Quantentheorie II Übung 13

Besprechung: 2021WE29 (KW29)

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This is a special exercise sheet which may help you in preparing the exam. It contains simple questions on all topics. Make sure you are able to answer these and similar questions! Beyond these questions, of course, all past exercise sheets provide valuable training.
For the tutorials in the last week of the semester: you are welcome to send questions and suggestions to your tutors beforehand by email. The tutorials may focus on particular, selected past exercises, or discuss and practice specific topics, or provide additional information or repetition of topics of the lecture based on your questions.

Questions

1. What are two common versions of the γ^μ-matrices? Which properties do you remember?
2. Can a spinor of the form $\psi(x) = (e^{-iEt}, 0, 0, 0)^T$ be a solution of the free Dirac equation? (if applicable, under which conditions?)
3. What is the role of the gauge covariant derivative $D^\mu = \partial^\mu - ieA^\mu$ in the context of the Dirac or Klein-Gordon equations?
4. What is the non-relativistic Hamiltonian for a charged particle in an electromagnetic field?
5. There are several ways how one can motivate the Klein-Gordon or the Dirac equations, some of which were discussed in the lecture. Can you describe some of them?
6. What is the Dirac equation in momentum space? Characterize the spinors $u(p, s)$ and $v(p, s)$.
7. Sketch/describe how one can derive the value $g = 2$ and spin-orbit coupling from the Dirac equation.
8. What is a possible basis of a 2-particle Hilbert space of two electrons (identical fermions), taking into account both the spin and position degree of freedom?
9. As far as we know, an electron on earth has the absolute same rest mass as an electron on the moon. How is this possible? (Since this is a non-scientific question you don't have to answer it) How can we describe it in various formalisms?
10. Consider a $2 \to 2$ process of 2-particle initial state and 2-particle final state. Describe the role of the direct and the exchange term contribution to the probability amplitude, and discuss the differences between distinguishable particles and two identical bosons or two identical fermions.

11. Discuss the chemical binding of the H_2 molecule. How does it arise from the fact that the two electrons are identical particles? Describe the quantum mechanical description.

12. What are some important properties of creation/annihilation operators?

13. How can you express the free Hamiltonian (for kinetic energy) in terms of creation/annihilation operators?

14. How can you express the interaction Hamiltonian of two particles bounded with the Coulomb potential in terms of creation/annihilation operators? Which mathematical operation appears?

15. What are the two approximation methods to describe scattering processes?

16. Compare the structure of wave functions for (i) 1-dimensional scattering at a potential barrier, (ii) 3-dimensional scattering at a short-range potential.

17. How can you derive the relationship between the scattering amplitude $f(\theta, \phi)$ and the differential cross section?

18. Describe the basic principles of Born's approximation and the partial wave/scattering phase method for the scattering amplitude.

19. What is the integral equation for the scattering wave function from which you can derive the first Born approximation?

20. What is the result of the first Born approximation for the scattering amplitude? Give and discuss some example potentials!

21. Describe the derivation of scattering phases for scattering at a hard sphere (sphere in which the potential $V = \infty$)!