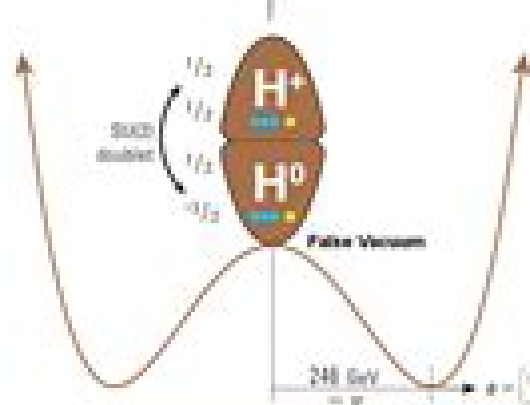


# The Standard Model of Particle Physics

Spin 0  
(Higgs Boson)



$$V(\phi) = -\frac{m^2\phi^2}{2} + \frac{\lambda\phi^4}{4}$$



(A) Unbroken Symmetry (Symmetric phase)

(B) Broken Symmetry (Higgs phase/condensate)

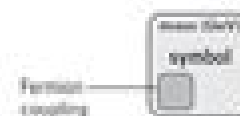
Spin 1/2  
(Fermions)



	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	
Left handed SU(2) doublet	$\begin{pmatrix} u \\ d \end{pmatrix}$	$\begin{pmatrix} c \\ s \end{pmatrix}$	$\begin{pmatrix} t \\ b \end{pmatrix}$	Quarks
Left handed SU(2) doublet	$\begin{pmatrix} \nu_e \\ e \end{pmatrix}$	$\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$	$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$	Leptons

10<sup>-12</sup> sec after BB, ~ 100 GeV

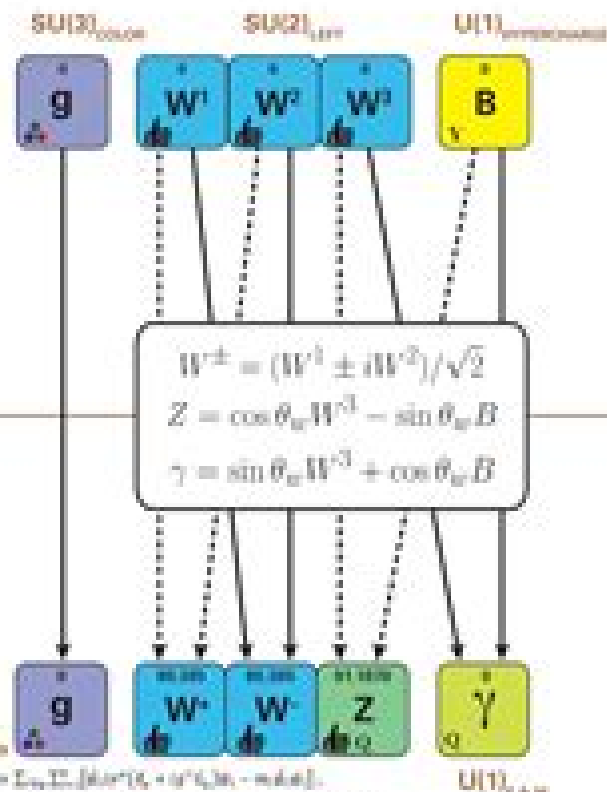
Spin 1  
(Gauge Bosons)



$$\cos \theta_W = \frac{g}{\sqrt{g^2 + g'^2}}$$

$$\sin \theta_W = \frac{g'}{\sqrt{g^2 + g'^2}}$$

$g$ : weak coupling constant  
 $g'$ : em. coupling constant



$$W^\pm = (W^1 \pm iW^2)/\sqrt{2}$$

$$Z = \cos \theta_W W^3 - \sin \theta_W B$$

$$\gamma = \sin \theta_W W^3 + \cos \theta_W B$$

$\mathcal{L}_{\text{int}} = -\frac{1}{2} g_{\text{color}}^2 \bar{\psi}_i \gamma_\mu T_a^i \psi_j A_\mu^a + \sum_{\text{fermions}} \bar{\psi}_i \gamma_\mu (g_W T_a^i W_\mu^a + g_Y Y_i B_\mu) \psi_i$   
where  $\psi_i$  is the spinor field,  $a, b$  the color charges, while the gauge field  $A_\mu^a = A_\mu^1 T_1 + A_\mu^2 T_2 + A_\mu^3 T_3 + A_\mu^4 T_4 + A_\mu^5 T_5 + A_\mu^6 T_6 + A_\mu^7 T_7 + A_\mu^8 T_8$ , the superscript 'a' is the gauge index from 1 to 8,  $g$  the coupling constant,  $\psi_i$  the sum of the spinors.



	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	
$\begin{pmatrix} u \\ d \end{pmatrix}_L$	$\begin{pmatrix} u \\ d \end{pmatrix}_L$	$\begin{pmatrix} c \\ s \end{pmatrix}_L$	$\begin{pmatrix} t \\ b \end{pmatrix}_L$	Quarks
$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L$	$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L$	$\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L$	$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$	Leptons

$$\mathcal{L}_f = \bar{\psi}_i \not{D} \psi_i - \bar{\psi}_i \psi_i - \bar{\psi}_i \psi_i^c$$

$$\text{where } \not{D} = \gamma_\mu (\partial_\mu + i g_W T_a^i W_\mu^a + i g_Y Y_i B_\mu) \text{ and } \psi_i^c = C \bar{\psi}_i^T$$

$$\mathcal{L}_b = \bar{\psi}_i \not{D} \psi_i - \bar{\psi}_i \psi_i - \bar{\psi}_i \psi_i^c$$

$$\text{where } \not{D} = \gamma_\mu (\partial_\mu + i g_W T_a^i W_\mu^a + i g_Y Y_i B_\mu) \text{ and } \psi_i^c = C \bar{\psi}_i^T$$

$$\mathcal{L}_g = -\frac{1}{4} g_{\text{color}}^2 F_{\mu\nu}^a F^{\mu\nu a} - \frac{1}{2} g_{\text{color}}^2 \bar{\psi}_i \gamma_\mu T_a^i \psi_j A_\mu^a$$

$$\text{where } F_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g_{\text{color}} (A_\mu^b A_\nu^c - A_\nu^b A_\mu^c)$$

# Quantum Field Theory

**Horatiu Nastase**



## **Quantum Field Theory:**

**Quantum Field Theory** François Gelis, 2019-07-11 This modern text combines fundamental principles with advanced topics and recent techniques in a rigorous and self contained treatment of quantum field theory Beginning with a review of basic principles starting with quantum mechanics and special relativity students can refresh their knowledge of elementary aspects of quantum field theory and perturbative calculations in the Standard Model Results and tools relevant to many applications are covered including canonical quantization path integrals non Abelian gauge theories and the renormalization group Advanced topics are explored with detail given on effective field theories quantum anomalies stable extended field configurations lattice field theory and field theory at a finite temperature or in the strong field regime Two chapters are dedicated to new methods for calculating scattering amplitudes spinor helicity on shell recursion and generalized unitarity equipping students with practical skills for research Accessibly written with numerous worked examples and end of chapter problems this is an essential text for graduate students The breadth of coverage makes it an equally excellent reference for researchers

Foundations Of Quantum Field Theory Klaus D Rothe, 2020-09-03 Based on a two semester course held at the University of Heidelberg Germany this book provides an adequate resource for the lecturer and the student The contents are primarily aimed at graduate students who wish to learn about the fundamental concepts behind constructing a Relativistic Quantum Theory of particles and fields So it provides a comprehensive foundation for the extension to Quantum Chromodynamics and Weak Interactions that are not included in this book

Quantum Field Theory Thanu Padmanabhan, 2016-02-02 This book describes in clear terms the Why What and the How of Quantum Field Theory The *raison d'être* of QFT is explained by starting from the dynamics of a relativistic particle and demonstrating how it leads to the notion of quantum fields Non perturbative aspects and the Wilsonian interpretation of field theory are emphasized right from the start Several interesting topics such as the Schwinger effect Davies Unruh effect Casimir effect and spontaneous symmetry breaking introduce the reader to the elegance and breadth of applicability of field theoretical concepts Complementing the conceptual aspects the book also develops all the relevant mathematical techniques in detail leading e.g. to the computation of anomalous magnetic moment of the electron and the two loop renormalisation of the self interacting scalar field It contains nearly a hundred problems of varying degrees of difficulty making it suitable for both self study and classroom use

**Quantum Field Theory for the Gifted Amateur** Tom Lancaster, Stephen J. Blundell, 2014-04-17 Quantum field theory is arguably the most far reaching and beautiful physical theory ever constructed with aspects more stringently tested and verified to greater precision than any other theory in physics Unfortunately the subject has gained a notorious reputation for difficulty with forbidding looking mathematics and a peculiar diagrammatic language described in an array of unforgiving weighty textbooks aimed firmly at aspiring professionals However quantum field theory is too important too beautiful and too engaging to be restricted to the professionals This book on quantum field theory is designed to be different It is written by

experimental physicists and aims to provide the interested amateur with a bridge from undergraduate physics to quantum field theory. The imagined reader is a gifted amateur possessing a curious and adaptable mind looking to be told an entertaining and intellectually stimulating story but who will not feel patronised if a few mathematical niceties are spelled out in detail. Using numerous worked examples, diagrams and careful physically motivated explanations, this book will smooth the path towards understanding the radically different and revolutionary view of the physical world that quantum field theory provides and which all physicists should have the opportunity to experience. Quantum Field Theory, as Simply as Possible Anthony Zee, 2023-01-17. Quantum field theory is by far the most spectacularly successful theory in physics but also one of the most mystifying. Quantum Field Theory as Simply as Possible provides an essential primer on the subject giving readers the conceptual foundations they need to wrap their heads around one of the most important yet baffling subjects in physics.

**General Principles of Quantum Field Theory** N.N. Bogolubov, Anatoly A. Logunov, A. I. Oksak, I. Todorov, 1989-12-31. The majority of the memorable results of relativistic quantum theory were obtained within the framework of the local quantum field approach. The explanation of the basic principles of the local theory and its mathematical structure has left its mark on all modern activity in this area. Originally the axiomatic approach arose from attempts to give a mathematical meaning to the quantum field theory of strong interactions of Yukawa type. The fields in such a theory are realized by operators in Hilbert space with a positive Poincaré invariant scalar product. This classical part of the axiomatic approach attained its modern form as far back as the sixties. It has retained its importance even to this day in spite of the fact that nowadays the main prospects for the description of the electro-weak and strong interactions are in connection with the theory of gauge fields. In fact, from the point of view of the quark model, the theory of strong interactions of Wightman type was obtained by restricting attention to just the physical local operators such as hadronic fields consisting of fundamental quark fields acting in a Hilbert space of physical states. In principle, there are enough such physical fields for a description of hadronic physics, although this means that one must reject the traditional local Lagrangian formalism. The connection is restored in the approximation of low energy phenomenological Lagrangians. *Quantum Field Theory* Lowell S. Brown, 1992. This book develops quantum field theory starting from its foundation in quantum mechanics. Quantum field theory is the basic theory of elementary particle physics. In recent years, many techniques have been developed which extend and clarify this theory. This book incorporates these modern methods, giving a thoroughly modern pedagogic account which starts from first principles. The path integral formulation is introduced right at the beginning. The method of dimensional continuation is employed to regulate and renormalize the theory. This facilitates the introduction of the concepts of the renormalization group at an early stage. The notion of spontaneous symmetry breakdown is also introduced early on by the example of superfluid helium. Topics in quantum electrodynamics are described which have an analog in quantum chromodynamics. Some novel techniques are employed such as the use of dimensional continuation to compute the Lamb

shift Many problems are included      **Introduction to Quantum Field Theory** Horatiu Nastase, 2019-10-17 Quantum Field Theory provides a theoretical framework for understanding fields and the particles associated with them and is the basis of particle physics and condensed matter research This graduate level textbook provides a comprehensive introduction to quantum field theory giving equal emphasis to operator and path integral formalisms It covers modern research such as helicity spinors BCFW construction and generalized unitarity cuts as well as treating advanced topics including BRST quantization loop equations and finite temperature field theory Various quantum fields are described including scalar and fermionic fields Abelian vector fields and Quantum ElectroDynamics QED and finally non Abelian vector fields and Quantum ChromoDynamics QCD Applications to scattering cross sections in QED and QCD are also described Each chapter ends with exercises and an important concepts section allowing students to identify the key aspects of the chapter and test their understanding      **Quantum Field Theory in Condensed Matter Physics** Alexei M. Tsvelik, 2007-01-18 A new edition of a successful advanced text in condensed matter physics      **Quantum Field Theory** Franz Mandl, Graham Shaw, 2013-06-06 Following on from the successful first 1984 and revised 1993 editions this extended and revised text is designed as a short and simple introduction to quantum field theory for final year physics students and for postgraduate students beginning research in theoretical and experimental particle physics The three main objectives of the book are to Explain the basic physics and formalism of quantum field theory To make the reader proficient in theory calculations using Feynman diagrams To introduce the reader to gauge theories which play a central role in elementary particle physics Thus the first ten chapters deal with QED in the canonical formalism and are little changed from the first edition A brief introduction to gauge theories Chapter 11 is then followed by two sections which may be read independently of each other They cover QCD and related topics Chapters 12 15 and the unified electroweak theory Chapters 16 19 respectively Problems are provided at the end of each chapter New to this edition Five new chapters giving an introduction to quantum chromodynamics and the methods used to understand it in particular path integrals and the renormalization group The treatment of electroweak interactions has been revised and updated to take account of more recent experiments      *An Introduction To Quantum Field Theory* Michael E. Peskin, 2018-05-04 An Introduction to Quantum Field Theory is a textbook intended for the graduate physics course covering relativistic quantum mechanics quantum electrodynamics and Feynman diagrams The authors make these subjects accessible through carefully worked examples illustrating the technical aspects of the subject and intuitive explanations of what is going on behind the mathematics After presenting the basics of quantum electrodynamics the authors discuss the theory of renormalization and its relation to statistical mechanics and introduce the renormalization group This discussion sets the stage for a discussion of the physical principles that underlie the fundamental interactions of elementary particle physics and their description by gauge field theories      *Mathematical Foundations Of Quantum Field Theory* Albert Schwarz, 2020-04-15 The book is very different from other books devoted to quantum field theory both in the style of

exposition and in the choice of topics Written for both mathematicians and physicists the author explains the theoretical formulation with a mixture of rigorous proofs and heuristic arguments references are given for those who are looking for more details The author is also careful to avoid ambiguous definitions and statements that can be found in some physics textbooks In terms of topics almost all other books are devoted to relativistic quantum field theory conversely this book is concentrated on the material that does not depend on the assumptions of Lorentz invariance and or locality It contains also a chapter discussing application of methods of quantum field theory to statistical physics in particular to the derivation of the diagram techniques that appear in thermo field dynamics and Keldysh formalism It is not assumed that the reader is familiar with quantum mechanics the book contains a short introduction to quantum mechanics for mathematicians and an appendix devoted to some mathematical facts used in the book

*Quantum Field Theory* Eduardo Fradkin, 2021-03-23 The only graduate level textbook on quantum field theory that fully integrates perspectives from high energy condensed matter and statistical physics Quantum field theory was originally developed to describe quantum electrodynamics and other fundamental problems in high energy physics but today has become an invaluable conceptual and mathematical framework for addressing problems across physics including in condensed matter and statistical physics With this expansion of applications has come a new and deeper understanding of quantum field theory yet this perspective is still rarely reflected in teaching and textbooks on the subject Developed from a year long graduate course Eduardo Fradkin has taught for years to students of high energy condensed matter and statistical physics this comprehensive textbook provides a fully multicultural approach to quantum field theory covering the full breadth of its applications in one volume Brings together perspectives from high energy condensed matter and statistical physics in both the main text and exercises Takes students from basic techniques to the frontiers of physics Pays special attention to the relation between measurements and propagators and the computation of cross sections and response functions Focuses on renormalization and the renormalization group with an emphasis on fixed points scale invariance and their role in quantum field theory and phase transitions Other topics include non perturbative phenomena anomalies and conformal invariance Features numerous examples and extensive problem sets Also serves as an invaluable resource for researchers

**Fundamental Problems in Quantum Field Theory** Takehisa Fujita, Naohiro Kanda, 2013-08-07 Quantum physics is based on four fundamental interactions of electromagnetic weak gravitational and strong forces All the interactions are expressed in terms of fermion and boson fields which can describe the quantum states of electrons nucleons and photons in atoms or nuclei Correct behaviors of these particles can now be described by the basic field theory terminology and this textbook explains for the first time quantum field theory in a unifying method At present modern quantum theory is at a critical junction between different theories and this textbook presents a clear description of fundamental quantum fields with a sound theoretical framework No exotic theoretical concepts such as general relativity nor spontaneous symmetry breaking nor quantum anomaly are adopted in this textbook and indeed all the

observed physical quantities can be well understood within the standard field theory framework without introducing any non physical particles or fields From this textbook readers will be guided through a concrete future direction of quantum field theory and will learn how the motion of electrons in any kind of material can be understood in terms of fields or state vectors Readers will also learn about application of basic field theory in quantum chemistry quantum biology and so on Fundamental Problems in Quantum Field Theory is a handy resource for undergraduate and graduate students as well as supervisors involved in advanced courses in quantum physics

An Invitation to Quantum Field Theory Luis Alvarez-Gaumé, Miguel A. Vázquez-Mozo, 2011-11-26 This book provides an introduction to Quantum Field Theory QFT at an elementary level with only special relativity electromagnetism and quantum mechanics as prerequisites For this fresh approach to teaching QFT based on numerous lectures and courses given by the authors a representative sample of topics has been selected containing some of the more innovative challenging or subtle concepts They are presented with a minimum of technical details the discussion of the main ideas being more important than the presentation of the typically very technical mathematical details necessary to obtain the final results Special attention is given to the realization of symmetries in particle physics global and local symmetries explicit spontaneously broken and anomalous continuous symmetries as well as discrete symmetries Beyond providing an overview of the standard model of the strong weak and electromagnetic interactions and the current understanding of the origin of mass the text enumerates the general features of renormalization theory as well as providing a cursory description of effective field theories and the problem of naturalness in physics Among the more advanced topics the reader will find are an outline of the first principles derivation of the CPT theorem and the spin statistics connection As indicated by the title the main aim of this text is to motivate the reader to study QFT by providing a self contained and approachable introduction to the most exciting and challenging aspects of this successful theoretical framework

**A Prelude to Quantum Field Theory** John Donoghue, Lorenzo Sorbo, 2022-03-08 A Prelude to Quantum Field Theory offers a short introduction to quantum field theory QFT a powerful framework for understanding particle behavior that is an essential tool across many subfields of physics A subject that is typically taught at the graduate level in most physics departments quantum field theory is a unification of standard quantum theories and special relativity which depicts all particles as excitations that arise in underlying fields It extends quantum mechanics the modern theory of one or few particles in a way that is useful for the analysis of many particle systems in the real world As it requires a different style of thinking from quantum mechanics which is typically the undergraduate physics student's first encounter with the quantum world many beginners struggle with the transition to quantum field theory especially when working with traditional textbooks Existing books on the subject often tend to be large sophisticated and complete and an overwhelming wealth of information and technical detail makes it difficult for the novice to discern what is most important This book is a concise friendly entry for QFT beginners guiding the reader from the style of quantum mechanical thinking to that of QFT and distilling the key ideas

without a welter of unnecessary detail In contrast with standard texts which are predominantly particle physics centric this book is designed to be subfield neutral usable by students of any background and interest and easily adaptable in a course setting according to instructors preferences The authors conviction is that QFT is a core element of physics that should be understood by all PhD physicists but that developing an appreciation for it does not require digesting a large encyclopedic volume

**Quantum Mechanics, Quantum Field Theory** R. Mirman, 2001

Excision of errors and confusion about quantum mechanics and stimulation of thoughtful and adventurous readers are pre eminent rationales of this entire work these requiring definitions and analysis of underlying concepts of quantum mechanics of quantum field theory why probability is given by the absolute square what wavefunctions are and are not and why and many others and also examination of some from the philosophy of science People s beliefs about quantum mechanics are often just the reverse of what fundamental principles give seen most spectacularly with the EPR paradox The puzzles the mystical the bizarre come merely from negligence from blunders including the outlandish belief that the universe must be explained using classical physics Careless unthinking physicists and gullible journalists who naively accept their confusion as statements about nature cause so much misunderstanding and nonsense about physics Among the many examples considered are the non existence in quantum mechanics of waves and particles so of wave particle duality the reason that general relativity must be the quantum theory of gravity the mystery of the cosmological constant why people believe in it though it would be obvious to a high school student that there cannot be any it must be zero the absurdity and wild incorrectness of much of the discussion about the vacuum the required locality of quantum mechanics and the impossibility of action at a distance and many others Many blunders not only about physics come from abuse of language the use of words phrases sentences without content with connotation but no denotation of names quantum mechanics particles waves and so on that deceive and misrepresent of questions that ask nothing It is not only in physics that answers to questions without meaning smother and hide

Quantum Field Theory in a Semiotic Perspective Hans Günter Dosch, Volkhard F. Müller, Norman Sieroka, 2006-03-30

Viewing physical theories as symbolic constructions came to the fore in the middle of the nineteenth century with the emancipation of the classical theory of the electromagnetic field from mechanics most notably this happened through the work of Helmholtz Hertz Poincar and later Weyl The epistemological problems that nourished this development are today highlighted within quantum field theory The present essay starts off with a concise and non technical outline of the firmly based aspects of relativistic quantum field theory i e the very successful description of subnuclear phenomena The particular methods by which these different aspects have to be accessed then get described as distinct facets of quantum field theory The authors show how these different facets vary with respect to the relation between quantum fields and associated particles Thus by emphasising the respective role of various basic concepts involved the authors claim that only a very general epistemic approach can properly account for this diversity an account they trace back to the philosophical writings of the

aforementioned physicists and mathematicians Finally what they call their semiotic perspective on quantum field theory gets related to recent discussions within the philosophy of science and turns out to act as a counterbalance to for instance structural realism

**Quantum Field Theory and the Standard Model** Matthew D. Schwartz, 2013-12-15 Providing a comprehensive introduction to quantum field theory this textbook covers the development of particle physics from its foundations to the discovery of the Higgs boson Its combination of clear physical explanations with direct connections to experimental data and mathematical rigor make the subject accessible to students with a wide variety of backgrounds and interests Assuming only an undergraduate level understanding of quantum mechanics the book steadily develops the Standard Model and state of the art calculation techniques It includes multiple derivations of many important results with modern methods such as effective field theory and the renormalization group playing a prominent role Numerous worked examples and end of chapter problems enable students to reproduce classic results and to master quantum field theory as it is used today Based on a course taught by the author over many years this book is ideal for an introductory to advanced quantum field theory sequence or for independent study

**Lectures On Quantum Field Theory** Ashok Das, 2008-09-12 This book consists of the lectures for a two semester course on quantum field theory and as such is presented in a quite informal and personal manner The course starts with relativistic one particle systems and develops the basics of quantum field theory with an analysis of the representations of the Poincar group Canonical quantization is carried out for scalar fermion Abelian and non Abelian gauge theories Covariant quantization of gauge theories is also carried out with a detailed description of the BRST symmetry The Higgs phenomenon and the standard model of electroweak interactions are also developed systematically Regularization and BPHZ renormalization of field theories as well as gauge theories are discussed in detail leading to a derivation of the renormalization group equation In addition two chapters one on the Dirac quantization of constrained systems and another on discrete symmetries are included for completeness although these are not covered in the two semester course

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