes index 1 Mathetical analysis I Title II Title Superanalysis III Series QA300 B459 1987 530 15 5 87 16293 ISBN 978 90 481 8392 0 ISBN 978 94 017 1963 6 eBook DOI 10 1007 978 94 017 1963 6 All Rights Reserved 1987 by Springer Science Business Media Dordrecht Originally published by D Reidel Publishing Company Dordrecht Holland in 1987 No part of the material protected by this copyright notice may be reproduced in whole or in part or utilized in any form or by any means electronic or mechanical including photocopying recording or storing in any electronic information system without first obtaining the written permission of the copyright owner CONTENTS EDITOR S FOREWORD ix INTRODUCTION 1 1 The Sources 1 2 Supermanifolds 3 3 Additional Structures on Supermanifolds 11 4 Representations of Lie Superalgebras and Supergroups 21 5 Conclusion 23 References 24 PART I CHAPTER 1 GRASSMANN ALGEBRA 29 1 Basic Facts on Associative Algebras 29 2 Grassmann Algebras 35 3 Algebras A U 55 CHAPTER 2 SUPERANALYSIS 74 1 Derivatives 74 2 Integral 76 CHAPTER 3 LINEAR ALGEBRA IN  $\mathbb{Z}_2$  GRADED SPACES 90 1 *Introduction to Superanalysis* Superanalysis Feliks Aleksandrovich Berezin, 1987 **Introduction to String**

**Theory** Sergio Cecotti, 2023-10-06 Graduate students typically enter into courses on string theory having little to no familiarity with the mathematical background so crucial to the discipline As such this book based on lecture notes edited and expanded from the graduate course taught by the author at SISSA and BIMSA places particular emphasis on said mathematical background The target audience for the book includes students of both theoretical physics and mathematics This explains the book s strange style on the one hand it is highly didactic and explicit with a host of examples for the physicists but in addition there are also almost 100 separate technical boxes appendices and starred sections in which matters discussed in the main text are put into a broader mathematical perspective while deeper and more rigorous points of view particularly those from the modern era are presented The boxes also serve to further shore up the reader s understanding of the underlying math In writing this book the author s goal was not to achieve any sort of definitive conciseness opting instead for clarity and completeness To this end several arguments are presented more than once from different viewpoints and in varying contexts Applied Functional Analysis Eberhard Zeidler, 2012-12-06 A theory is the more impressive the simpler are its premises the more distinct are the things it connects and the broader is its range of applicability Albert Einstein There are two different ways of teaching mathematics namely i the systematic way and ii the application oriented way More precisely by i I mean a systematic presentation of the material governed by the desire for

mathematical perfection and completeness of the results In contrast to i approach ii starts out from the question What are the most important applications and then tries to answer this question as quickly as possible Here one walks directly on the main road and does not wander into all the nice and interesting side roads The present book is based on the second approach It is addressed to undergraduate and beginning graduate students of mathematics physics and engineering who want to learn how functional analysis elegantly solves mathematical problems that are related to our real world and that have played an important role in the history of mathematics The reader should sense that the theory is being developed not simply for its own sake but for the effective solution of concrete problems viii Preface Our introduction to applied functional analysis is divided into two parts Part I Applications to Mathematical Physics AMS Vol 108 Part II Main Principles and Their Applications AMS Vol 109 A detailed discussion of the contents can be found in the preface to AMS Vol 108      **Felix Berezin** Mikhail A. Shifman, 2007 Felix Berezin was an outstanding Soviet mathematician who in the 1960s and 70s was the driving force behind the emergence of the branch of mathematics now known as supermathematics The integral over the anticommuting Grassmann variables that he introduced in the 1960s laid the foundation for the path integral formulation of quantum field theory with fermions the heart of modern supersymmetric field theories and superstrings The Berezin integral is named for him as is the closely related construction of the Berezinian which may be regarded as the superanalog of the determinant This book features a masterfully written memoir by Berezin's widow Elena Karpel who narrates a remarkable account of Berezin's life and his struggle for survival under the totalitarian Soviet regime Supplemented with recollections by his close friends and colleagues Berezin's accomplishments in mathematics his novel ideas and breakthrough works are reviewed in two articles written by Andrei Losev and Robert Minlos      **Topics in Statistical and Theoretical Physics** R. L. Dobrushin, 1996      **Progress In Analysis, Proceedings Of The 3rd Isaac Congress (In 2 Volumes)** Heinrich G W Begehr, Robert Pertsch Gilbert, Man-wah Wong, 2003-08-04 The biannual ISAAC congresses provide information about recent progress in the whole area of analysis including applications and computation This book constitutes the proceedings of the third meeting      Geometric Methods in Physics Piotr Kielanowski, S. Twareque Ali, Anatol Odziejewicz, Martin Schlichenmaier, Theodore Voronov, 2012-11-05 The Biannual workshops on Geometric Methods in Physics are among the most important meetings in the field Every year some 80 to 100 participants from both mathematics and physics join to discuss new developments and to interchange ideas This volume contains contributions by selected speakers at the XXX meeting in 2011 as well as additional review articles and shows that the workshop remains at the cutting edge of ongoing research The 2011 workshop focussed on the works of the late Felix A Berezin 1931-1980 on the occasion of his 80th anniversary as well as on Bogdan Mielnik and Stanisław Lech Woronowicz on their 75th and 70th birthday respectively The groundbreaking work of Berezin is discussed from today's perspective by presenting an overview of his ideas and their impact on further developments He was among other fields active in representation theory general concepts of quantization

and coherent states supersymmetry and supermanifolds Another focus lies on the accomplishments of Bogdan Mielnik and Stanisław Lech Woronowicz Mielnik's geometric approach to the description of quantum mixed states the method of quantum state manipulation and their important implications for quantum computing and quantum entanglement are discussed as well as the intricacies of the quantum time operator Woronowicz's fruitful notion of a compact quantum group and related topics are also addressed

**Supermathematics and its Applications in Statistical Physics** Franz Wegner, 2016-03-25 This text presents the mathematical concepts of Grassmann variables and the method of supersymmetry to a broad audience of physicists interested in applying these tools to disordered and critical systems as well as related topics in statistical physics Based on many courses and seminars held by the author one of the pioneers in this field the reader is given a systematic and tutorial introduction to the subject matter The algebra and analysis of Grassmann variables is presented in part I The mathematics of these variables is applied to a random matrix model path integrals for fermions dimer models and the Ising model in two dimensions Supermathematics the use of commuting and anticommuting variables on an equal footing is the subject of part II The properties of supervectors and supermatrices which contain both commuting and Grassmann components are treated in great detail including the derivation of integral theorems In part III supersymmetric physical models are considered While supersymmetry was first introduced in elementary particle physics as exact symmetry between bosons and fermions the formal introduction of anticommuting spacetime components can be extended to problems of statistical physics and since it connects states with equal energies has also found its way into quantum mechanics Several models are considered in the applications after which the representation of the random matrix model by the nonlinear sigma model the determination of the density of states and the level correlation are derived Eventually the mobility edge behavior is discussed and a short account of the ten symmetry classes of disorder two dimensional disordered models and superbosonization is given

**Several Complex Variables III** G.M. Khenkin, 2012-12-06 We consider the basic problems notions and facts in the theory of entire functions of several variables i.e. functions  $J(z)$  holomorphic in the entire  $n$  space 1 the zero set of an entire function is not discrete and therefore one has no analogue of a tool such as the canonical Weierstrass product which is fundamental in the case  $n = 1$  Second for  $n \geq 1$  there exist several different natural ways of exhausting the space

**Quantum Geometry** Margaret Prugovecki, 2013-03-14 This monograph presents a review and analysis of the main mathematical physical and epistemological difficulties encountered at the foundational level by all the conventional formulations of relativistic quantum theories ranging from relativistic quantum mechanics and quantum field theory in Minkowski space to the various canonical and covariant approaches to quantum gravity It is however primarily devoted to the systematic presentation of a quantum framework meant to deal effectively with these difficulties by reconsidering the foundations of these subjects analyzing their epistemic nature and then developing mathematical tools which are specifically designed for the elimination of all the basic inconsistencies A carefully documented historical survey is included and

additional extensive notes containing quotations from original sources are incorporated at the end of each chapter so that the reader will be brought up to date with the very latest developments in quantum field theory in curved spacetime quantum gravity and quantum cosmology The survey further provides a backdrop against which the new foundational and mathematical ideas of the present approach to these subjects can be brought out in sharper relief **Connections in Classical and Quantum Field Theory** L. Mangiarotti, Gennadi Aleksandrovich Sardanashvili, 2000 Geometrical notions and methods play an important role in both classical and quantum field theory and a connection is a deep structure which apparently underlies the gauge theoretical models in field theory and mechanics This book is an encyclopaedia of modern geometric methods in theoretical physics It collects together the basic mathematical facts about various types of connections and provides a detailed exposition of relevant physical applications It discusses the modern issues concerning the gauge theories of fundamental fields The authors have tried to give all the necessary mathematical background thus making the book self contained This book should be useful to graduate students physicists and mathematicians who are interested in the issue of deep interrelations between theoretical physics and geometry **Quantization of Gauge Systems** Marc Henneaux, Claudio Teitelboim, 2020-06-16 This book is a systematic study of the classical and quantum theories of gauge systems It starts with Dirac's analysis showing that gauge theories are constrained Hamiltonian systems The classical foundations of BRST theory are then laid out with a review of the necessary concepts from homological algebra Reducible gauge systems are discussed and the relationship between BRST cohomology and gauge invariance is carefully explained The authors then proceed to the canonical quantization of gauge systems first without ghosts reduced phase space quantization Dirac method and second in the BRST context quantum BRST cohomology The path integral is discussed next The analysis covers indefinite metric systems operator insertions and Ward identities The antifield formalism is also studied and its equivalence with canonical methods is derived The examples of electromagnetism and abelian 2 form gauge fields are treated in detail The book gives a general and unified treatment of the subject in a self contained manner Exercises are provided at the end of each chapter and pedagogical examples are covered in the text **Integrable Hamiltonian Hierarchies** Vladimir Gerdjikov, Gaetano Vilasi, Alexandar Borisov Yanovski, 2008-12-02 This book presents a detailed derivation of the spectral properties of the Recursion Operators allowing one to derive all the fundamental properties of the soliton equations and to study their hierarchies **Supersymmetry and Equivariant de Rham Theory** Victor W Guillemin, Shlomo Sternberg, 2013-03-09 Equivariant cohomology on smooth manifolds is the subject of this book which is part of a collection of volumes edited by J Br ning and V W Guillemin The point of departure are two relatively short but very remarkable papers by Henry Cartan published in 1950 in the Proceedings of the Colloque de Topologie These papers are reproduced here together with a modern introduction to the subject written by two of the leading experts in the field This introduction comes as a textbook of its own though presenting the first full treatment of equivariant cohomology in the de

Rahm setting The well known topological approach is linked with the differential form aspect through the equivariant de Rahm theorem The systematic use of supersymmetry simplifies considerably the ensuing development of the basic technical tools which are then applied to a variety of subjects leading up to the localization theorems and other very recent results

*Geometric Algebra for Physicists* Chris Doran,Anthony Lasenby,2007-11-22 Geometric algebra is a powerful mathematical language with applications across a range of subjects in physics and engineering This book is a complete guide to the current state of the subject with early chapters providing a self contained introduction to geometric algebra Topics covered include new techniques for handling rotations in arbitrary dimensions and the links between rotations bivectors and the structure of the Lie groups Following chapters extend the concept of a complex analytic function theory to arbitrary dimensions with applications in quantum theory and electromagnetism Later chapters cover advanced topics such as non Euclidean geometry quantum entanglement and gauge theories Applications such as black holes and cosmic strings are also explored It can be used as a graduate text for courses on the physical applications of geometric algebra and is also suitable for researchers working in the fields of relativity and quantum theory

**Mathematical Foundations of Supersymmetry** Claudio Carmeli,Lauren Caston,Rita Fiorese,2011 Supersymmetry is a highly active area of considerable interest among physicists and mathematicians It is not only fascinating in its own right but there is also indication that it plays a fundamental role in the physics of elementary particles and gravitation The purpose of the book is to lay down the foundations of the subject providing the reader with a comprehensive introduction to the language and techniques as well as detailed proofs and many clarifying examples This book is aimed ideally at second year graduate students After the first three introductory chapters the text is divided into two parts the theory of smooth supermanifolds and Lie supergroups including the Frobenius theorem and the theory of algebraic superschemes and supergroups There are three appendices The first introduces Lie superalgebras and representations of classical Lie superalgebras the second collects some relevant facts on categories sheafification of functors and commutative algebra and the third explains the notion of Frechet space in the super context

*Progress in Analysis* International Society for Analysis, Applications, and Computation. Congress,2003-01-01 The biannual ISAAC congresses provide information about recent progress in the whole area of analysis including applications and computation This book constitutes the proceedings of the third meeting Contents Volume 1 Function Spaces and Fractional Calculus V I Burenkov Asymptotic Decomposition Methods of Small Parameters Averaging Theory J A Dubinski Integral Transforms and Applications S Saitoh et al Analytic Functionals Hyperfunctions and Generalized Functions M Morimoto Geometric Function Theory G Kohr complex Function Spaces R Aulaskari Value Distribution Theory and Complex Dynamics C C Yang Clifford Analysis K Grlebeck et al Octonions T Dray Nonlinear Potential Theory O Martio Classical and Fine Potential Theory Holomorphic and Finely Holomorphic Functions P Tamrazov Differential Geometry and Control Theory for PDEs B Gulliver et al Differential Geometry and Quantum Physics Dynamical Systems B Fiedler Attractors for Partial

Differential Equations G Raugel Spectral Theory of Differential Operators B Vainberg Pseudodifferential Operators  
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 Paper - Proceedings Of The Sixth International Conference* Valerio Tognetti, Roberto Casalbuoni, Riccardo Giachetti, Ruggero  
 Vaia, Paola Verrucchi, 1999-04-01 This book contains the invited contributions to the 6th International Conference on Path  
 Integrals from peV to TeV held in Florence in 1998 The conference devoted to functional integration brought together many  
 physicists with interests ranging from elementary particles to nuclear solid state liquid state polymer and complex systems  
 physics The variety of topics is reflected in the book which is a unique collection of papers on manifold applications of  
 functional methods in several areas of physics Geometry In Partial Differential Equations Themistocles M  
 Rassias, Agostino Prastaro, 1994-01-17 This book emphasizes the interdisciplinary interaction in problems involving geometry  
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 supermanifolds of the geometrical methods just introduced for PDEs and the harmonic theory which proved to be very  
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