DOWNLOAD PDF GAUGE THEORY IN PARTICLE PHYSICS

Chapter 1 : Introduction to gauge theory - Wikipedia

This is a practical introduction to the principal ideas in gauge theory and their applications to elementary particle physics. It explains technique and methodology with simple exposition backed up by many illustrative examples.

A fascinating aspect of string theory is that extended objects strings perceive spacetime geometry very differently from point particles. This makes it possible to have physical processes which change the topology of spacetime. String theory is automatically a theory of quantum gravity. As such, it should be possible to understand the process of black hole formation and evaporation within string theory. This is made difficult by the fact that black holes are intrinsically non-perturbative. These dualities provide a non-perturbative definition of string theory, in terms of a dual non-gravitational quantum field theory. The challenge then becomes understanding the way in which gravitational physics, and in particular the physics of black holes, emerges from the dual field theory. Extracting physical predictions from quantum field theory is a real challenge, in some cases requiring numerical simulations for example lattice gauge theory. However in some cases analytical tools are available. An important analytical approach to understanding quantum field theory is through the study of classical field configurations. Many quantum field theories have soliton solutions which carry magnetic charge. By studying the dynamics of these magnetic monopoles, one can obtain non-perturbative information about the behavior of the quantum field theory. In particular, in certain supersymmetric field theories, magnetic monopoles have provided crucial evidence for S-duality -- a symmetry which maps strong coupling to weak coupling, and exchanges electric and magnetic charge. In large part this is due to the exciting prospect of creating a deconfined quark-gluon plasma at RHIC , a heavy ion collider now running at Brookhaven. Given the complicated multi-particle dynamics of a heavy ion collision, clear signatures of a quark-gluon plasma are difficult to come by. Reliable predictions require a good understanding of nuclear and nucleon structure, thermalization processes in a heavy-ion collision, the nature of the QCD phase transition, and the hydrodynamics of a quark-gluon plasma. QCD also exhibits interesting behavior at high baryon density. When the baryon density is sufficiently large, it becomes energetically favorable for quarks to bind together in pairs. This pairing is the analog of Cooper pairing in ordinary superconductivity. The pairing turns the QCD ground state into a color superconductor -- a novel phenomenon which could be important for understanding core-collapse supernovae. The group has pioneered the practical applications of domain wall fermions to lattice QCD. This technique allows one to realize chiral symmetry on a lattice, at the price of introducing an extra spatial dimension. Good control over chiral symmetry makes it possible to study many previously intractable problems. The necessary large-scale lattice calculations have been made possible through the in-house development of some impressive computer resources. A custom-built massively parallel supercomputer processors, teraflop performance has been running lattice simulations for the past 3 years. A next-generation, 10 teraflop machine is currently under development. See the lattice page for more information. Professor Timothy Halpin-Healy, Professor Andrew Millis The Columbia condensed matter theory group investigates many aspects of the physics of matter, from the possibility of novel electronic states in new materials or near quantum critical points to the applied physics of spins in semiconductors and heterostructures. The group has strong connections to faculty in chemistry and chemical engineering working on biophysics and other topics. Millis has recently joined the group, which is expected to grow further in the coming years. This exponential expansion was originally proposed as a way of solving many of the problems of conventional cosmology. Thus cosmology may turn out to be the best arena for testing string theory, a possibility which is being vigorously explored at the ISCAP center.

DOWNLOAD PDF GAUGE THEORY IN PARTICLE PHYSICS

Chapter 2 : Gauge Theory of Elementary Particle Physics

In physics, a gauge theory is a type of field theory in which the Lagrangian is invariant under certain Lie groups of local transformations.. The term gauge refers to any specific mathematical formalism to regulate redundant degrees of freedom in the Lagrangian.

Global symmetry[edit] In physics , the mathematical description of any physical situation usually contains excess degrees of freedom ; the same physical situation is equally well described by many equivalent mathematical configurations. For instance, in Newtonian dynamics , if two configurations are related by a Galilean transformation an inertial change of reference frame they represent the same physical situation. These transformations form a group of " symmetries " of the theory, and a physical situation corresponds not to an individual mathematical configuration but to a class of configurations related to one another by this symmetry group. This idea can be generalized to include local as well as global symmetries, analogous to much more abstract "changes of coordinates" in a situation where there is no preferred " inertial " coordinate system that covers the entire physical system. A gauge theory is a mathematical model that has symmetries of this kind, together with a set of techniques for making physical predictions consistent with the symmetries of the model. Example of global symmetry[edit] When a quantity occurring in the mathematical configuration is not just a number but has some geometrical significance, such as a velocity or an axis of rotation, its representation as numbers arranged in a vector or matrix is also changed by a coordinate transformation. The coordinate transformation has affected both the coordinate system used to identify the location of the measurement and the basis in which its value is expressed. As long as this transformation is performed globally affecting the coordinate basis in the same way at every point , the effect on values that represent the rate of change of some quantity along some path in space and time as it passes through point P is the same as the effect on values that are truly local to P. Local symmetry[edit] Use of fiber bundles to describe local symmetries[edit] In order to adequately describe physical situations in more complex theories, it is often necessary to introduce a "coordinate basis" for some of the objects of the theory that do not have this simple relationship to the coordinates used to label points in space and time. In mathematical terms, the theory involves a fiber bundle in which the fiber at each point of the base space consists of possible coordinate bases for use when describing the values of objects at that point. Two such mathematical configurations are equivalent describe the same physical situation if they are related by a transformation of this abstract coordinate basis a change of local section, or gauge transformation. In most gauge theories, the set of possible transformations of the abstract gauge basis at an individual point in space and time is a finite-dimensional Lie group. The simplest such group is U 1 , which appears in the modern formulation of quantum electrodynamics QED via its use of complex numbers. QED is generally regarded as the first, and simplest, physical gauge theory. The set of possible gauge transformations of the entire configuration of a given gauge theory also forms a group, the gauge group of the theory. An element of the gauge group can be parameterized by a smoothly varying function from the points of spacetime to the finite-dimensional Lie group, such that the value of the function and its derivatives at each point represents the action of the gauge transformation on the fiber over that point. A gauge transformation with constant parameter at every point in space and time is analogous to a rigid rotation of the geometric coordinate system; it represents a global symmetry of the gauge representation. As in the case of a rigid rotation, this gauge transformation affects expressions that represent the rate of change along a path of some gauge-dependent quantity in the same way as those that represent a truly local quantity. This is analogous to a non-inertial change of reference frame, which can produce a Coriolis effect. Gauge fields[edit] The "gauge covariant" version of a gauge theory accounts for this effect by introducing a gauge field in mathematical language, an Ehresmann connection and formulating all rates of change in terms of the covariant derivative with respect to this connection. The gauge field becomes an essential part of the description of a mathematical configuration. A configuration in which the gauge field can be eliminated by a gauge transformation has the property that its field strength in mathematical language, its curvature is zero everywhere; a gauge theory is not limited to these configurations. In other words, the distinguishing characteristic of a gauge theory is that the gauge field does not merely compensate for a poor choice of coordinate system; there is generally no gauge transformation that makes the gauge field vanish. When analyzing the dynamics of a gauge theory, the gauge field must be treated as a dynamical variable, similar to other objects in the description of a physical situation. In addition to its interaction with other objects via the covariant derivative, the gauge field typically contributes energy in the form of a "self-energy" term. One can obtain the equations for the gauge theory by: This is the sense in which a gauge theory "extends" a global symmetry to a local symmetry, and closely resembles the historical development of the gauge theory of gravity known as general relativity. Physical experiments[edit] Gauge theories used to model the results of physical experiments engage in: We cannot express the mathematical descriptions of the "setup information" and the "possible measurement outcomes", or the "boundary conditions" of the experiment, without reference to a particular coordinate system, including a choice of gauge. One assumes an adequate experiment isolated from "external" influence that is itself a gauge-dependent statement. Mishandling gauge dependence calculations in boundary conditions is a frequent source of anomalies , and approaches to anomaly avoidance classifies gauge theories[clarification needed]. Continuum theories[edit] The two gauge theories mentioned above, continuum electrodynamics and general relativity, are continuum field theories. The techniques of calculation in a continuum theory implicitly assume that: Determination of the likelihood of possible measurement outcomes proceed by: They fail only at the smallest and largest scales due to omissions in the theories themselves, and when the mathematical techniques themselves break down, most notably in the case of turbulence and other chaotic phenomena. Quantum field theories[edit] Other than these classical continuum field theories, the most widely known gauge theories are quantum field theories , including quantum electrodynamics and the Standard Model of elementary particle physics. The starting point of a quantum field theory is much like that of its continuum analog: However, continuum and quantum theories differ significantly in how they handle the excess degrees of freedom represented by gauge transformations. Continuum theories, and most pedagogical treatments of the simplest quantum field theories, use a gauge fixing prescription to reduce the orbit of mathematical configurations that represent a given physical situation to a smaller orbit related by a smaller gauge group the global symmetry group, or perhaps even the trivial group. More sophisticated quantum field theories, in particular those that involve a non-abelian gauge group, break the gauge symmetry within the techniques of perturbation theory by introducing additional fields the Faddeevâ€”Popov ghosts and counterterms motivated by anomaly cancellation , in an approach known as BRST quantization. While these concerns are in one sense highly technical, they are also closely related to the nature of measurement, the limits on knowledge of a physical situation, and the interactions between incompletely specified experimental conditions and incompletely understood physical theory. Classical gauge theory[edit] Classical electromagnetism[edit] Historically, the first example of gauge symmetry discovered was classical electromagnetism. In electrostatics , one can either discuss the electric field, E, or its corresponding electric potential , V. Knowledge of one makes it possible to find the other, except that potentials differing by a constant, V.

Chapter 3 : Theoretical Research | Department of Physics

Gauge Theory of Elementary Particle Physics. GTEPP - Problems and Solutions. The Russian translation was published by Mir (Moscow) in The Chinese issue was published by Science Press (Beijing) in

Aharonovâ€"Bohm effect In quantum mechanics, a particle such as an electron is also described as a wave. For example, if the double-slit experiment is performed with electrons, then a wave-like interference pattern is observed. The electron has the highest probability of being detected at locations where the parts of the wave passing through the two slits are in phase with one another, resulting in constructive interference. But now suppose that the electrons in the experiment are subject to electric or magnetic fields. For example, if an electric field was imposed on one side of the axis but not on the other, the results of the experiment would be affected. The results of the experiment will be different, because phase relationships between the two parts of the electron wave have changed, and therefore the locations of constructive and destructive interference will be shifted to one side or the other. It is the electric potential that occurs here, not the electric field, and this is a manifestation of the fact that it is the potentials and not the fields that are of fundamental significance in quantum mechanics. Schematic of double-slit experiment in which Aharonovâ€"Bohm effect can be observed: One such example is the Aharonovâ€"Bohm effect , shown in the figure. But the solenoid has been positioned so that the electron cannot possibly pass through its interior. If one believed that the fields were the fundamental quantities, then one would expect that the results of the experiment would be unchanged. In reality, the results are different, because turning on the solenoid changed the vector potential A in the region that the electrons do pass through. Now that it has been established that it is the potentials V and A that are fundamental, and not the fields E and B, we can see that the gauge transformations, which change V and A, have real physical significance, rather than being merely mathematical artifacts. Suppose we imagine the two parts of the electron wave as tiny clocks, each with a single hand that sweeps around in a circle, keeping track of its own phase. Although this cartoon ignores some technical details, it retains the physical phenomena that are important here. Not only that, but it is not even necessary to change the speed of each clock by a fixed amount. This is another example of a gauge transformation: Summary[edit] In summary, gauge symmetry attains its full importance in the context of quantum mechanics. In the application of quantum mechanics to electromagnetism, i. These two gauge symmetries are in fact intimately related. Types of gauge symmetries[edit] The description of the electrons in the subsection above as little clocks is in effect a statement of the mathematical rules according to which the phases of electrons are to be added and subtracted: Experiments have verified this testable statement about the interference patterns formed by electron waves. Except for the "wrap-around" property, the algebraic properties of this mathematical structure are exactly the same as those of the ordinary real numbers. In mathematical terminology, electron phases form an Abelian group under addition, called the circle group or U 1. Group means that addition associates and has an identity element , namely "0". Also, for every phase there exists an inverse such that the sum of a phase and its inverse is 0. Other examples of abelian groups are the integers under addition, 0, and negation, and the nonzero fractions under product, 1, and reciprocal. Gauge fixing of a twisted cylinder. As a way of visualizing the choice of a gauge, consider whether it is possible to tell if a cylinder has been twisted. If the cylinder has no bumps, marks, or scratches on it, we cannot tell. Once this arbitrary choice the choice of gauge has been made, it becomes possible to detect it if someone later twists the cylinder. In , Chen Ning Yang and Robert Mills proposed to generalize these ideas to noncommutative groups. A noncommutative gauge group can describe a field that, unlike the electromagnetic field, interacts with itself. For example, general relativity states that gravitational fields have energy, and special relativity concludes that energy is equivalent to mass. Hence a gravitational field induces a further gravitational field. The nuclear forces also have this self-interacting property. Gauge bosons[edit] Surprisingly, gauge symmetry can give a deeper explanation for the existence of interactions, such as the electric and nuclear interactions. This arises from a type of gauge symmetry relating to the fact that all particles of a given type are experimentally indistinguishable from one another. Imagine that Alice and Betty are identical twins, labeled at birth by bracelets reading A and B. Because the girls are identical, nobody would be able to tell if they had been switched at birth; the labels A and B are arbitrary, and can be interchanged. Such a permanent interchanging of their identities is like a global gauge symmetry. There is also a corresponding local gauge symmetry, which describes the fact that from one moment to the next, Alice and Betty could swap roles while nobody was looking, and nobody would be able to tell. If Alice and Betty are in fact quantum-mechanical particles rather than people, then they also have wave properties, including the property of superposition , which allows waves to be added, subtracted, and mixed arbitrarily. It follows that we are not even restricted to complete swaps of identity. The fact that the symmetry is local means that we cannot even count on these proportions to remain fixed as the particles propagate through space. According to the principles of quantum mechanics, particles do not actually have trajectories through space. In terms of empirical measurements, the wavelength can only be determined by observing a change in the wave between one point in space and another nearby point mathematically, by differentiation. A wave with a shorter wavelength oscillates more rapidly, and therefore changes more rapidly between nearby points. We then measure the two waves at some other, nearby point, in order to determine their wavelengths. But there are two entirely different reasons that the waves could have changed. They could have changed because they were oscillating with a certain wavelength, or they could have changed because the gauge function changed from a mixture to, say, Something in the theory must be changed. The result is that we have an explanation for the presence of electromagnetic interactions: In the case of electromagnetism, the particle corresponding to electromagnetic waves is the photon. In general, such particles are called gauge bosons , where the term "boson" refers to a particle with integer spin. In the simplest versions of the theory, gauge bosons are massless, but it is also possible to construct versions in which they have mass, as is the case for the gauge bosons that transmit the nuclear decay forces.

Chapter 4 : Particle Physics, Gauge Theory | profhugodegaris

A gauge theory is a type of theory in physics. The word gauge means a measurement, a thickness, an in-between distance, (as in railroad tracks) or a resulting number of units per certain parameter (a number of loops in an inch of fabric or a number of lead balls in a pound of ammunition.).

Chapter 5 : Gauge theory - Wikipedia

This is a practical introduction to the principal ideas in gauge theory and their applications to elementary particle physics. It explains technique and methodology with simple exposition backed.

Chapter 6 : Gauge Theory of Elementary Particle Physics - Ta-Pei Cheng; Ling-Fong Li - Oxford University

Gauge Theories in Particle Physics, Volume 1: From Relativistic Quantum Mechanics to QED, Third Edition presents an accessible, practical, and comprehensive introduction to the three gauge theories of the standard model of particle physics: quantum electrodynamics (QED), quantum chromodynamics (QCD), and the electroweak theory.

Chapter 7 : Gauge theory | physics | calendrierdelascience.com

Part 5 of a series: covering Guage Theory, Symmetry and the Higgs.

Chapter 8 : Theoretical Physics | Department of Physics

Gauge theory, class of quantum field theory, a mathematical theory involving both quantum mechanics and Einstein's special theory of relativity that is commonly used to describe subatomic particles and their associated wave fields.

Chapter 9 : Gauge Theory of Elementary Particle Physics by Ta-Pei Cheng

It offers an accessible and practical introduction to the three gauge theories included in the Standard Model of particle physics: quantum electrodynamics (QED), quantum chromodynamics (QCD), and the Glashow-Salam-Weinberg (GSW) electroweak theory.