

Physics Of Ferromagnetism International Series Of

Principles of Nuclear Magnetism has, over the years, established itself as the classic single volume treatise which gives a comprehensive account of all the concepts, theories, and results associated with the study of nuclear magnetism.

Since the discovery of the giant magnetoresistance (GMR) effect in magnetic multilayers in 1988, a new branch of physics and technology, called spin-electronics or spintronics, has emerged, where the flow of electrical charge as well as the flow of electron spin, the so-called "spin current", are manipulated and controlled together. Recent progress in the physics of magnetism and the application of spin current has progressed in tandem with the nanofabrication technology of magnets and the engineering of interfaces and thin films. This book is intended to provide an introduction and guide to the new physics and applications of spin current. The emphasis is placed on the interaction between spin and charge currents in magnetic nanostructures.

Spintronics (short for spin electronics, or spin transportelectronics) exploits both the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices. Controlling the spin of electrons within a device can produce surprising and substantial changes in its properties. Drawing from many cutting edge fields, including physics, materials science, and electronics device technology, spintronics has provided the key concepts for many next generation information processing and transmitting technologies. This book discusses all aspects of spintronics from basic science to applications and covers: • magnetic semiconductors • topological insulators • spin current science • spin caloritronics • ultrafast magnetization reversal • magnetoresistance effects and devices • spin transistors • quantum information devices This book provides a comprehensive introduction to Spintronics for researchers and students in academia and industry.

The Feynman path integrals are becoming increasingly important in the applications of quantum mechanics and field theory. The path integral formulation of quantum anomalies, i.e. the quantum breaking of certain symmetries, can now cover all the known quantum anomalies in a coherent manner. In this book the authors provide an introduction to the path integral method in quantum field theory and its applications to the analyses of quantum anomalies. No previous knowledge of field theory beyond advanced undergraduate quantum mechanics is assumed. The book provides the first coherent introductory treatment of the path integral formulation of chiral and Weyl anomalies, with applications to gauge theory in two and four dimensions, conformal field theory and string theory. Explicit and elementary path integral calculations of most of the quantum anomalies covered are given. The conceptual basis of the path integral bosonization in two-dimensional theory, which may have applications to condensed matter theory, for example, is clarified. The book also covers the recent interesting developments in the treatment of fermions and chiral anomalies in lattice gauge theory.

Lectures on Solid State Physics

Statistical Physics of Spin Glasses and Information Processing

Helium Three

Theory of Fluctuations in Superconductors

An Introduction

The Principles of Nuclear Magnetism

The ninth volume of Annual Reviews of Computational Physics has as a special feature a comprehensive compendium of interatomic potentials as used for materials properties. Other articles deal with simulations of magnetic nanostructures, improved Monte Carlo methods (e.g. for nucleation studies in Ising models), fluid

dynamics with large mean free paths, the growing field of OC sociophysics, OCO and teaching of undergraduate computational physics (including an introduction to Java)."

Physics of Ferromagnetism 2e Oxford University Press on Demand

Over the past twenty years our understanding of polymer solutions has undergone a dramatic evolution. New methods and concepts have extended the frontier of the theory from dilute solutions in which polymers move independently of each other, to concentrated solutions where many polymers entangle with each other. This book provides a comprehensive account of the modern theory for the dynamical properties of polymer solutions. This includes viscoelasticity, diffusion, dynamic light scattering and flow and electric birefringence. Nonlinear viscoelasticity is discussed in detail on the basis of molecular dynamical models. The book fills a gap between classical theory and modern developments and constructs a consistent picture for the dynamics of polymer solutions over the entire concentration range.

The energy cost associated with modern information technologies has been increasing exponentially over time, stimulating the search for alternative information storage and processing devices. Magnetic skyrmions are solitonic nanometer-scale quasiparticles whose unique topological properties can be thought of as that of a Mobius strip. Skyrmions are envisioned as information carriers in novel information processing and storage devices with low power consumption and high information density. As such, they could contribute to solving the energy challenge. In order to be used in applications, isolated skyrmions must be thermally stable at the scale of years. In this work, their stability is studied through two main approaches: the Kramers' method in the form of Langer's theory, and the forward flux sampling method. Good agreement is found between the two methods. We find that small skyrmions possess low internal energy barriers, but are stabilized by a large activation entropy. This is a direct consequence of the existence of stable modes of deformation of the skyrmion. Additionally, frustrated exchange that arises at some transition metal interfaces leads to new collapse paths in the form of the partial nucleation of the corresponding antiparticle, as merons and antimerons.

Structure, Properties and Preparation of Perovskite-Type Compounds

International Series in Natural Philosophy

Beam Plasma Interaction, Hydrodynamics, Hot Dense Matter

Current Medical Applications and Alternative Therapy of Cancer

Principles and Applications

Path Integrals and Quantum Anomalies

This book is on inertial confinement fusion, an alternative way to produce electrical power from hydrogen fuel by using powerful lasers or particle beams. It involves the compression of tiny amounts (micrograms) of fuel to thousand times solid density and pressures otherwise existing only in the centre of stars. Thanks to advances in laser technology, it is now possible to produce such extreme states of matter in the laboratory. Recent developments have boosted laser intensities again with new possibilities for laser particle accelerators, laser nuclear physics, and fast ignition of fusion targets. This is a reference book for those working on beam plasma physics, be it in the context of fundamental research or applications to fusion energy or novel ultra-bright laser sources. The book combines quite different areas of physics: beam target interaction, dense plasmas, hydrodynamic implosion and instabilities, radiative energy transfer as well as fusion reactions. Particular attention is given to simple and useful modelling, including dimensional analysis and similarity solutions. Both authors have worked in this field for more than 20 years. They want to address in particular those teaching this topic to students and all those interested in understanding the technical basis.

Heavy electrons are found among a number of lanthanide and actinide compounds, and are characterized by a large effective mass which becomes comparable to the mass of a muon. Heavy electrons exhibit rich phenomena such as unconventional superconductivity, weak anti-ferromagnetism, or pseudo meta-magnetism. This book is intended not only as a monograph, but can readily serve as an advanced textbook on theoretical and experimental physics of strongly correlated electrons. Over the last two decades, heavy electrons have been the focus of very active experimental and theoretical studies. Many established ideas and techniques have been insufficient to describe and understand heavy electrons and their impact properly. On the theoretical side, quantum fluctuations make mean-field theories difficult to handle, while on the experimental side, extreme conditions such as strong magnetic fields and pressure at ultra-low temperatures may be required. Heavy electron systems as described in this book offer a case study for applying and testing most of the major tools in theoretical and experimental condensed matter physics.

Graduate students and researchers working on strongly correlated condensed matter systems will find in this book a comprehensive introduction and many examples how conventional concepts of solids may work or not work, and how they can be refined and sharpened in the context of heavy electron systems.

This book is the first comprehensive text on a class of instruments used by scientists to study the innermost structure of matter. The author, one of the world's leading experts in this field, describes the principles of operation, the factors determining performance, and the state of the art in understanding and application of these instruments.

Multipole theory provides a powerful way of characterising the electromagnetic behaviour of a medium, be it microscopic or macroscopic. This text describes the concept of multipole theory, as well as its successes and failures in applications to transmission, scattering and reflection.

Practical Nanotechnology for Petroleum Engineers

Plasma Spectroscopy

Quantum Hall Systems

Introduction to Ferromagnetism

Precision Study of the Electroweak Interactions

Thermal Stability of Metastable Magnetic Skyrmions

This book presents a complete encyclopedia of superconducting fluctuations, summarising the last thirty-five years of work in the field. The first part of the book is devoted to an extended discussion of the Ginzburg-Landau phenomenology of fluctuations in its thermodynamical and time-dependent versions and its various applications. The second part deals with microscopic justification of the Ginzburg-Landau approach and presents the diagrammatic theory of fluctuations. The third part is devoted to a less-detailed review of the manifestation of fluctuations in observables: diamagnetism, magnetoconductivity, various tunneling characteristics, thermoelectricity, and NMR relaxation. The final chapters turn to the manifestation of fluctuations in unconventional superconducting systems: nanodrops, nanorings, Berezinsky-Kosterlitz-Thouless state, quantum phase transition between superconductor and insulator, and thermal and quantum fluctuations in weak superconducting systems. The book ends with a brief discussion on theories of high temperature superconductivity, where fluctuations appear as the possible protagonist

of this exciting phenomenon.

This book is a state-of-the-art introduction to a very recent activity in solid state physics which has developed during the last 10 years and promises to become an important new tool for analysing electronic, atomic and magnetic properties of surfaces, interfaces and film structures. Important applications are to be expected for information storage like e.g. magnetic recording. The subject is one of the most recent examples of the successful history of light-matter interaction, and a most promising tool for non-destructive, high-sensitivity analysis of material specific properties of solids.

This book, in the broadest sense, is an application of quantum mechanics and statistical mechanics to the field of magnetism. Under certain well described circumstances, an immensely large number of electrons moving in the solid state of matter will collectively produce permanent magnetism. Permanent magnets are of fundamental interest, and magnetic materials are also of great practical importance as they provide a large field of technological applications. The physical details describing the many electron problem of magnetism are presented in this book on the basis of the local density functional approximation. The emphasis is on realistic magnets, for which the equations describing the many electron problem can only be solved by using computers. The great, recent and continuing improvements of computers are, to a large extent, responsible for the progress in the field. Along with a detailed introduction to the density functional theory, this book presents representative computational methods and provides the reader with a complete computer programme for the determination of the electronic structure of a magnet on a PC. A large part of the book is devoted to a detailed treatment of the connections between electronic properties and magnetism, and how they differ in the various known magnetic systems. Current trends are exposed and explained for a large class of alloys and compounds. The modern field of artificially layered systems - known as multilayers - and their industrial applications are dealt with in detail. Finally, an attempt is made to relate the rich thermodynamic properties of magnets to the ab initio results originating from the electronic structure.

This is an introduction to the mathematical foundations of quantum field theory, using operator algebraic methods and emphasizing the link between the mathematical formulations and related physical concepts. It starts with a general probabilistic description of physics, which encompasses both classical and quantum physics. The basic key physical notions are clarified at this point. It then introduces operator algebraic methods for quantum theory, and goes on to discuss the theory of special relativity, scattering theory, and sector theory in this context.

International Series of Monographs in Solid State Physics

Non-linear Optics in Metals

Stellar Magnetism

Multipole Theory in Electromagnetism

Introduction to the Theory of Ferromagnetism

Bose-Einstein Condensation

This book presents cutting-edge topics in modern theoretical physics - quantum Hall systems - the subject of two Nobel Prizes in 1985 and 1998.

A number of new analytical techniques have been developed to establish a theory of spin glasses. This book provides a broad overview of the interdisciplinary field between statistical physics and information sciences/engineering.

Stellar magnetism is the study of the magnetic field of the Sun and other stars and is a rapidly developing field of astrophysics. This book, an authoritative account with broad astronomical scope, has grown out of the lifelong work of an outstanding researcher in the subject.

This text deals with the behaviour of superconductors in external fields varying in time, and with transport phenomena in superconductors.

Annual Reviews of Computational Physics

Mathematical Theory of Quantum Fields

The Physics of Inertial Fusion

IX

The Standard Model in the Making

Energy Measurement in Particle Physics

This text presents the different aspects of the study of anomalies. Much emphasis is now being placed on the formulation of the theory using the mathematical ideas of differential geometry and topology. It includes derivations and calculations

This second edition of Amikam Aharoni's Introduction to the Theory of Ferromagnetism is a textbook for first year graduate and advanced undergraduate students in physics and engineering as well as a reference book for practising engineers and experimental physicists who work in the field of magnetism. For this edition, the author has updated the material especially of chapters 9 ('The Nucleation Problem') and 11 ('Numerical Micro-magnetics'), which now contain the state of the art required by students and professionals who work on advanced topics of ferromagnetism.

Effective medium theory dates back to the early days of the theory of electricity. Faraday 1837 proposed one of the earliest models for a composite metal-insulator dielectric, and around 1870 Maxwell and later Garnett (1904) developed models to describe a composite or mixed material medium. The subject has been developed

considerably since and while the results are useful for predicting materials performance, the theory can also be used in a wide range of problems in physics and materials engineering. This book develops the topic of effective medium theory by bringing together the essentials of both the static and the dynamical theory. Electromagnetic systems are thoroughly dealt with, as well as related areas such as the CPA theory of alloys, liquids, the density functional theory etc, with applications to ultrasonics, hydrodynamics, superconductors, porous media and others, where the unifying aspects of the effective medium concept are emphasized. In this new second edition two further chapters have been added to deal with the theory of electrolytes and the exciting frontiers in electromagnetic and related areas of cloaking research all from the perspective of effective medium theory. In addition, a new appendix with notes on the example problems makes this an ideal graduate level text book and research reference source.

The second, updated edition of this essential reference book provides a wealth of detail on a wide range of electronic and photonic materials, starting from fundamentals and building up to advanced topics and applications. Its extensive coverage, with clear illustrations and applications, carefully selected chapter sequencing and logical flow, makes it very different from other electronic materials handbooks. It has been written by professionals in the field and instructors who teach the subject at a university or in corporate laboratories. The Springer Handbook of Electronic and Photonic Materials, second edition, includes practical applications used as examples, details of experimental techniques, useful tables that summarize equations, and, most importantly, properties of various materials, as well as an extensive glossary. Along with significant updates to the content and the references, the second edition includes a number of new chapters such as those covering novel materials and selected applications. This handbook is a valuable resource for graduate students, researchers and practicing professionals working in the area of electronic, optoelectronic and photonic materials.

Anomalies in Quantum Field Theory

Classical, Quantum, and Symmetry Aspects, with Applications

Spintronics for Next Generation Innovative Devices

Springer Handbook of Electronic and Photonic Materials

The Global Approach to Quantum Field Theory

Explores the application of magnetic nanoparticles in drug delivery, magnetic resonance imaging, and alternative cancer therapy ***Magnetic Nanoparticles in Human Health and Medicine*** ***addresses recent progress in improving diagnosis by magnetic resonance imaging (MRI) and using non-invasive and non-toxic magnetic nanoparticles for targeted drug delivery. Focusing on cancer diagnosis and***

therapy, the book covers both fundamental principles and advanced theoretical and experimental research on the magnetic properties, biocompatibilization, biofunctionalization, and application of magnetic nanoparticles in nanobiotechnology and nanomedicine. Chapters written by a panel of international specialists in the field of magnetic nanoparticles and their applications in biomedicine cover magnetic hyperthermia (MHT), MRI contrast agents, biomedical imaging, modeling and simulation, nanobiotechnology, toxicity issues, and more. Readers are provided with accurate information on the use of magnetic nanoparticles in diagnosis, drug delivery, and therapeutics—featuring discussion of current problems, proposed solutions, and future research directions. Topics include magnetic nanoparticles with antioxidant activity, iron oxide nanoparticles in nanomedicine, superparamagnetic hyperthermia in clinical trials, and simulating the physics of magnetic particle heating for biomedical applications. This comprehensive volume: Covers both general research on magnetic nanoparticles in medicine and specific applications in cancer therapeutics Discusses the use of magnetic nanoparticles in alternative cancer therapy by magnetic and superparamagnetic hyperthermia Explores targeted medication delivery using magnetic nanoparticles as a future replacement of conventional techniques Reviews the use of MRI with magnetic nanoparticles to increase the diagnostic accuracy of medical imaging Magnetic Nanoparticles in Human Health and Medicine is a valuable resource for researchers in the fields of nanomagnetism, nanomaterials, magnetic nanoparticles, nanoengineering, biopharmaceuticals nanobiotechnologies, nanomedicine, and biopharmaceuticals, particularly those focused on cancer diagnosis and therapeutics.

This volume presents in a pedagogical yet complete way correlated systems in one dimension. After an introduction to the basic concepts of correlated systems, it gives a step-by-step description of the techniques needed to treat one dimension, and discusses the resulting physics.

To reduce the amount of Rare-earth Elements in high efficient permanent magnet electric motors, the magnetic stray flux has to be reduced. Additionally, a temperature reduction inside the motor reduces the necessary amount of the so called Heavy Rare-earth Elements, which account for the bulk part of the magnet material costs. In this thesis a permanent magnet motor in wet rotor configuration for an automotive application is designed. It was shown that by simple thermal improvements of the electric insulation system the maximum temperature of the stator can be reduced. Extensive measurements on different combinations of insulation material of the stator and the development of a new thermal model for orthocyclic wound stators were performed. Due to the use of fiber cans eddy current losses

could be eliminated and the stray flux minimized. In a second stage a magnetizing fixture was build up, which is able to magnetize the buried magnets inside the rotor. The rotor and the magnetizing fixture was developed, so that the magnets can be optimal magnetized. To check the quality of the magnets the magnetizing coil was developed in a way, such that the hysteresis curve of every single magnet during magnetization can be measured. Different magnets were tested and ways to calculate parasitics are given. Um die Menge an Selten Erden in hoch-effizienten permanent erregten Elektromotoren zu reduzieren, muss der magnetische Streufluss verringert werden. Eine Temperaturreduktion im Motor verringert zudem die nötige Menge an so genannten schweren Selten Erden, welche einen Großteil der Kosten der Magnetmaterialien ausmachen. In dieser Arbeit wird dazu ein permanent erregter Nasläufer für eine automotive Anwendung ausgelegt. Es konnte gezeigt werden, dass durch einfache Maßnahmen im Bereich der elektrischen Isolation die maximale Temperatur im Stator reduziert werden konnte. Umfangreiche Messungen an verschiedenen Kombinationen von elektrischen Isolationen des Stators und die Entwicklung eines neuen thermischen Modells für orthozyklisch gewickelte Statoren wurden getätigt. Durch Einsatz von Spaltrohren aus Faserverbundwerkstoffen konnten die Wirbelstromverluste beseitigt werden und der Streufluss minimiert werden. In einem zweiten Schritt wurde eine Magnetisiervorrichtung aufgebaut, mit der die zu Anfang unmagnetisierten eingebetteten Magneten im Rotor aufmagnetisiert werden konnten. Der Rotor wurde zudem zusammen mit der Magnetisierungsspule so ausgelegt, dass die Magnete optimal magnetisiert werden können. Um die Qualität der Magnete zu testen wurde die Magnetisierungsspule zudem so ausgelegt, dass eine Messung der Hystereseurve jedes einzelnen Magneten während der Magnetisierung möglich ist. Verschiedene Magnete wurden vermessen und Möglichkeiten zur Bestimmung von parasitären Effekten gegeben.

Although the behaviour of natural phenomena can be explained by a few simple and symmetric basic laws there is an astounding variety of possibilities. These are caused by a process known as symmetry breaking, and vortices are one of the most common manifestations. This book concentrates on the dynamics of vortices in various contexts and gives a unified view of the underlying phenomena.

Theory of Nonequilibrium Superconductivity

Theoretical Solid State Physics

Physics of Ferromagnetism 2e

Vortices in Nonlinear Fields

Braid Groups, Composite Fermions, and Fractional Charge

Spin Current

Lectures on Solid State Physics is a compilation of lectures concerned with various branches of solid state physics. It aims to develop basic physical ideas that lead to a better understanding of phenomena and effects. Comprised of 11 chapters, this book discusses several topics on solid state physics: structure of solids; interference effects in crystals; lattice dynamics; perfect and imperfect crystals; electrons and electron theory of metals; semiconductors; electrical contact effects; transport phenomena, and magnetism. Students, physics graduates, electrical engineers, chemists, and metallurgists will find this book invaluable.

This second edition of Amikam Aharoni's Introduction to the Theory of Ferromagnetism is a textbook for first year graduate and advanced undergraduate students in physics and engineering as well as a reference book for practising engineers and experimental physicists who work in the field of magnetism. For this edition, the author has updated the material especially of chapters 9 ('The Nucleation Problem') and 11 ('Numerical Micro-magnetics'), which now contain the state of the art required by students and professionals who work on advanced topics of ferromagnetism.

The Standard Model is an important theory in particle physics, which unifies the theories of electromagnetic and weak interactions in atomic particles. Much work has been done over the past decade on testing the truth of this theory, and one important testing ground is the e^+e^- collision experiment. In this book the authors describe the predictions of the Standard Model relating to these experiments, summarizing the important developments so far and paving the way for experiments at higher energies.

The condensed phases of helium three provide an exciting laboratory for many fundamental questions in condensed matter physics. Due to its light mass and weak interatomic potential, the condensed phases of helium display quantum effects more dramatically than any other atomic system. Intuition based on classical experience is often misleading in these phases: the solid phase for instance is less ordered at low temperature than the liquid phase. The present book is unique in covering all the low temperature properties of helium three as liquid, superfluid, and solid. It provides an introduction to the extensive literature on helium three from the point of view of an experimentalist, and includes the analogy of its properties with the cosmological 'big bang'. Graduate students, researchers, and professionals in condensed matter physics and low temperature physics will find this the standard reference work for the decade to come.

Motor design for maximum material exploitation and magnetization procedure with in-line quality check for mass production

Theory of Itinerant Electron Magnetism

From Liquid Crystals to Superfluids, from Non-equilibrium Patterns to Cosmic Strings

Magnetic Nanoparticles in Human Health and Medicine

Dynamics of Heavy Electrons

The Theory of Polymer Dynamics

This book is a concise but well-organized introduction to nanotechnology (NT) which the upstream oil industry is now vigorously adapting to develop its own unique applications for improved oilfield operations and, oil and gas production. Its reader will learn nanotechnology fundamentals, be introduced to important NT products and applications from other industries and learn about the current state of development of various NT applications in the upstream oil industry, which include innovative use of nanoparticles for enhanced oil recovery; drilling and completions; reservoir sensing; and production operations and flow assurance. Key Features Exclusive title on potential of nanoparticle-based agents and interventions for improving myriad of oilfield operations Unique guide for nanotechnology applications developers and users for oil and gas production Introduces nanotechnology for oil and gas managers and engineers Includes research data discussions relevant to field Offers a practical applications-oriented approach

Bose-Einstein condensation represents a new state of matter and is one of the cornerstones of quantum physics, resulting in the 2001 Nobel Prize. Providing a useful introduction to one of the most exciting fields of physics today, this text will be of interest to a growing community of physicists, and is easily accessible to non-specialists alike.

Theoretical Solid State Physics, Volume 1 focuses on the study of solid state physics. The volume first takes a look at the basic concepts and structures of solid state physics, including potential energies of solids, concept and classification of solids, and crystal structure. The book then explains single-electron approximation wherein the methods for calculating energy bands; electron in the field of crystal atoms; laws of motion of the electrons in solids; and electron statistics are discussed. The text describes general forms of solutions and relationships, including collective electron interactions, Hartree-Fock and Heitler-London methods, and electron-electron scattering. The volume also reviews the magnetic properties of solids. Paramagnetism and diamagnetism of free electrons, solids, and atoms; behavior of electrons in a magnetic field; and basic concepts of magnetism are discussed. The book also considers the dielectric properties of solids and dynamics of crystal lattices. The volume is a dependable source of data for readers interested in solid state physics.

This book, in the broadest sense, is an application of quantum mechanics and statistical mechanics to the field of magnetism. The microscopic theory of many electron systems which provide the physical understanding of magnetism, is presented in detail. Emphasis is given on how to solve the equations numerically by means of suitable computer programmes, and how to apply them to practical problems arising in mechanical engineering or material sciences.

Calorimetry

Quantum Physics in One Dimension

Effective Medium Theory

Structure, Properties and Preparation of Perovskite-Type Compounds, Volume 5 presents the various methods of preparing powders,

single crystals, and thin films of perovskite-type compounds. This book discusses the structure of perovskite-type compounds and their properties. Organized into 11 chapters, this volume begins with an overview of the structure, properties, and preparation of perovskite-type compounds. This text then examines how X-ray diffraction can be used to determine unit cell data and to orient single crystals. Other chapters consider the effect of nuclear radiation on the properties of ferroelectric materials. This book discusses as well the phase transitions in perovskite-type compounds, which are often associated with a change in ferroelectric properties. The final chapter explores the two techniques in the preparation of the ternary carbides with the perovskite structure, which involves melting the appropriate proportions of the two metals and carbon under argon. This book is a valuable resource for solid-state chemists.

This new volume takes a complete look at how classical field theory, quantum mechanics and quantum field theory are interrelated. It takes a global approach and discusses the importance of quantization by relating it to different theories such as tree amplitude and conservation laws. There are special chapters devoted to Euclideanization and renormalization, space and time inversion and the closed-time-path formalism.

Plasma is ubiquitous, whether it occurs in cooking gas flames, fluorescent lamps or in the sun and the stars. This book deals with the light that these plasmas emit, the characteristics of the light, and why it occurs. The author provides a framework from which a coherent account of this phenomena can be made.

This book is a textbook for graduate students and researchers who are interested in ferromagnetism. The emphasis is primarily on explanation of physical concepts rather than on a rigorous theoretical treatment.