PHYSICS OF FUNDAMENTAL INTERACTIONS

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7th Semester. Lectures: 34 hours, Seminars: 34 hours
8th Semester. Lectures: 34 hours, Seminars: 34 hours

The task of a one-year course "Physics of fundamental interactions" is to study basic concepts and methods of modern theory of elementary particles and their interactions and transmutations.

During the course a student should gain an insight into the foundations of quantum field theory, description and calculation of the processes of elementary particle scattering and decay, the theory of their structure and main principles, on which this theory is based.

This theory is based on the concept of local gauge symmetries. During the course students get to know about main experimental discoveries in the field of elementary particles, which have led to the modern knowledge about their structure and laws of their interaction.

The course consists of two large parts: Part I – "The standard model of electroweak interaction", studied in the 7th term, and Part II – "Quantum chromodynamics", studied in the 8th term.

While giving this course it is supposed that students have already studied the courses of "Physics", "Theoretical mechanics", "Quantum mechanics", "Electrodynamics", "Mathematical analysis", "Analytical geometry" and "Group theory".

The contents of the discipline

<u>1. Introduction</u>

1.1 In search of "elementary" particles. Leptons, photons, hadrons, isotopic invariance, interaction forces.
1.2 Quark hypothesis, structure of hadrons, colour, colour confinement, scaling, asymptotic freedom, parton model.

<u>2. Relativistic quantum mechanics</u>

2.1 Klein-Gordon equation
2.2 Dirac equation, antiparticles.
2.3 Gamma matrix algebra, solutions of free Dirac equation, their sense, impulsive moment and electronic spin. Fermions with the zero mass.
2.4 Schrodinger-Pauli equation, electron magnetic moment.

<u>3. The fundamentals of quantum electrodynamics.</u>

3.1 Lagrangian, local gage symmetry and electrodynamics.
3.2 Maxwell potential equations. Gauge principle.
3.3 Perturbation theory, Feynman diagrams.
3.4 Scattering cross-section. Muon-electron scattering, photon propagator.
3.5 Compton scattering, electron propagator.

4. Weak interactions.

4.1 Beta decay, Fermi theory.
4.2 Parity failure, chirality.
4.3 CP-parity.
4.4 Muon lifetime.
4.5 Kaon decay.
4.6 Generation mixing, Cabibbo-Kobayashi-Maskawa mixing matrix.
4.7 CP-parity failure.
4.8 Neutral low currents. Neutrino and antineutrino deep inelastic scattering by nucleon.

5. The standard model of electroweak interaction

5.1 Combination of electromagnetic and weak interactions on the base of $SU_L(2)xU_Y(1)$ symmetry.
5.2 Weinberg angle, neutral low currents, W- and Z-bosons.
5.3 Nonrenormalizability of the theory with massive bosons. Non-Abelian gauge symmetry. Boson self-action.
5.4 Spontaneous alteration of symmetry. Appearance of mass. Goldstone bosons.
5.5 Higgs mechanism. Salam-Weinberg model.
5.6 Higgs field selection. W- and Z-bosons masses. Boson-higgs interaction.
5.7 Fermion masses. Fermion-higgs interaction. The idea of theory renormalizability. Lepton-quark analogy.
5.8 Experimental theory status.

6. Colour and colour gauge symmetry.

6.1 Experimental indications of quark colours.
6.2 Colour gage symmetry and Yang-Mills equation for gluon field.
6.3 Group SU(3). Gell-Mann matrixes and their properties.
6.4 Fierz identities.
6.5 Casimir operators in fundamental and adjoint representation.

7. Quantization QCD and asymptotic freedom.

7.1 Transverse amplitude in QED and QCD. Gluon self-action. Feynman rule for QCD.
7.2 Dispersion relations and optical theorem.
7.3 Concepts of divergences, subtractions, regularizations and renormalizations.
7.4 Effective charge in QCD. The concept of renormalization group.
7.5 Zero charge in QED, its relation to the optical theorem and dispersion relations.
7.6 Effective charge in QCD. Asymptotic freedom.

8. Quark-hadron duality and hadronic processes.

8.1 Electron-positron annihilation into hadrons. R-relation.
8.2 Quark-hadron duality.
8.3 Vacuum condensate and QCD sum rule.
8.4 Chiral invariance.

9. Parton model factorization and modification.

9.1 QCD factorization and hard processes.
9.2 Deep inelastic scattering. Parton distribution functions and their moments.
9.3 Structural functions. Калан-Гросс relation.
9.4 Conserved operators and their properties. Sum rule.

9.5 Evolution equation.
9.6 Deep inelastic scattering of polarized particles. Spin crisis.
9.7 Дрелл-Ян process.

10. Experimental status of QCD and What's going to happen next?

10.1 Experimental status of QCD.
10.2 Application of QCD to the processes in Large Hadron Collider. Formation of Higgs bosons in hadron collision.
10.3 Movement to "grand unification".

4.1 Methodical recommendations to the tutor.

The course is given to students after they have studied electrodynamics, relativity theory, quantum mechanics and group theory. The focus is made on the use of symmetries, especially local gage symmetries, Feynman diagrams and verification of experimental predictions, made on their base. In the course we also discuss experimental methods of studying reactions with elementary particles and emphasize an experimental, rather than theoretical way of studying physics of fundamental interactions.

4.2 Methodical recommendations to the students

As before, a student should get used to the idea that it is necessary to learn English terminology as quickly as possible, because the most literature on this course and the database are written in English. A student should understand the main ideas of the construction of elementary particle theory and its consequences. During the course a student is offered to put the acquired knowledge into practice by doing calculations and assessing the simplest cross-sections and particle lifetime.