

Chapter 6

Quantum Field Theory in General Space-Times

After these lengthy preliminaries, we are finally ready to discuss curved space-time.

CANONICAL FORMALISM

The standard free field in flat space-time is governed by the Klein-Gordon equation,

$$\frac{\partial^2 \phi}{\partial t^2} - \nabla^2 \phi + m^2 \phi = 0.$$

An action integral which generates this equation is

$$S = \int_{\mathbf{R}^N} d^N x \frac{1}{2} [\eta^{\mu\nu} \partial_\mu \phi(\underline{x}) \partial_\nu \phi(\underline{x}) - m^2 \phi(\underline{x})^2],$$

where η is the metric tensor of flat space-time, (5.4), and $N \equiv d + 1$ is the space-time dimension. (There was a time when to suggest that N could be something other than 4 was to mark oneself as a mathematician dabbling in physics. Nowadays, under the influence of Kaluza-Klein and superstring theories, no apology is necessary.)

The reader who is unfamiliar with the extension of the Lagrangian formalism of Chapter 1 to field theories would benefit from reading Hill 1951. Suffice it to say here that the integrand of S is called the *Lagrangian density*, $\mathcal{L}$, and that the space-time integration combines the summation over degrees of freedom, which creates a Lagrangian in the sense of Chapter 1, with the time integration which forms the action from the Lagrangian. Thenceforth, in much of the formalism the space and time variables are treated on an equal footing.

We shall generalize the Klein-Gordon Lagrangian [density] to curved space-time, and then quantize the resulting theory “canonically” in analogy with quantum mechanics.

A geometrically covariant generalization of $\mathcal{L}$ to a (pseudo-)Riemannian manifold is

$$\mathcal{L} = \frac{1}{2} [g(\underline{x})^{\mu\nu} \nabla_\mu \phi(\underline{x}) \nabla_\nu \phi(\underline{x}) - m^2 \phi(\underline{x})^2 - \xi R(\underline{x}) \phi(\underline{x})^2], \quad (6.1)$$

Aspects Of Quantum Field Theory In Curved Spacetime

Peter Collas, David Klein



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Aspects of Quantum Field Theory in Curved Spacetime Stephen A. Fulling, 1989-08-24 The theory of quantum fields on curved spacetimes has attracted great attention since the discovery by Stephen Hawking of black hole evaporation It remains an important subject for the understanding of such contemporary topics as inflationary cosmology quantum gravity and superstring theory This book provides for mathematicians an introduction to this field of physics in a language and from a viewpoint which such a reader should find congenial Physicists should also gain from reading this book a sound grasp of various aspects of the theory some of which have not been particularly emphasised in the existing review literature The topics covered include normal mode expansions for a general elliptic operator Fock space the Casimir effect the Klein paradox particle definition and particle creation in expanding universes asymptotic expansion of Green's functions and heat kernels and renormalisation of the stress tensor The style is pedagogic rather than formal some knowledge of general relativity and differential geometry is assumed but the author does supply background material on functional analysis and quantum field theory as required The book arose from a course taught to graduate students and could be used for self study or for advanced courses in relativity and quantum field theory

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Spacetime Stefan Hollands, 2000 *Aspects of Quantum Field Theory in Curved Space-time* Stephen A. Fulling, 1989 The theory of quantum fields on curved spacetimes has attracted great attention since the discovery by Stephen Hawking of black hole evaporation It remains an important subject for the understanding of such contemporary topics as inflationary cosmology quantum gravity and superstring theory This book provides for mathematicians an introduction to this field of physics in a language and from a viewpoint which such a reader should find congenial Physicists should also gain from reading this book a sound grasp of various aspects of the theory some of which have not been particularly emphasised in the existing review literature The topics covered include normal mode expansions for a general elliptic operator Fock space the Casimir effect the Klein paradox particle definition and particle creation in expanding universes asymptotic expansion of Green's functions and heat kernels and renormalisation of the stress tensor The style is pedagogic rather than formal some knowledge of general relativity and differential geometry is assumed but the author does supply background material on functional analysis and quantum field theory as required The book arose from a course taught to graduate students and could be used for self study or for advanced courses in relativity and quantum field theory

Finite Aspects of Quantum Field Theory on Curved Space-time A. C. Ottewill, University of Oxford, 1982 *Quantum Fields in Curved Space* N. D. Birrell, P. C. W. Davies, 1984-02-23 Identifies information sources and shows how to develop a job search strategy Gives valuable advice on job interviews and on how a new employee can keep his job

Quantum Field Theory in Curved Spacetime Leonard Parker, David Toms, 2009-08-20 Suitable for graduate students this book develops quantum field theory in curved spacetime in a pedagogical style

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field theory in curved spacetime has been remarkably fruitful It can be used to explain how the large scale structure of the universe and the anisotropies of the cosmic background radiation that we observe today first arose Similarly it provides a deep connection between general relativity thermodynamics and quantum field theory This book develops quantum field theory in curved spacetime in a pedagogical style suitable for graduate students The authors present detailed physically motivated derivations of cosmological and black hole processes in which curved spacetime plays a key role They explain how such processes in the rapidly expanding early universe leave observable consequences today and how in the context of evaporating black holes these processes uncover deep connections between gravitation and elementary particles The authors also lucidly describe many other aspects of free and interacting quantized fields in curved spacetime Aspects of (quantum) Field Theory on Curved Spacetimes, Particularly in the Presence of Boundaries Umberto Lupo, 2015

Cosmological Applications of Algebraic Quantum Field Theory in Curved Spacetimes Thomas-Paul Hack, 2015-08-17 This book provides a largely self contained and broadly accessible exposition on two cosmological applications of algebraic quantum field theory QFT in curved spacetime a fundamental analysis of the cosmological evolution according to the Standard Model of Cosmology and a fundamental study of the perturbations in inflation The two central sections of the book dealing with these applications are preceded by sections providing a pedagogical introduction to the subject Introductory material on the construction of linear QFTs on general curved spacetimes with and without gauge symmetry in the algebraic approach physically meaningful quantum states on general curved spacetimes and the backreaction of quantum fields in curved spacetimes via the semiclassical Einstein equation is also given The reader should have a basic understanding of General Relativity and QFT on Minkowski spacetime but no background in QFT on curved spacetimes or the algebraic approach to QFT is required **The Dirac Equation in Curved Spacetime** Peter Collas, David Klein, 2019-03-21 This book explains and develops the Dirac equation in the context of general relativistic quantum mechanics in a range of spacetime dimensions It clarifies the subject by carefully pointing out the various conventions used and explaining how they are related to each other The prerequisites are familiarity with general relativity and an exposure to the Dirac equation at the level of special relativistic quantum mechanics but a review of this latter topic is given in the first chapter as a reference and framework for the physical interpretations that follow Worked examples and exercises with solutions are provided Appendices include reviews of topics used in the body of the text This book should benefit researchers and graduate students in general relativity and in condensed matter *Advances in Algebraic Quantum Field Theory* Romeo Brunetti, Claudio Dappiaggi, Klaus Fredenhagen, Jakob Yngvason, 2015-09-04 This text focuses on the algebraic formulation of quantum field theory from the introductory aspects to the applications to concrete problems of physical interest The book is divided in thematic chapters covering both introductory and more advanced topics These include the algebraic perturbative approach to interacting quantum field theories algebraic quantum field theory on curved spacetimes from its structural

aspects to the applications in cosmology and to the role of quantum spacetimes algebraic conformal field theory the Kitaev's quantum double model from the point of view of local quantum physics and constructive aspects in relation to integrable models and deformation techniques The book is addressed to master and graduate students both in mathematics and in physics who are interested in learning the structural aspects and the applications of algebraic quantum field theory

Quantum Mechanics in Curved Space-Time Jurgen Audretsch, V. de Sabbata, 2012-12-06 Quantum mechanics and quantum field theory on one hand and Gravity as a theory of curved space time on the other are the two great conceptual schemes of modern theoretical physics For many decades they have lived peacefully together for a simple reason it was a coexistence without much interaction There has been the family of relativists and the other family of elementary particle physicists and both sides have been convinced that their problems have not very much to do with the problems of the respective other side This was a situation which could not last forever because the two theoretical schemes have a particular structural trait in common their claim for totality and universality Namely on one hand all physical theories have to be formulated in a quantum mechanical manner and on the other hand gravity as curved space time influences all processes and vice versa It was therefore only a question of time that physically relevant domains of application would attract a general interest which demand a combined application of both theoretical schemes But it is immediately obvious that such an application of both schemes is possible if the schemes are taken as they are Something new is needed which reconciles gravity and quantum mechanics During the last two decades we are now doing the first steps towards this more general theory and we are confronted with fundamental difficulties

Proceedings of the 16th International Conference on General Relativity & Gravitation Nigel Bishop, Sunil D. Maharaj, 2002 The 16th conference of the International Society on General Relativity and Gravitation GR16 held at the International Convention Centre in Durban South Africa from 15 to 21 July was attended by 450 delegates from around the world The scientific programme comprised 18 plenary lectures one public lecture and 19 workshops which excepting three plenary lectures are presented in this proceedings It was the first major international conference on general relativity and gravitation held on the African continent

High Energy Physics And Cosmology - Proceedings Of The 1990 Summer School Jogesh C Pati, Seifallah Randjbar-Daemi, Ergin Sezgin, Qaisar Shafi, 1991-05-16 This School presented topics of current interest in high energy physics including Superstrings Unified Theories and Cosmology

Differential Equations, Asymptotic Analysis, and Mathematical Physics Michael Demuth, Bert-Wolfgang Schulze, 1997 This volume contains a collection of original papers associated with the International Conference on Partial Differential Equations held in Potsdam July 29 to August 2 1996 The conference has taken place every year on a high scientific level since 1991 this event is connected with the activities of the Max Planck Research Group for Partial Differential Equations at Potsdam Outstanding researchers and specialists from Armenia Belarus Belgium Bulgaria Canada China France Germany Great Britain India Israel Italy Japan Poland Romania Russia Spain Sweden Switzerland Ukraine and the USA contribute to this

volume The main topics concern recent progress in partial differential equations microlocal analysis pseudo differential operators on manifolds with singularities aspects in differential geometry and index theory operator theory and operator algebras stochastic spectral analysis semigroups Dirichlet forms Schrodinger operators semiclassical analysis and scattering theory

The de Sitter (dS) Group and Its Representations Mohammad Enayati, Jean-Pierre Gazeau, Hamed Pejhan, Anzhong Wang, 2024-04-29 This Second Edition is a comprehensive update integrating the latest research and theoretical advancements in the field of de Sitter dS group representations Building on the success of the first edition the book offers a more in depth analysis of mathematical aspects conceptual foundations and practical implications related to the dS group including its Lie manifold Lie algebra and co adjoint orbits viewing the latter as potential classical elementary systems within the context of dS spacetime Additionally the examination of unitary irreducible representations UIRs sheds light on the potential existence of quantum elementary systems within the dS spacetime framework The authors emphasize consistency with Wigner's approach to elementary systems incorporate Wigner's principles and exploring projective UIRs of the dS group and provide a deeper insight into the nature of dS elementary systems Particular attention is paid to the smooth transition from classical to quantum theory the physical content under vanishing curvature and the thermal interpretation from a quantum perspective The book also focuses on the physical interpretation of elementary systems in curved spacetimes recognizing the limitations of traditional concepts derived from flat Minkowski spacetime and the Poincaré group

Physical Theory Lawrence Sklar, 2014 In nine new essays distinguished philosophers of science discuss outstanding issues in scientific methodology especially that of the physical sciences and address philosophical questions that arise in the exploration of the foundations of contemporary science

Qubits and Spacetime Caslav Brukner, Jakub Mielczarek, Daniele Oriti, 2022-08-30

Dialogues Between Physics and Mathematics Mo-Lin Ge, Yang-Hui He, 2022-12-10 This volume celebrates the 100th birthday of Professor Chen Ning Frank Yang Nobel 1957 one of the giants of modern science and a living legend Starting with reminiscences of Yang's time at the research centre for theoretical physics at Stonybrook now named C N Yang Institute by his successor Peter van Nieuwenhuizen the book is a collection of articles by world renowned mathematicians and theoretical physicists This emphasizes the Dialogue Between Physics and Mathematics that has been a central theme of Professor Yang's contributions to contemporary science Fittingly the contributions to this volume range from experimental physics to pure mathematics via mathematical physics On the physics side the contributions are from Sir Anthony Leggett Nobel 2003 Jian Wei Pan Willis E Lamb Award 2018 Alexander Polyakov Breakthrough Prize 2013 Gerard 't Hooft Nobel 1999 Frank Wilczek Nobel 2004 Qikun Xue Fritz London Prize 2020 and Zhongxian Zhao Bernd T Matthias Prize 2015 covering an array of topics from superconductivity to the foundations of quantum mechanics In mathematical physics there are contributions by Sir Roger Penrose Nobel 2022 and Edward Witten Fields Medal 1990 on quantum twistors and quantum field theory respectively On the mathematics side the contributions by Vladimir Drinfeld Fields Medal 1990 Louis Kauffman

Wiener Gold Medal 2014 and Yuri Manin Cantor Medal 2002 offer novel ideas from knot theory to arithmetic geometry. Inspired by the original ideas of C N Yang, this unique collection of papers by masters of physics and mathematics provides at the highest level contemporary research directions for graduate students and experts alike. *Quantum Field Theory in Curved Spacetime and Black Hole Thermodynamics* Robert M. Wald, 1994-11-15. In this book, Robert Wald provides a coherent pedagogical introduction to the formulation of quantum field theory in curved spacetime. He begins with a treatment of the ordinary one-dimensional quantum harmonic oscillator, progresses through the construction of quantum field theory in flat spacetime to possible constructions of quantum field theory in curved spacetime, and ultimately to an algebraic formulation of the theory. In his presentation, Wald disentangles essential features of the theory from inessential ones, such as a particle interpretation, and clarifies relationships between various approaches to the formulation of the theory. He also provides a comprehensive up-to-date account of the Unruh effect, the Hawking effect, and some of its ramifications. In particular, the subject of black hole thermodynamics, which remains an active area of research, is treated in depth. This book will be accessible to students and researchers who have had introductory courses in general relativity and quantum field theory, and will be of interest to scientists in general relativity and related fields.

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