FSI3005 Qualitative and Approximate Methods in Theoretical Physics 5.0 credits

Kvalitativa och approximativa metoder i teoretisk fysik

This is a translation of the Swedish, legally binding, course syllabus.

If the course is discontinued, students may request to be examined during the following two academic years

Establishment

Course syllabus for FSI3005 valid from Spring 2009

Grading scale

Education cycle

Third cycle

Specific prerequisites

The course will be of interest to PhD students who specialize or want to specialize in theoretical physics, as well as to young researchers working in this field.

Elementary calculus, elementary complex analysis, classical mechanics and electrodynamics, quantum mechanics.

Language of instruction

The language of instruction is specified in the course offering information in the course catalogue.

Intended learning outcomes

After completed course, the PhD student should be able to:

- know some "tools of the trade" in theoretical physics.
- estimate mathematical expressions.
- use dimensional analysis.
- perform model estimates in physical problems.
- use various methods of perturbation theory.
- use qualitative and approximate methods.

Course contents

The course is devoted to some "tools of the trade" in theoretical physics, the methods that are widely used by experienced theorists but rarely taught in a single course. These are the qualitative and approximate methods that allow one to reveal the characteristic features of the studied problem and in many cases find its approximate solution without (or prior to) finding the full solution of the problem.

Normally, the knowledge of these methods comes with experience and is a part of the "folklore" of theoretical physics. The present course is an attempt of collecting some of these approaches in a single course.

The topics to be covered include: Estimates of mathematical expressions (derivatives and integrals), approximate methods of solving algebraic and differential equations, dimensional analysis, model estimates in physical problems (including problems in quantum mechanics and atomic physics), various cases of perturbation theory, sudden and adiabatic perturbations, WKB approximation, methods based on analytic properties of physical quantities, qualitative methods in relativistic quantum mechanics, quantum field theory and particle physics (no prior knowledge of which is assumed).

Disposition

1. Introduction. Why use approximate and qualitative methods? An example: the power of dimensional analysis. Stages of simplification and qualitative analyses of physical problems.
2. Estimates of mathematical expressions. Estimates of derivatives. The notion of the scale height. Estimates of integrals. Matching the different limits. Asymptotic series. Integrals of fast oscillating functions and integration by parts. The steepest descent method and the method of the stationary phase. Approximate methods of solving algebraic and differential equations.
3. Dimensional analysis. Motion of simple pendulum. Newton's gravity law. Flow of fluid through a spillway. Fluid motion in pipes. Motion of a body in a fluid.

4. Model estimates in quantum mechanics and atomic physics. Stationary states. The uncertainty principle and the Bohr radius. Lifetimes of excited states of the atoms. Scattering processes and estimates of cross sections. The Rutherford formula. Resonance effects. Inapplicability of classical mechanics for scattering with large impact parameters.
5. Various cases of perturbation theory. Perturbations in continuous spectrum. Perturbations in the case of close discrete energy levels. Sudden and adiabatic perturbations. Atomic ionization due to beta decay and nuclear reactions. Ionization due to a slow passage of a heavy particle.
6. WKB approximation. Wave functions and the Stokes lines. Matching of the wave functions. Mean kinetic energy and the virial theorem. Quasiclassical matrix elements. Barrier penetration.
7. Methods based on the analytic properties of physical quantities. Dependence of sound speed on wave vector. Analytic properties of dielectric constant and of scattering amplitude. Scattering amplitude near the threshold.
8. Qualitative approach to quantum processes in strong external fields. Effects of a strong external field on differential characteristics and on total rates of quantum processes. An example: beta decay in a strong laser field.
9. Qualitative methods in relativistic quantum mechanics, particle physics and quantum field theory (propagator approach). Propagator and its physical meaning. Coordinate and momentum representation. Propagator for Schrödinger equation. Particles in an external field. Photon propagator. Relativistic propagators for particles of spin 0 and 1/2. Scattering amplitudes and bound states. Simplest quantum electrodynamics processes and their cross sections.

Course literature

- **A.B. Migdal, Qualitative methods in quantum theory, W.A. Benjamin, Reading, Advanced Book Program, 1977. (Frontiers in physics, v. 48)**
- **L.I. Sedov, Similarity and dimensional methods in mechanics, CRC Press, Boca Raton, 1993.**
- **A. Erdelyi, Asymptotic expansions, Dover, New York, 1956.**

Examination

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

Other requirements for final grade

Hand in assignments and an oral exam.

Ethical approach

- All members of a group are responsible for the group's work.
- In any assessment, every student shall honestly disclose any help received and sources used.
- In an oral assessment, every student shall be able to present and answer questions about the entire assignment and solution.