

1. **September 26th 2023- Introduction**

Reminders of Group Theory.

Definition of a Group. Finite and Infinite Groups. Order of a Group. Abelian Groups. Subgroups. Left and Right Cosets. Invariant Subgroups.

Representations.

Definition of Representation of a group. Reducible and completely reducible representations. Lie Groups and Lie Algebras. Jacobi identity. Classification of Lie Algebras. Simple and semisimple groups and algebras. Compact algebras. $SU(N)$, $SO(N)$, $Sp(N)$: definition and generators. Finite dimensional unitary representations of Lie Groups. Fundamental, Conjugate and Adjoint representations. Casimir Operator.

The Action. Hamilton principle. Euler-Lagrangian equations. Noether's Theorem. Noether's currents and conserved charges.[1]

Gauge theories. Abelian case: QED. [2]

2. **September 28th 2023** [1, 3, 2].

Yang - Mills theories [2]. Geometry of gauge invariance [1]. Definition and properties of the S matrix. [3] Cross section for scattering processes: definition and derivation of the formula. Decay width of a particle.[2]

3. **October 3rd 2023** [3, 2, 4].

Optical theorem [3]. LSZ reduction formula.[2, 4]. Introduction to the Feynman path integral [2].

4. **October 5th 2023** [2, 4].

More on path integral. Green's functions and generating functional. Prescriptions for derivation of the Feynman rules. Propagator of the free scalar field.

5. **October 10th 2023** [2].

Self interacting scalar field: Feynman rules. Grassman numbers.

6. **October 12th, 2023**

Quantization of gauge theories. Gauge fixing . Generating functional of QED. Feynman rules for QED.[2] Introduction to the Fadeev-Popov Determinant. [2, 1].

7. **October 17th, 2023. Reference text:** [2, 1].

Exponentiation of the Fadeev Popov determinant. Lagrangian density of QCD and its generating functional. Dimensional regularization. Feynman parametrization. Calculation of integrals with one propagator in D dimensions.

8. **October 19th, 2023.**

Quark self-energy: calculation at one loop. Power counting. Superficial degree of divergence and index of divergence. Theorem of convergence. Renormalizable interactions.[2] Primitively divergent diagrams in QED [1].

9. **October 24th, 2023.**

Renormalizability of QCD. Primitively divergent diagrams in QCD [2, 1]. Systematics of renormalization: counterterms. Pole mass. Subtraction schemes. Calculation of the quark field and quark mass renormalization constants in the $\overline{\text{MS}}$ scheme [2, 4].

10. **October 26th, 2023.**

Calculation of the quark field and quark mass renormalization constants in the on-shell subtraction scheme [2, 4]. Relation between the $\overline{\text{MS}}$ renormalized mass and the pole mass.[4] QCD: renormalized lagrangian, counterterms and Slavnov-Taylor identities.[2]

11. **October 31st, 2023.**

Ward and Ward-Takayashi identities in QED [1]. BRS symmetry in brief.[2] Calculation of the photon self-energy and the electric charge renormalization constant in QED.[4]

12. **November 7th, 2023.**

Introduction to the renormalization group. Beta function, mass anomalous dimension, anomalous dimension. Their properties in the $\overline{\text{MS}}$ and $\overline{\text{MS}}$ schemes. Formulae to determine β , γ_m , γ in the $\overline{\text{MS}}$ and $\overline{\text{MS}}$ schemes. 't Hooft Weinberg equation.[2]

13. **November 9th, 2023. Reference text: [2, 1].**

Solution of the 't Hooft Weinberg equation in the $\overline{\text{MS}}$ and $\overline{\text{MS}}$ schemes. Properties of the solution. Asymptotic freedom. Asymptotic freedom violation in QCD. Beta function in QED and comparison of the behaviour of the coupling in QCD and QED. Connection between asymptotic freedom and non abelian nature of gauge theories [2]. Goldstone's theorem and Spontaneous Symmetry Breaking [1].

14. **November 14th, 2023. Reference text: [3].**

Historical survey about the electroweak interactions and the birth of the Standard Model. The Standard Model of electroweak interactions: the gauge group, the mixing of neutral gauge bosons, the Weinberg angle.

15. **November 16th, 2023. Reference text: [3].**

The Higgs mechanism in the Standard Model. Masses of W^\pm , Z^0 . Yukawa lagrangian for a single lepton doublet. Relation between the Fermi constant and the Higgs vev.

16. **November 21th, 2023. Reference text: [3].**

Extension of the SM Lagrange density to all fermions. The Yukawa lagrangian, mass matrices and CKM matrix. Calculation of the decay width $H \rightarrow f\bar{f}$, f being fermion.

17. **November 23th, 2023. Reference text: [5].**

Properties of the CKM matrix, CP violation, unitarity triangle. CP violation in the neutral kaon system. Parameters ϵ_K , $\text{Re}(\epsilon'/\epsilon)$.

18. **November 30th, 2023. Reference text: [3].**

Calculation of the decay width $Z \rightarrow f\bar{f}$, f being a fermion. Invisible width of the Z , number of light neutrinos. Calculation of the decay width $\pi^- \rightarrow \mu^- \bar{\nu}_\mu$. Helicity suppression.

19. **December 7th, 2023. Reference text: [1].**

Calculation of the differential decay rate for semileptonic B to D decay. Deep inelastic scattering, Bjorken scaling, Callan Gross relation. Introduction to the PDF.

20. **December 12th, 2023. Reference text: [1].**

Deep inelastic scattering with neutrino and antineutrino. Relations among the PDF. Brief introduction to Gribov Lipatov and Altarelli Parisi equations.

References

- [1] M. E. Peskin and D. V. Schroeder,
An Introduction to quantum field theory, Addison-Wesley publishing Company.
- [2] T. Muta,
Foundations of Quantum Chromodynamics, World Scientific.
- [3] O. Nachtmann,
Elementary particle Physics: Concepts and phenomena
Springer-Verlag.
- [4] M.D. Schwartz,
Quantum Field Theory and the Standard Model
Cambridge University Press.
- [5] B. Kayser, <https://arxiv.org/abs/hep-ph/9702264>