From Spinors To Quantum Mechanics By Gerrit Coddens

Symmetry and Dynamics have played, sometimes dualistic, sometimes complimentary, but always a very essential role in the physicist's description and conception of Nature. These are again the basic underlying themes of the present volume. It collects self-contained introductory contributions on some of the recent developments both in mathematical concepts and in physical applications which are becoming very important in current research. So we see in this volume, on the one hand, differential geometry, group representations, topology and algebras and on the other hand, particle equations, particle dynamics and particle interactions. Specifically, this book contains a complete exposition of the theory of deformations of symplectic algebras and quantization, expository material on topology and geometry in physics, and group representations. On the more physical side, we have studies on the concept of particles, on conformal spinors of Cartan, on gauge and supersymmetric field theories, and on relativistic theory of particle interactions and the theory of magnetic resonances. The contributions collected here were originally delivered at two Meetings in Turkey, at Blacksea University in Trabzon and at the University of Bosphorus in Istanbul. But they have been thoroughly revised, updated and extended for this volume. It is a pleasure for me to acknowledge the support of UNESCO, the support and hospitality of Blacksea and Bosphorus Universities for these two memorable Meetings in Mathematical Physics, and to thank the Contributors for their effort and care in preparing this work.

The quantum theory is the first theoretical approach that helps one to successfully understand the atomic and sub-atomic worlds which are too far from the cognition based on the common intuition or the experience of the daily-life. This is a very coherent theory in which a good system of hypotheses and appropriate mathematical methods allow one to describe exactly the dynamics of the quantum systems whose measurements are systematically affected by objective uncertainties. Thanks to the quantum theory we are able now to use and control new quantum devices and technologies in quantum optics and lasers, quantum electronics and quantum computing or in the modern field of nano-technologies.

We give a systematic treatment of a spin 1=2 particle in a combined electromagnetic field and a weak gravitational field that is produced by a slowly moving matter source. This paper continues previous work on a spin zero particle, but it is largely self-contained and may serve as an introduction to spinors in a Riemann space. The analysis is based on the Dirac equation expressed in generally covariant form and coupled minimally to the electromagnetic field. The restriction to a slowly moving matter source, such as the earth, allows us to describe the gravitational field by a gravitoelectric (Newtonian) potential and a gravitomagnetic (frame-dragging) vector potential, the existence of which has recently been experimentally verified. Our main interest is the coupling of the orbital and spin angular momenta of the particle to the gravitomagnetic field. Specifically we calculate the gravitational gyromagnetic ratio as g{sub g} = 1 ; this is to be compared with the electromagnetic gyromagnetic ratio of g{sub e} = 2 for a Dirac electron.

Foundations of Quantum Mechanics is written in simple and elegant style. Mathematical derivations are presented in complete detail with a lucid discussion of their physical significance. Symmetries inherent in quantum systems are brought out in a lucid wa

Classic undergraduate text explores wave functions for the hydrogen atom, perturbation theory, the Pauli exclusion principle, and the structure of simple and complex molecules. Numerous tables and figures.

Quantum mechanics, its properties including wavefunctions, complex numbers and uncertainty, are necessary and completely reasonable and understandable, with no weirdness. Classical physics is impossible. Much uncertainty comes from Fourier analysis. Waves and particles and collapse of wavefunctions are meaningless. Their seeming appearance in analyzed. Reasons and limitations of superposition are considered. Gravitation is an example of nonlinearity. All objects interact so nonlinearity is universal. How quantum mechanics then fits in is shown. Dirac's equation comes from Poincaré group. Physics is necessarily impossible in any space but that with dimension 3+1. Spin-statistics is a property of rotation groups.

To mathematicians, mathematics is a happy game, to scientists a mere tool and to philosophers a Platonic mystery - or so the caricature runs. The caricature reflects the alleged 'cultural gap' between the disciplines a gap for which there too often has been, sadly, sound historical evidence. In many minds the lack of communication between philosophy and the exact disciplines is especially prominent. Yet in the past there was no separation - exact knowledge, covering both scientists and mathemati cians, was known as natural philosophy and the business of providing a critical view of the nature of reality and an accurate mathematical de scription of it constituted a single task from the glorious tradition begun by the early Greek philosophers even up until Newton's day (but I am thinking of Descartes and Leibniz I). The lack of communication between these professional groups has been particularly unfortunate, for the past half century has seen the most ex citing developments in mathematical physics since Newton. These devel opments hinged on the introduction of vast new reaches of mathematics into physics (non-Euclidean geometries, covariant formulations, non commutative algebras, functional analysis and so on) and conversely have challenged mathematicians to develop the appropriate mathematical fields. Equally, these developments have posed profound philosophical problems to do with the rejection of traditional conceptions concerning the nature of physical reality and physical theorising.

Characteristic of Schwabl's work, this volume features a compelling mathematical presentation in which all intermediate steps are derived and where numerous examples for application and exercises help the reader to gain a thorough working knowledge of the subject. The treatment of relativistic wave equations and their symmetries and the fundamentals of quantum field theory lay the foundations for advanced studies in solid-state physics, nuclear and elementary particle physics. New material has been added to this third edition.

This book is the first volume of proceedings from the joint conference X International Symposium “Quantum Theory and Symmetries” (QTS-X) and XII International Workshop “Lie Theory and Its Applications in Physics” (LT-XII), held on 19–25 June 2017 in Varna, Bulgaria. The QTS series was founded on the core principle that symmetries underlie all descriptions of quantum systems. It has since evolved into a symposium at the forefront of theoretical and mathematical physics. The LT series covers the whole field of Lie theory in its widest sense, together with its applications in many areas of physics. As an interface between mathematics and physics, the workshop serves as a meeting place for mathematicians and theoretical and mathematical physicists. In dividing the material between the two volumes, the Editor has sought to select papers that are more oriented toward mathematics for the first volume, and those focusing more on physics for the second. However, this division is relative, since many papers are equally suitable for either volume. The topics addressed in this volume represent the latest trends in the fields covered by the joint conferences: representation theory, integrability, entanglement, quantum groups, number theory, conformal geometry, quantum affine superalgebras, noncommutative geometry. Further, they present various mathematical results: on minuscule modules, symmetry breaking operators, Kashiwara crystals, meta-conformal invariance, the superintegrable Zernike system.

This book contains a systematic exposition of the theory of spinors in finite-dimensional Euclidean and Riemannian spaces. The applications of spinors in field theory and relativistic mechanics of continuous media are considered. The main mathematical part is connected with the study of invariant algebraic and geometric relations between spinors and tensors. The theory of spinors and the methods of the tensor representation of spinors and spinor equations are thoroughly expounded in four-dimensional and three-dimensional spaces. Very useful and important relations are derived that express the derivatives of the spinor fields in terms of the derivatives of various tensor fields. The problems associated with an invariant description of spinors as objects that do not depend on the choice of a coordinate system are addressed in detail. As an application, the author considers an invariant tensor formulation of certain classes of differential spinor equations containing, in particular, the most important spinor equations of field theory and quantum mechanics. Exact solutions of the Einstein–Dirac equations, nonlinear Heisenberg's spinor equations, and equations for relativistic spin fluids are given. The book presents a large body of factual material and is suited for use as a handbook. It is intended for specialists in theoretical physics, as well as for students and post-graduate students of physical and mathematical specialties.

This book is a modern introduction to the ideas and techniques of quantum field theory. After a brief overview of particle physics and a survey of relativistic wave equations and Lagrangian methods, the author develops the quantum theory of scalar and spinor fields, and then of gauge fields. The emphasis throughout is on functional methods, which have played a large part in modern field theory. The book concludes with a brief survey of "topological" objects in field theory and, new to this edition, a chapter devoted to supersymmetry. Graduate students in particle physics and high energy physics will benefit from this book.

This book on the theory of three-dimensional spinors and their applications fills an important gap in the literature. It gives an introductory treatment of spinors. From the reviews: "Gathers much of what can be done with 3-D spinors in an easy-to-read, self-contained form designed for applications that will supplement many available spinor treatments. The book...should be appealing to graduate students and researchers in relativity and mathematical physics." -—MATHEMATICAL REVIEWS

Relativistic Quantum Mechanics - Wave Equations concentrates mainly on the wave equations for spin-0 and spin-1/2 particles. Chapter 1 deals with the Klein-Gordon equation and its properties and applications. The chapters that follow introduce the Dirac equation, investigate its covariance properties and present various approaches to obtaining solutions. Numerous applications are discussed in detail, including the two-center Dirac equation, hole theory, CPT symmetry, Klein's paradox, and relativistic symmetry principles. Chapter 15 presents the relativistic wave equations for higher spin (Proca, Rarita-Schwinger, and Bargmann-Wigner). The extensive presentation of the mathematical tools and the 62 worked examples and problems make this a unique text for an advanced quantum mechanics course.

An explanation of how quantum processes may be visualised without ambiguity, in terms of a simple physical model.

Written by two of the most prominent leaders in particle physics, Relativistic Quantum Mechanics: An Introduction to Relativistic Quantum Fields provides a classroom-tested introduction to the formal and conceptual foundations of quantum field theory.

Designed for advanced undergraduate- and graduate-level physics students, the text only requires previous courses in classical mechanics, relativity, and quantum mechanics. The introductory chapters of the book summarize the theory of special relativity and its application to the classical description of the motion of a free particle and a field. The authors then explain the quantum formulation of field theory through the simple example of a scalar field described by the Klein–Gordon equation as well as its extension to the case of spin 1?2 particles described by the Dirac equation. They also present the elements necessary for constructing the foundational theories of the standard model of electroweak interactions, namely quantum electrodynamics and the Fermi theory of neutron beta decay. Many applications to quantum electrodynamics and weak interaction processes are thoroughly analyzed. The book also explores the timely topic of neutrino oscillations. Logically progressing from the fundamentals to recent discoveries, this textbook provides students with the essential foundation to study more advanced theoretical physics and elementary particle physics. It will help them understand the theory of electroweak interactions and gauge theories. View the second book in this collection: Electroweak Interactions.

Focusing on the principles of quantum mechanics, this text for upper-level undergraduates and graduate students introduces and resolves special physical problems with more than 100 exercises. 1967 edition.

This text systematically presents the basics of quantum mechanics, emphasizing the role of Lie groups, Lie algebras, and their unitary representations. The mathematical structure of the subject is brought to the fore, intentionally avoiding significant overlap with material from standard physics courses in quantum mechanics and quantum field theory. The level of presentation is attractive to mathematics students looking to learn about both quantum mechanics and representation theory, while also appealing to physics students who would like to know more about the mathematics underlying the subject. This text showcases the numerous differences between typical mathematical and physical treatments of the subject. The latter portions of the book focus on central mathematical objects that occur in the Standard Model of particle physics, underlining the deep and intimate connections between mathematics and the physical world. While an elementary physics course of some kind would be helpful to the reader, no specific background in physics is assumed, making this book accessible to students with a grounding in multivariable calculus and linear algebra. Many exercises are provided to develop the reader's understanding of and facility in quantum-theoretical concepts and calculations.

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Invented by Dirac in creating his relativistic quantum theory of the electron, spinors are important in quantum theory, relativity, nuclear physics, atomic and molecular physics, and condensed matter physics. Essentially, they are the mathematical entities that correspond to electrons in the same way that ordinary wave functions correspond to classical particles. Because of their relations to the rotation group SO(n) and the unitary group SU(n), this discussion will be of interest to applied mathematicians as well as physicists.

This book is intended for physicists and chemists who need to understand the theory of atomic and molecular structure and processes, and who wish to apply the theory to practical problems. As far as practicable, the book provides a self-contained account of the theory of relativistic atomic and molecular structure, based on the accepted formalism of bound-state Quantum Electrodynamics. The author was elected a Fellow of the Royal Society of London in 1992.

When does physics depart the realm of testable hypothesis and come to resemble theology? Peter Woit argues that string theory isn't just going in the wrong direction, it's not even science. Not Even Wrong shows that what many physicists call superstring “theory” is not a theory at all. It makes no predictions, not even wrong ones, and this very lack of falsifiability is what has allowed the subject to survive and flourish. Peter Woit explains why the mathematical conditions for progress in physics are entirely absent from superstring theory today, offering the other side of the story.

This textbook gives a connected mathematical derivation of the important mathematical results, concentrating on the central ideas without including elaborate detail or unnecessary rigour, and explaining in the simplest terms the symbols and concepts which confront the researcher in solid state, nuclear or high-energy physics.

Quantum physics and special relativity theory were two of the greatest breakthroughs in physics during the twentieth century and contributed to paradigm shifts in physics. This book combines these two discoveries to provide a complete description of the fundamentals of relativistic quantum physics, guiding the reader effortlessly from relativistic quantum mechanics to basic quantum field theory. The book gives a thorough and detailed treatment of the subject, beginning with the classification of particles, the Klein–Gordon equation and the Dirac equation. It then moves on to the canonical quantization procedure of the Klein–Gordon, Dirac and electromagnetic fields. Classical Yang–Mills theory, the LSZ formalism, perturbation theory, elementary processes in QED are introduced, and regularization, renormalization and radiative corrections are explored. With exercises scattered through the text and problems at the end of most chapters, the book is ideal for advanced undergraduate and graduate students in theoretical physics.

From Spinors To Quantum MechanicsWorld Scientific
Quantum Mechanics deals with various aspects of quantum mechanics and covers topics ranging from the uncertainty principle and the principle of superposition to conservation laws, Schrödinger's equation, and perturbation theory. Spin, radiation, and the identity of particles are also discussed, along with the atom, the diatomic molecule, elastic and inelastic collisions, and Feynman diagrams. Comprised of 16 chapters, this volume begins with an overview of non-relativistic quantum theory and the basic concepts of quantum mechanics such as the principles of uncertainty and superposition, operators, and the density matrix. Subsequent chapters deal with conservation laws in quantum mechanics; Schrödinger's equation and general properties of its solutions; perturbations independent of time and dependent on time; spin and the spin operator; and the principle of indistinguishability of similar particles. The atom and its electron states are also examined, together with diatomic molecules; elastic and inelastic collisions; photons and electrons; Dirac's equation; and particles and antiparticles. The final chapter is devoted to Feynman diagrams, paying particular attention to the scattering matrix, radiative corrections, and radiative shift of atomic levels. This book will be of interest to physicists.
This book continues the fundamental work of Arnold Sommerfeld and David Hestenes formulating theoretical physics in terms of Minkowski space-time geometry. We see how the standard matrix version of the Dirac equation can be reformulated in terms of a real space-time algebra, thus revealing a geometric meaning for the “number i” in quantum mechanics. Next, it is examined in some detail how electroweak theory can be integrated into the Dirac theory and this way interpreted in terms of space-time geometry. Finally, some implications for quantum electrodynamics are considered. The presentation of real quantum electromagnetism is expressed in an addendum. The book covers both the use of the complex and the real languages and allows the reader acquainted with the first language to make a step by step translation to the second one.
This monograph is a sequel to my earlier work, General Relativity and Matter [1], which will be referred to henceforth as GRM. The monograph, GRM, focuses on the full set of implications of General Relativity Theory, as a fundamental theory of matter in all domains, from elementary particle physics to cosmology. It is shown there to exhibit an explicit unification of the gravitational and electromagnetic fields of force with the inertial manifestations of matter, expressing the latter explicitly in terms of a covariant field theory within the structure of this general theory. This monograph will focus, primarily, on the special relativistic limit of the part of this general field theory of matter that deals with inertia, in the domain where quantum mechanics has been evoked in contemporary physics as a funda mental explanation for the behavior of elementary matter. Many of the results presented in this book are based on earlier published works in the journals, which will be listed in the Bibliography. These results will be presented here in an expanded form, with more

discussion on the motivation and explanation for the theoretical development of the subject than space would allow in normal journal articles, and they will be presented in one place where there would then be a more unified and coherent explication of the subject.

The French mathematician Élie Cartan (1869–1951) was one of the founders of the modern theory of Lie groups, a subject of central importance in mathematics and also one with many applications. In this volume, he describes the orthogonal groups, either with real or complex parameters including reflections, and also the related groups with indefinite metrics. He develops the theory of spinors (he discovered the general mathematical form of spinors in 1913) systematically by giving a purely geometrical definition of these mathematical entities; this geometrical origin makes it very easy to introduce spinors into Riemannian geometry, and particularly to apply the idea of parallel transport to these geometrical entities. The book is divided into two parts. The first is devoted to generalities on the group of rotations in n-dimensional space and on the linear representations of groups, and to the theory of spinors in three-dimensional space. Finally, the linear representations of the group of rotations in that space (of particular importance to quantum mechanics) are also examined. The second part is devoted to the theory of spinors in spaces of any number of dimensions, and particularly in the space of special relativity (Minkowski space). While the basic orientation of the book as a whole is mathematical, physicists will be especially interested in the final chapters treating the applications of spinors in the rotation and Lorentz groups. In this connection, Cartan shows how to derive the "Dirac" equation for any group, and extends the equation to general relativity. One of the greatest mathematicians of the 20th century, Cartan made notable contributions in mathematical physics, differential geometry, and group theory. Although a profound theorist, he was able to explain difficult concepts with clarity and simplicity. In this detailed, explicit treatise, mathematicians specializing in quantum mechanics will find his lucid approach a great value.

From Spinors to Quantum Mechanics discusses group theory and its use in quantum mechanics. Chapters 1 to 4 offer an introduction to group theory, and it provides the reader with an exact and clear intuition of what a spinor is, showing that spinors are just a mathematically complete notation for group elements. Chapter 5 contains the first rigorous derivation of the Dirac equation from a simple set of assumptions. The remaining chapters will interest the advanced reader who is interested in the meaning of quantum mechanics. They propose a novel approach to the foundations of quantum mechanics, based on the idea that the meaning of the formalism is already provided by the mathematics.In the traditional approach to quantum mechanics as initiated by Heisenberg, one has to start from a number of experimental results and then derive a set of rules and calculations that reproduce the observed experimental results. In such an inductive approach the underlying assumptions are not given at the outset. The reader has to figure them out, and this has proven to be difficult. The book shows that a different, bottom-up approach to quantum mechanics is possible, which merits further investigation as it demonstrates that with the methods used, the reader can obtain the correct results in a context where one would hitherto not expect this to be possible.

The text Quantum Mechanics - An Introduction has found many friends among physics students and researchers so that the need for a third edition has arisen. There was no need for a major revision of the text but I have taken the opportunity to make several amendments and improvements. A number of misprints and minor errors have been corrected and a few clarifying remarks have been added at various places. A few figures have been added or revised, in particular the three-dimensional density plots in Chap. 9. I am grateful to several colleagues for helpful comments, in particular to Prof. R.A. King (Calgary) who supplied a comprehensive list of corrections. I also thank Dr. A. Scherdin for help with the figures and Dr. R. Mattiello who has supervised the preparation of the third edition of the book. Furthermore I acknowledge the agreeable collaboration with Dr. H. 1. Kolsch and his team at Springer-Verlag, Heidelberg.

The main topic of this book is quantum mechanics, as the title indicates. It specifically targets those topics within quantum mechanics that are needed to understand modern semiconductor theory. It begins with the motivation for quantum mechanics and why classical physics fails when dealing with very small particles and small dimensions. Two key features make this book different from others on quantum mechanics, even those usually intended for engineers: First, after a brief introduction, much of the development is through Fourier theory, a topic that is at the heart of most electrical engineering theory. In this manner, the explanation of the quantum mechanics is rooted in the mathematics familiar to every electrical engineer. Secondly, beginning with the first chapter, simple computer programs in MATLAB are used to illustrate the principles. The programs can easily be copied and used by the reader to do the exercises at the end of the chapters or to just become more familiar with the material. Many of the figures in this book have a title across the top. This title is the name of the MATLAB program that was used to generate that figure. These programs are available to the reader. Appendix D lists all the programs, and they are also downloadable at http://booksupport.wiley.com

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.

Trieste, Italy, 5 September 2005 and Losinj, Croatia, 7-9 September 2005

Masterful exposition develops important concepts from experimental evidence and theory related to wave nature of free particles. Topics include classical mechanics of point particles and problems of atomic and molecular structure. 1957 edition.

Relativistic Quantum Mechanics. Wave Equations concentrates mainly on the wave equations for spin-0 and spin-1/2 particles. Chapter 1 deals with the Klein-Gordon equation and its properties and applications. The chapters that follow introduce the Dirac equation, investigate its covariance properties and present various approaches to obtaining solutions. Numerous applications are discussed in detail, including the two-center Dirac equation, hole theory, CPT symmetry, Klein's paradox, and relativistic symmetry principles. Chapter 15 presents the relativistic wave equations for higher spin (Proca, Rarita-Schwinger, and Bargmann-Wigner). The extensive presentation of the mathematical tools and the 62 worked examples and problems make this a unique text for an advanced quantum mechanics course. This third edition has been slightly revised to bring the text up-to-date.

Classical Charged Particle Beam Optics used in the design and operation of all present-day charged particle beam devices, from low energy electron microscopes to high energy particle accelerators, is entirely based on classical mechanics. A question of curiosity is: How is classical charged particle beam optics so successful in practice though the particles of the beam, like electrons, are quantum mechanical? Quantum Mechanics of Charged Particle Beam Optics answers this question with a comprehensive formulation of ‘Quantum Charged Particle Beam Optics’ applicable to any charged particle beam device.

More than a generation of Gennan-speaking students around the world have worked their way to an understanding and appreciation of the power and beauty of modern theoretical physics - with mathematics, the most fundamental of sciences - using Walter Greiner's textbooks as their guide. The idea of developing a coherent, complete presentation of an entire field of science in a series of closely related textbooks is not a new one. Many older physicists remember with real pleasure their sense of adventure and discovery as they worked their ways through the classic series by Sommerfeld, by Planck and by Landau and Lifshitz. From the students' viewpoint, there are a great many obvious advantages to be gained through use of consistent notation, logical ordering of topics and coherence of presentation; beyond this, the complete coverage of the science provides a unique opportunity for the author to convey his personal enthusiasm and love for his subject. The present five volume set, Theoretical Physics, is in fact only that part of the complete set of textbooks developed by Greiner and his students that presents the quantum theory. I have long urged him to make the remaining volumes on classical mechanics and dynamics, on electromagnetism, on nuclear and particle physics, and on special topics available to an English-speaking audience as well, and we can hope for these companion volumes covering all of theoretical physics some time in the future.

This book is designed to make accessible to nonspecialists the still evolving concepts of quantum mechanics and the terminology in which these are expressed. The opening chapters summarize elementary concepts of twentieth century quantum mechanics and describe the mathematical methods employed in the field, with clear explanation of, for example, Hilbert space, complex variables, complex vector spaces and Dirac notation, and the Heisenberg uncertainty principle. After detailed discussion of the Schrödinger equation, subsequent chapters focus on isotropic vectors, used to construct spinors, and on conceptual problems associated with measurement, superposition, and decoherence in quantum systems. Here, due attention is paid to Bell's inequality and the possible existence of hidden variables. Finally, progression toward quantum computation is examined in detail: if quantum computers can be made practicable, enormous enhancements in computing power, artificial intelligence, and secure communication will result. This book will be of interest to a wide readership seeking to understand modern quantum mechanics and its potential applications.

Quantum mechanics impacts on many areas of physics from pure theory to applications. However it is difficult to interpret, and philosophical contradictions and counter-intuitive results are apparent at a fundamental level. This book presents current understanding of the theory, providing a historical introduction and discussing many of its interpretations. Fully revised from the first edition, this book contains state-of-the-art research including loophole-free experimental Bell test, and theorems on the reality of the wave function including the PBR theorem, and a new section on quantum simulation. More interpretations are now included, and these are described and compared, including discussion of their successes and difficulties. Other sections have been expanded, including quantum error correction codes and the reference section. It is ideal for researchers in physics and maths, and philosophers of science interested in quantum physics and its foundations.

1. Hilbert Space The words "Hilbert space" here will always denote what math ematicians call a separable Hilbert space. It is composed of vectors each with a denumerable infinity of coordinates ql' q2' Q3, ... Usually the coordinates are considered to be complex numbers and each vector has a squared length ~rIQrI2. This squared length must converge in order that the q's may specify a Hilbert vector. Let us express qr in terms of real and imaginary parts, qr = Xr + iYr' Then the squared length is l:.r(x; + y;). The x's and y's may be looked upon as the coordinates of a vector. It is again a Hilbert

vector, but it is a real Hilbert vector, with only real coordinates. Thus a complex Hilbert vector uniquely determines a real Hilbert vector. The second vector has, at first sight, twice as many coordinates as the first one. But twice a denumerable in finity is again a denumerable infinity, so the second vector has the same number of coordinates as the first. Thus a complex Hilbert vector is not a more general kind of quantity than a real one.