DOWNLOAD PDF HOW TO QUANTIZE A CLASSICAL FIELD

Chapter 1 : Wim Dickhoff's home page

When someone says they have a classical field theory they want to quantize, that means they usually have a Lagrangian density in terms of a scalar, gauge, vector, spinor, or other type of field. Additionally, the Lagrangian usually obeys a known (that is known to them) type of symmetry (eg rotational invariance) and they usually have the.

A prominent role in his current research is played by the description and analysis of all experimental data that are directly linked to the single-particle propagator of the corresponding nucleus. Such data include all proton and neutron elastic scattering observables such as the differential cross section, polarization data, total and reaction cross sections. In addition, the removal part of the propagator determines the nuclear charge density, single-particle level structure and its fragmentation that have been explored by one-nucleon knock-out reactions at electron scattering facilities like NIKHEF in Amsterdam, Mainz, and JLab in Virginia. Focus of the research in the group aims to provide a solid theoretical background for studying nuclei with extreme ratios of neutrons to protons or vice versa that are being probed at rare isotope beam facilities. Together with the radiochemistry group of Profs. Sobotka and Charity he employs the Dispersive Optical Model to provide a road map to these exotic nuclei that are important for nuclear astrophysics. Particular attention is paid to the predicted properties of neutrons in the nuclear ground state including the neutron distribution. Wide ranging phenomena are studied in his group: Teaching Does teaching play a significant role at a Research University? Washington University is of course a Research University. This trend was completely opposite to the national trend that continues to show asubstantial decline in the total number of bachelors degrees in physics. Students who come to Washington University to study science today require a different approach than students in the past. This is mostly related to technology but also to changes in culture. A standard physics lecture from 20 years ago may well fail to keep most of todays audience awake unless the instructor is extremely gifted. Research has also shown that conceptual understanding by means of standard physics instruction is not as good as it should be. For these reasons we engage students in our year-long introductory course intellectually in the classroom by using Eric Mazurs "Peer Instruction" method. The more spectacular consequence of this method is that part of the lecture time students are talking in class with each other about conceptual understanding of physics questions. The special atmosphere and common interest in physics makes teaching this section a special delight. Does recruiting for a physics major make sense in todays world? I know of no better way for a student to learn how to solve NEW problems. A physics education provides both a technical and theoretical background to acquire these essential skills. A flexible student will therefore be able to apply these skills in completely different settings. While most of our graduates go on to graduate school in physics, there are just as many who either successfully apply to Law, Business, and Medical Schools or succeed in securing a job right after graduation. The title of his thesis was "The particle-hole interaction and pion condensation. During this time along-standing collaboration with Klaas Allaart from the Free University was started involving quite a few graduate students over the years. Louis and became assistant professor in the Washington University physics department in Since he is a "volle" professor. A list of graduate students that he has supervised and is currently collaborating with can be brought up by clicking the relevant buttons on the left side of the screen. A complete list of publications can also be found together with recent research topics, group meeting information, and downloadable lectures. Information related to the book entitled "Many-body theory exposed! After his tenure Prof. Dickhoff initiated a new course called Physics and Society Phys which has been team-taught together with Profs. Bender, Friedlander until his retirement , and Ogilvie every year. Dickhoff is also a member of the faculty in the Environmental Studies program at Washington University. Dickhoff received a Kemper award for the development of the course Phys Awesome Ideas in Physics. After teaching this course in and , this course has since been taken over by Prof. Dickhoff has a strong commitment to teaching and advocates the "Peer Instruction Method" for Introductory Physics courses as developed by Eric Mazur from Harvard University.

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Chapter 2 : What does it mean to quantize a field | Physics Forums

The recipe to quantize a classical field theory is similar to the one used for going from Hamiltonian of a classical system to the quantum theory.

Quantized Radiation Field The Fourier coefficients of the expansion of the classical radiation field should now be replaced by operators. The operator is parameterized in terms of and. This type of operator is called a field operatoror a quantized field. The Hamiltonian operator can also be written in terms of the creation and annihilation operators. For our purposes, we may remove the infinite constant energy due to the ground state energy of all the oscillators. It is simply the energy of the vacuum which we may define as zero. Note that the field fluctuations that cause this energy density, also cause the spontaneous decay of excited states of atoms. One thing that must be done is to cut off the sum at some maximum value of. We do not expect electricity and magnetism to be completely valid up to infinite energy. Certainly by the gravitational or grand unified energy scale there must be important corrections to our formulas. The energy density of the vacuum is hard to define but plays an important role in cosmology. At this time, physicists have difficulty explaining how small the energy density in the vacuum is. Until recent experiments showed otherwise, most physicists thought it was actually zero due to some unknown symmetry. In any case we are not ready to consider this problem. With this subtraction, the energy of the vacuum state has been defined to be zero. The total momentum in the transverse radiation field can also be computed from the classical formula for the Poynting vector. This time the can really be dropped since the sum is over positive and negative , so it sums to zero. We can compute the energy and momentum of a single photon state by operating on that state with the Hamiltonian and with the total momentum operator. The state for a single photon with a given momentum and polarization can be written as. The energy of single photon state is. The momentum of the single photon state is. The mass of the photon can be computed. So the energy, momentum, and mass of a single photon state are as we would expect. The vector potential has been given two transverse polarizations as expected from classical Electricity and Magnetism. The result is two possible transverse polarization vectors in our quantized field. The photon states are also labeled by one of two polarizations, that we have so far assumed were linear polarizations. The polarization vector, and therefore the vector potential, transform like a Lorentz vector. We know that the matrix element of vector operators is associated with an angular momentum of one. When a photon is emitted, selection rules indicate it is carrying away an angular momentum of one, so we deduce that the photon has spin one. We need not add anything to our theory though; the vector properties of the field are already included in our assumptions about polarization. These are the transverse mode of the photon,. We have separated the field into transverse and longitudinal parts. The longitudinal part is partially responsible for static E and B fields, while the transverse part makes up radiation. The component of the photon is not present in radiation but is important in understanding static fields. By assuming the canonical coordinates and momenta in the Hamiltonian have commutators like those of the position and momentum of a particle, led to an understanding that radiation is made up of spin-1 particles with mass zero. All fields correspond to a particle of definite mass and spin. We now have a pretty good idea how to quantize the field for any particle.

Chapter 3 : The quantization of the electromagnetic field

In physics, quantization is the process of transition from a classical understanding of physical phenomena to a newer understanding known as quantum mechanics. (It is a procedure for constructing a quantum field theory starting from a classical field theory.).

Dilaton The dilaton made its first appearance in Kaluzaâ€"Klein theory , a five-dimensional theory that combined gravitation and electromagnetism. It appears in string theory. The impetus arose from the fact that complete analytical solutions for the metric of a covariant N-body system have proven elusive in general relativity. This outcome revealed a previously unknown and already existing natural link between general relativity and quantum mechanics. The field equations are amenable to such a generalization, as shown with the inclusion of a one-graviton process, [23] and yield the correct Newtonian limit in d dimensions, but only with a dilaton. Furthermore, some speculate on the view of the apparent resemblance between the dilaton and the Higgs boson. Finally, since this theory can combine gravitational, electromagnetic, and quantum effects, their coupling could potentially lead to a means of testing the theory through cosmology and experimentation. Nonrenormalizability of gravity[edit] Further information: Renormalization General relativity, like electromagnetism , is a classical field theory. One might expect that, as with electromagnetism, the gravitational force should also have a corresponding quantum field theory. However, gravity is perturbatively nonrenormalizable. The theory must be characterized by a choice of finitely many parameters, which could, in principle, be set by experiment. For example, in quantum electrodynamics these parameters are the charge and mass of the electron, as measured at a particular energy scale. On the other hand, in quantizing gravity there are, in perturbation theory, infinitely many independent parameters counterterm coefficients needed to define the theory. For a given choice of those parameters, one could make sense of the theory, but since it is impossible to conduct infinite experiments to fix the values of every parameter, it has been argued that one does not, in perturbation theory, have a meaningful physical theory. At low energies, the logic of the renormalization group tells us that, despite the unknown choices of these infinitely many parameters, quantum gravity will reduce to the usual Einstein theory of general relativity. On the other hand, if we could probe very high energies where quantum effects take over, then every one of the infinitely many unknown parameters would begin to matter, and we could make no predictions at all. It is conceivable that, in the correct theory of quantum gravity, the infinitely many unknown parameters will reduce to a finite number that can then be measured. One possibility is that normal perturbation theory is not a reliable guide to the renormalizability of the theory, and that there really is a UV fixed point for gravity. Since this is a question of non-perturbative quantum field theory, it is difficult to find a reliable answer, but some people still pursue this option. Another possibility is that there are new, undiscovered symmetry principles that constrain the parameters and reduce them to a finite set. This is the route taken by string theory , where all of the excitations of the string essentially manifest themselves as new symmetries. Effective field theory In an effective field theory , all but the first few of the infinite set of parameters in a nonrenormalizable theory are suppressed by huge energy scales and hence can be neglected when computing low-energy effects. Thus, at least in the low-energy regime, the model is a predictive quantum field theory. An example is the well-known calculation of the tiny first-order quantum-mechanical correction to the classical Newtonian gravitational potential between two masses. Background independence A fundamental lesson of general relativity is that there is no fixed spacetime background, as found in Newtonian mechanics and special relativity ; the spacetime geometry is dynamic. While easy to grasp in principle, this is the hardest idea to understand about general relativity, and its consequences are profound and not fully explored, even at the classical level. To a certain extent, general relativity can be seen to be a relational theory , [29] in which the only physically relevant information is the relationship between different events in space-time. On the other hand, quantum mechanics has depended since its inception on a fixed background non-dynamic structure. In the case of quantum mechanics, it is time that is given and not dynamic, just as in Newtonian classical mechanics. In relativistic quantum field theory, just as in classical field theory, Minkowski spacetime is the fixed background of the theory. String theory[edit

] Interaction in the subatomic world: Although string theory had its origins in the study of quark confinement and not of quantum gravity, it was soon discovered that the string spectrum contains the graviton , and that "condensation" of certain vibration modes of strings is equivalent to a modification of the original background. Background independent theories[edit] Loop quantum gravity is the fruit of an effort to formulate a background-independent quantum theory. Topological quantum field theory provided an example of background-independent quantum theory, but with no local degrees of freedom, and only finitely many degrees of freedom globally. Semi-classical quantum gravity[edit] Quantum field theory on curved non-Minkowskian backgrounds, while not a full quantum theory of gravity, has shown many promising early results. In an analogous way to the development of quantum electrodynamics in the early part of the 20th century when physicists considered quantum mechanics in classical electromagnetic fields , the consideration of quantum field theory on a curved background has led to predictions such as black hole radiation. Phenomena such as the Unruh effect , in which particles exist in certain accelerating frames but not in stationary ones, do not pose any difficulty when considered on a curved background the Unruh effect occurs even in flat Minkowskian backgrounds. The vacuum state is the state with the least energy and may or may not contain particles. See Quantum field theory in curved spacetime for a more complete discussion. Problem of Time[edit] Main article: Problem of Time A conceptual difficulty in combining quantum mechanics with general relativity arises from the contrasting role of time within these two frameworks. In quantum theories time acts as an independent background through which states evolve, with the Hamiltonian operator acting as the generator of infinitesimal translations of quantum states through time. Candidate theories[edit] There are a number of proposed quantum gravity theories. They also face the common problem that, as yet, there is no way to put quantum gravity predictions to experimental tests, although there is hope for this to change as future data from cosmological observations and particle physics experiments becomes available. String theory Projection of a Calabiâ€”Yau manifold , one of the ways of compactifying the extra dimensions posited by string theory One suggested starting point is ordinary quantum field theories which are successful in describing the other three basic fundamental forces in the context of the standard model of elementary particle physics. However, while this leads to an acceptable effective quantum field theory of gravity at low energies, [27] gravity turns out to be much more problematic at higher energies. For ordinary field theories such as quantum electrodynamics , a technique known as renormalization is an integral part of deriving predictions which take into account higher-energy contributions, [35] but gravity turns out to be nonrenormalizable: In this way, string theory promises to be a unified description of all particles and interactions. Sorting through this large family of solutions remains a major challenge. Loop quantum gravity[edit] Main article: Its second idea is that the quantum discreteness that determines the particle-like behavior of other field theories for instance, the photons of the electromagnetic field also affects the structure of space. The main result of loop quantum gravity is the derivation of a granular structure of space at the Planck length. This is derived from following considerations: In the case of electromagnetism, the quantum operator representing the energy of each frequency of the field has a discrete spectrum. Thus the energy of each frequency is quantized, and the quanta are the photons. In the case of gravity, the operators representing the area and the volume of each surface or space region likewise have discrete spectrum. Thus area and volume of any portion of space are also quantized, where the quanta are elementary quanta of space. It follows, then, that spacetime has an elementary quantum granular structure at the Planck scale, which cuts off the ultraviolet infinities of quantum field theory. The quantum state of spacetime is described in the theory by means of a mathematical structure called spin networks. Spin networks were initially introduced by Roger Penrose in abstract form, and later shown by Carlo Rovelli and Lee Smolin to derive naturally from a non-perturbative quantization of general relativity. Spin networks do not represent quantum states of a field in spacetime: The theory is based on the reformulation of general relativity known as Ashtekar variables , which represent geometric gravity using mathematical analogues of electric and magnetic fields. One version starts with the canonical quantization of general relativity. These represent histories of spin networks. Other approaches[edit] There are a number of other approaches to quantum gravity. The approaches differ depending on which features of general relativity and quantum theory are accepted unchanged, and which features are modified.

Chapter 4 : [] Extending Hamilton's principle to quantize classical fields

quantize simple harmonic oscillators greatly simplii¬•es the EM i¬•eld problem. In the end, we get to see how the basic quanta of the EM i¬•elds, which are called photons, are created and annihilated in.

Gold Member vanesch said: I probably had not made myself too clear when we discussed this. I recall asking similar questions when I was a student and it looked to me as if the idea of quantizing classical fields seemed pretty obvious to everybody I would talk to. To the point that they did not even seem to understand why I was bothered. So I decided that there was something very obvious that I was missing entirely and that one day I would finally get it. But I never did. Just as an example: One makes an analogy between the position and momentum of a point particle and the field and momentum density of classical fields. That step alway makes me want to go: Unless one pushes too far the analogy with a vibrating rope, one must admit that there is no relation between the fields we use even at the classical level!! Likewise, the "momentum density" we derive from our actions have nothing to do again, even at classical level! Most books use the rope analogy, where the displacement field i san actual position, to suggest that this is th eright way to do. From my point of view, the fact that this ultimately work in the "quantize a classical field approach" is a mystery. It does ultimately give the correct answer but I would find it hard to convince students that this is a sensible thing to try. Sounds like a wild guess to me!! Whereas in my approach, I would get the commutation relations from simple considerations of states in the number representation picture. Then my "fields" built out of those operators would automatically inherit the correct commutation relations. You take as essential entities "particles" which are described by creation and annihilation operators. You see "quantum fields" as a kind of bookkeeping device. Traditional QFT takes as essential entities "fields" and we apply quantum theory to their classical configuration space. The resulting "lumpiness" in the form of particles is simply a consequence. I have to say I personally always had the last view without ever understanding your point of view. I need to see where it would enter in my approach and why it would be needed! But I also bet that I will never find the field approach natural. But it looks as if I am the only one thinking this! As hinted here, I suppose that both formalisms will turn out to be equivalent, if you add the necessary assumptions. If this is the case, it is just a matter of interpretation, whatever you like best, or whichever picture allows more easily to go to the next step whatever that may be. I agree, I think it must be just a bookkeeping trick to work in terms of fields. Then I would recover the usual expressions for quantum fields. But that begs the question: I guess one could do everything that way and never talk about classical fields at all actually, it would look like a classical field theory with the fields being quantize except that it would be a superficial analogy, without any power. But in order to apply the formalism to actual experiments, there is the need to express things in terms of particles of definite momenta. After that one must still impose Lorentz invariance, etc etc. SO at this point only, someone could say: Then, after doing this with a few theories, it would be clear that we might as well start with classical field theories and then quantize the fields.

Chapter 5 : quantum mechanics - How do I quantize a classical field theory - Physics Stack Exchange

On the other hand, we may quantize the Dirac field under an given external classical EM field: briefly speaking, one solves minimally coupled Dirac equation and take the solution space as 1-particle Hilbert space, and then second quantize the theory by building a Fock space based on this 1-particle space.(A more detailed description can be.

It provides a unified picture of the wave nature and the particle nature of light. The derivation also serves as a template for the quantization of other fields. Many of the arguments presented here can be applied to phonons, magnons, plasmons, electrons, spinons, holons and other quantum particles that inhabit solids. We consider electromagnetic waves in vacuum. It is linear for light waves propagating in vacuum. However, we have already seen that the dispersion equation for light, sound, electrons, neutrons, etc. For instance, for a wave propagating in the x-direction, the vector potential has the form, The electric and magnetic fields are both perpendicular to the propagation direction in this case, Quantization To be able to quantize the electromagnetic field, it is convenient to expand the waves in normal modes. Consider a cubic metal cavity of length L on a side. Standing waves will exist in such a cavity. Electromagnetic waves do not penetrate into an ideal metal so only modes where the electric field is zero at the boundaries of the cavity are allowed. The boundary conditions do not matter. The same results are found for a cavity with periodic boundary conditions. The spatial part of the electric field has the form, Consider a single mode specified by the mode numbers nx, ny, and nz and the polarization. For notational convenience, we will assign a unique integer s to each mode. The choice of the polarization plus the fact that the vector potential must be perpendicular to the propagation vector k restricts the vector potential to point in a specific direction. This above equation is mathematically equivalent to the equation for a one-dimensional harmonic oscillator. The allowed quantum energy levels for a one-dimensional harmonic oscillator are where Transcribing this back to the problem of a single mode of the electromagnetic field we find that the allowed quantum energies for the mode are also, but in this case the frequency is, The integer j represents the number of photons in mode s. The first sum is the zero point energies of the harmonic oscillators. In order to evaluate the sum, it is convenient to convert it to an integral. To do this the number of modes at every frequency or every wavelength will be calculated. Density of states We can determine how many modes there are at every frequency if we know how many modes there are for every wavenumber k. These allowed values of k form a cubic lattice in k space. There are twice as many linearly independent normal modes as there are points in k-space because the electric field has two independent components that are perpendicular to the propagation direction. The density of states can also be expressed in terms of frequency. That is the temperture of the surface of the sun. The peak in the spectrum is then in the visible at about 0. The form above can be used to generate Planck curves for other temperatures. The wavelength at the peak of the distribution can be found by differentiating the expression for the energy density and setting the result equal to zero. The intensity radiated by a blackbody has the same wavelength dependence as the energy density. This is known as the Stefan-Boltzmann law. Similarly the toal energy density is, Thermodynamic properties Once the distribution of microscopic quantum levels are known, it is possible to calculate many thermodynamic quantities. In general, this is done by constructing a partition function that takes the appropriate average over all of the microscopic states. Partition functions are beyond the scope of this course so we will simply state that the Helmholtz free energy is, The derivation of this result is found in books on statistical mechanics. Each photon has a momentum, When the photons strike the walls of the cavity they therefore exert a pressure. The radiation pressure is, Finally, a certain amount of energy must be added to the cavity to increase the temperature. This is described by the specific heat. Recipe for the quantization of fields The above derivation includes many important results but it also serves as a recipe for quantizing fields. The steps in this recipe are: Determine the classical normal modes. If the equations are nonlinear, this may be difficult. Linearize the equations if necessary. The nonlinear terms can be included later as perturbations. Quantize the normal modes. Calculate the density of modes. Knowing the distribution of the quantum states, deduce thermodynamic quantities. The results for the quantization of the wave equation in 1-, 2-, and 3-dimensions are summarized in the following table.

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Quantization of the EM Field The Hamiltonian for the Maxwell field may be used to quantize the field in much the same way that one dimensional wave mechanics was quantized. The radiation field can be shown to be the transverse part of the field while static charges give rise to and.

Quantization methods[edit] Quantization converts classical fields into operators acting on quantum states of the field theory. The lowest energy state is called the vacuum state. The reason for quantizing a theory is to deduce properties of materials, objects or particles through the computation of quantum amplitudes , which may be very complicated. Such computations have to deal with certain subtleties called renormalization , which, if neglected, can often lead to nonsense results, such as the appearance of infinities in various amplitudes. The full specification of a quantization procedure requires methods of performing renormalization. The first method to be developed for quantization of field theories was canonical quantization. While this is extremely easy to implement on sufficiently simple theories, there are many situations where other methods of quantization yield more efficient procedures for computing quantum amplitudes. However, the use of canonical quantization has left its mark on the language and interpretation of quantum field theory. The classical field is treated as a dynamical variable called the canonical coordinate , and its time-derivative is the canonical momentum. Technically, one converts the field to an operator, through combinations of creation and annihilation operators. The field operator acts on quantum states of the theory. The procedure is also called second quantization. This procedure can be applied to the quantization of any field theory: However, it leads to a fairly simple picture of the vacuum state and is not easily amenable to use in some quantum field theories , such as quantum chromodynamics which is known to have a complicated vacuum characterized by many different condensates. Quantization schemes[edit] Even within the setting of canonical quantization, there is difficulty associated to quantizing arbitrary observables on the classical phase space. This is the ordering ambiguity: Classically the position and momentum variables x and p commute, but their quantum mechanical counterparts do not. Various quantization schemes have been proposed to resolve this ambiguity, [1] of which the most popular is the Weyl quantization scheme. Nevertheless, the Groenewoldâ€”van Hove theorem says that no perfect quantization scheme exists. Specifically, if the quantizations of x and p are taken to be the usual position and momentum operators, then no quantization scheme can perfectly reproduce the Poisson bracket relations among the classical observables. Covariant canonical quantization[edit] There is a way to perform a canonical quantization without having to resort to the non covariant approach of foliating spacetime and choosing a Hamiltonian. This method is based upon a classical action, but is different from the functional integral approach. The method does not apply to all possible actions for instance, actions with a noncausal structure or actions with gauge "flows". It starts with the classical algebra of all smooth functionals over the configuration space. This algebra is quotiented over by the ideal generated by the Eulerâ€”Lagrange equations. Then, this quotient algebra is converted into a Poisson algebra by introducing a Poisson bracket derivable from the action, called the Peierls bracket. There is also a way to quantize actions with gauge "flows".

Chapter 7 : Why quantizing fields? | Physics Forums

must take classical relativistic objects such as the Riemann tensor or metric field and quantize them: i.e., make them operators subject to non-vanish- ing commutation relations.

Chapter 8 : Quantum gravity - Wikipedia

Abstract. We study the problem of quantizing the classical fields with intrinsic second class constraints in a finite volume in this paper. To illustrate our idea clearly, we study the classical Schrodinger field in a finite volume.

Chapter 9 : quantization in nLab

Canonical quantisation is a naive method of quantisation of a classical theory in which one assumes that the commutation relations obeyed by observable operators and their canonically conjugate momenta within the quantum theory are determined by their corresponding Poisson brackets of the classical theory.