UNIVERSITY OF DHAKA

Syllabuses of the Department of Theoretical Physics

for

M. S. Course

for the

Session: 2009-2010 to 2012-2013

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Department of Theoretical Physics
University of Dhaka

Syllabus for M.S. Courses
Session: 2009-2010 to 2012-2013

Effective from 2009-10

1. Total number of required credits is thirty, spread over one year., There will be 4 credits allocated for a final oral exam. There will be six credits allocated for a thesis written under the guidance of a faculty which will be presented for examination. The remaining twenty credits will be earned by the taking appropriate number of courses.
2. 60 lectures, each of 50 minutes duration will constitute 4 credits, 3 credit courses will involve 45 lectures accordingly.
3. There will be another oral exam based on the presented thesis which will be of 40% of marks provided for the thesis and the remaining 60% will be evaluated by the scrutiny of the thesis itself.
4. For the computational physics courses the final written examination will worth 50 marks while the remaining 50 marks will be allocated for Laboratory evaluation using computers - out of which 20 will be based on in-class evaluation and the remaining 30 will be allocated for a final laboratory exam.

Rules regarding the M.S. Exam

The rules regarding examinations, fees etc. will remain the same as the usual University rules.

Six Courses	2 x 4+4x3 = 20	Credits
Thesis Evaluation	4	"
Thesis Defense	2	"
General Viva Exam	4	"
Total =	30	(Credits)

TPG 501: Introduction to Condensed Matter Physics (4 credit)

1. Review of Crystal Structure: 6 lect

(a) Bravais Lattice, Primitive Celis, Wigner-Seitz Cells, Symmetries: The space groups, translational and point groups. Monatomic Lattice, Compounds: Rock Salt, NaCl, CsCI, Fluorite, Zinc Blende, Wurtzite, Perovskites. (b) Complex Structures: Equilibrium structures, phase diagrams, superlattices, phase separation, Non-equilibrium structures in alloys, dynamics of phase separation.

2. Pseudo potential Theory and Band Theory: 7 lect

Bloch Theorem, Kronig-Penney model, Orthogonalized Plane waves, Linear Augmented plane waves, LMTO method, Augmented space method. Disordered systems.

3. Electron-Electron Interactions: 8 lect

Hartree and Hartree-Fock equations (HFE). HFE for Jellium. Density Functional theory. Thomas- Fermi theory, Kohn-Sharn equations.

4. Properties of Liquid Metals and Their Alloys: 6 lect

Static Structure functions and pair distribution functions. Thermodynamics properties. Transport properties, atomic transport, Electronic transport and Thermal transport properties.

5. Superconductivity: 10 lect

(a) Phenomenology of Superconductor :Free energy, Thermodynamics, Landau-Ginzburg Free energy, calculation of coherence Length, Saturation depth, Surface energy, SQUIDS.

(b) Microscopic theory of Superconductivity: Electron-ion interaction, Electron-phonon interaction, Electron-Electron interaction, Cooper pairs, BCS Theory; Instability of the Normal State: Cooper Problem, Self-Consistent ground state. Thermodynamics of superconductors, Superconductor in External Magnetic field: Bogoliubov Hamiltonian, Interaction with electromagnetic field. Derivation of Meissner effect. Josephson effect.

6. Electron-Phonon Interaction: Transport Phenomena: 7 lect

Interaction of Electrons with acoustic phonons, Electron-Phonon interaction in Polar Solids, Polarons, The Boltzmann Transport equation for electrons and phonon systems. Relaxation time Approximation. The variational method. Transport Coefficient: without magnetic field, with magnetic field. Transport in Metals and Semiconductors: The electrical conductivity, Transport Coefficients in the relaxation time approximation.

7. Phonon-phonon interaction: 6 lect

One phonon absorption.Multi-phonon absorption, Raman and Brillouin scattering. Frequency shift and life time of phonons, The anharmonic contributions to the free energy Thermal expansion. Thermal conductivity of the lattice.

8. Magnetism: 10 lect

Magnetism as a quantum phenomenon, Many electron systems and Hund's rule: Coulomb correlation effect. Paramagnetism and Diamagnetism in Atoms. The Hubbard model. The Heisenberg model and Spin wave approximation.

Reference:

1. Michael P. Marder: Condensed Matter Physics (John Wiley and Sons, 2000)
2. O. Madelung : Introduction to Solid State Theory. (Springer-Verlag Berlin 1978).
3. J.M. Ziman.: Electrons and Phonons, (Oxford Univ. Press, London 1963).

TPG 502: Advanced Condensed Matter Physics (4 credit)

1. Introduction & Overview of Modern Condensed Matter Physics **5 lect**

Overview of modern condensed matter physics, Review of the second quantization techniques, Review of pictures of quantum dynamics and time-dependent perturbation theory, Low-energy excitations in condensed matter.

2. Non-Relativistic Quantum Field Theory for Many-Body Systems **10 lect**

Basic properties of Green functions, Temperature-dependent quantum field theory in the path integral formalism, The physical meaning of Green functions, Non-interacting Green functions at T = 0 and T > 0, Interacting Green functions and Lehmann representation at T = 0 and T > 0, Relating Green functions to physical observables, Wick's theorem, Application of Green functions to diagrammatic analysis and perturbation theory.

3. Applications of Green Function Techniques to Interacting Electrons & Phonons **6 lect**

Hartree-Fock approximation, Random phase approximation, Linear response theory & Kubo formalism, Phonons, Electron-phonon interactions.

4. Fermi Liquid Theory 6 lect.

Overview of the Fermi liquid theory - phenomenology, Vertex contributions to the Fermi liquid theory the quantum-field approach, Basic physical relations of the Fermi liquid theory and bosonic excitations, Ferml-liquid theory with non-perturbative strong interactions: the Kondo effect.

5. Breakdown of the Fermi Liquid Theory & the Luttinger Liquids **3 lect**

Limitations of Fermi liquid theory, The Tomonaga-Luttinger liquid theory.

6. Interacting Bosons and Super fluidity **5 lect**

Basic formalism for interacting bosons at T=0, Perturbation theory and Feynman rules, Weakly interacting bosons, Field theory of interacting bosons at T -,t. 0, Bosonic superfluid in liquid helium.

7. Introduction to Bose-Einstein Condensation in Cold Gases and Magnetic Insulators **5 lect**

Introduction, Basic criteria of BEC in non-interacting Bose gas, Properties of the alkali atoms, Methods for trapping and cooling atoms, The ground state of trapped bosons, BEC in magnetic insulators,

8. Conventional Superconductivity 6 lect.

Phenomenology of superconductivity, The Cooper instability and electron pairing, Microscopic theory of superconductivity by Bardeen, Cooper and Schrieffer (BCS), Thermodynamic properties of superconductors, Theory of quasiparticle and Cooper pair tunneling, Heavy-fermion superconductors,

9. High-Temperature Superconductivity in the Cuprates & Iron Pnictides **7 lect**

General properties of high-temperature superconducting cuprates. Microscopic models to high temperature superconductivity from Hubbard and t-J models, Recent development in phenomenology, A new class of high-temperature superconductors: the iron pnictides.

10. Topological Field Theory & Fractional Quantum Hall (FQH) Effect **7 lect**

Topological objects: solitons, vortices, and hedgehogs - field theory beyond Feynman diagrams, Integer and fractional quantum Hall effects in two-dimensional electron gas, Braid groups, permutation groups, and fractional statistics, Effective theory of the FQH liquids and topological orders, Edge excitations of the FQH liquids, Basic properties of anyon models, Candidate non-abelian anyons in FQH states & possible experimental verifications.

Reference Books:

1. "Quantum Theory of Many-Particle Systems", A. L. Fetter and J. D. Walecka, Dover Publications, Inc. (2003). [ISBN: 0-486-42827-3]
2. "Methods of Quantum Field Theory in Statistical Physics", A. A. Abrikosov, L. P. Gorkov, and I. E. Dzyaloshinski, Dover Publications, Inc. (1975). [ISBN: 0-486-63228-8]
3. "Quantum Field Theory in a Nutshell", A. Zee, Princeton University Press (2003). [ISBN: 0-691-01019-61
4. "Quantum Field Theory of Many-Body Systems", X.-G. Wen, Oxford University Press (2004). [ISBN: 0-19-853094-3]
5. "Fractional Statistics and Quantum Theory", A. Khare, 2nd Edition, World Scientific (2005). [ISBN: 981-256·-160-9]
6. "Theory of Superconductivity", J. R. Schrieffer, Westview Press (1999). [ISBN: 0-7382-0120-0]

TPG 510 - Many Body Quantum Physics (3 credits)

1. Introduction: 4 lect

Second Quantization: Many particle Hilbert Space and Creation and Destruction operators for Bosons and Fermions. Application: Degenerate Electron gas.

2. Green's Functions: 10 lect

Interaction picture, Time-ordered Products. Definition of Green's functions and their relation to observables. Lehmann representation. Physical Interpretation of Green's functions. Wick's theorem. Diagrammatic representation of Perturbation theory: Feynman diagrams. Dyson's equations.

3. Fermi Systems: 10 lect

Hartree-Fock approximation. Imperfect Fermi gas. Ladder Diagrams and Bethe-Salpeter equation. Degenerate electron gas. Ring Diagrams. Correlation energy.

4. Linear Response Theory: 8 lect

General Theory of Linear response to an external perturbation. Screening in electron gas. Plasma Oscillations.

5. Bose Systems: 5 lect

Green's functions. Perturbation theory and Feynman rules. Weakly interacting bose gas.

6. Finite Temperature Green's Functions: 8 lect

Green's function for finite temperature: definitions and exmaples. Perturbation theory and Wick's theorem at finite temperatures. Diagrammatic analysis and Feynman rules.

Textbooks:

1. L. Fetter and J. D. Walecka - Quantum Theory of Many-Particle Systems, McGraw-Hill.
2. G. D. Mahan- Many-Body Physics, Academic Press.
3. R. D. Mattuck- A Guide of Feynman diagrams in Many-Body Problem, Dover.

TPG520: Equilibrium Statistical Mechanics-I (3 credits)

1. Ensemble: 8 lect.

Micro Canonical, Canonical and Grand Canonical ensembles; Ensemble and Time average, Ergodicity. Ensembles for systems with indefinite number of particles.

2. Partition Function: 10 lect.

Calculation of partition functions for non-interacting systems and interacting systems.

Relation of partition function with thermodynamics. Equation of state. Applications.

3. Virial Equation of State: 10 lect.

Equation of state; Virial coefficients; Scaling properties of different gases. Virial coefficient calculation for hard-sphere and Lennard-Jones potentials.

4. Quantum Statistics: 7 lect.

Density matrix; quantum mechanical ensembles: canonical and grand canonical ensembles; Applications: spin-112 particle in magnetic field; Systems of noninteracting particles.

5. Classical Theory of Liquids: 10 lect.

i) Pair. correlation functions. Yvon-Born-Green function. MSA, HNC, MHNC, VMHNC. Gibbs.
ii) Bogoliubov variation scheme.

References

1. F. Reif, Fundamentals of Statistical and Thermal Physics, McGraw-Hill, NY.
2. K. Huang- Statistical Mechanics, John Wiley and Sons, NY.
3. D.A. McQuarrie, Statistical Mechanics, harper and Row, NY.
4. J.P. Hansen and I. McDonald, Theory of Liquid Metals.
5. M. Shimoji, Liquid Metals, Academic Press, London.
6. R. Balescu, Equilibrium and Non-equilibrium Statistical Mechanics, John Wiley and Sons, NY

TPG521: Equilibrium Statistical Mechanics-II (3 credits)

1. Continuum Mechanics: 6 lect.

Derivation of the continuity equation, some applications of the fundamental equations of continuum mechanics; The Navier-Stokes Equation and its solution.

2. Brownian Motion, Equations of Motion and the Fokker-Plank Equation: 10 lect.

Langevin Equation: The Free Langevin Equation and the Langevin equation in the Force Field. Fokker-Plank Equation: Derivation of the Fokker-Plank equation from the Langevin Equation in the absence and present of Force field, Derivation of Smoluchowski Equation for the overdamped.Langevin Equation. Examples and Applications.

3. Time Correlation Functions: 8 lect

Self intermediate and Intermediate scattering functions, velocity autocorrelation function, Longitudinal and Transverse current correlation function. Relation between time correlation function and diffusion coefficient and viscosity.

4. Boltzman Transport theory: 8 lect.

The relaxation time approximation, Boltzmann semi-classical equation and its solution for electrical and thermal conductivity; Ziman's theory from time-dependent perturbation theory. Fermi Liquid.

5. Phase Transitions, Renormalization Group Theory: 10 lect.

The Thermodynamic State Functions:, The Legendre transformation of internal energy: Thermodynamic potentials, Thermodynamic response functions. Stability Criterion, Thermodynamic Classification of phase transition, Co-existence curves: Clausius-Clapeyron Equation, Critical point exponent and universality, Widom scaling, Kadanof construction, Symmetry of the wave function, Exchange interaction of fermions, Definition of Ising Model and Exact solution in one dimension, Ising model in 2D: A qualitative approach, Mean-field model: Bragg-William theory. Static Scalling Hypothesis, Renormalization Group, The Ginzburg-Landau Theory.

6. Perculations: 3 lect

The phenomenon of perculation; Theoretical Description of perculation, Percolation in one One Dimension.

References

1. Franz Schwabl, Statistical Mechanics, Springer, Berlin.
2. D.A. McQuarrie, Statistical Mechanics, harper and Row, NY.
3. U. Balucani and M. Zoppi, Dynamics of Liquid State, Clarendon Press. Oxford.

TPG525: Non-equilibrium Statistical Mechanics (4 credits)

1. Stochastic Theory & Master Equation: 12 lect.

1. Introduction

Stochastic process, Markov process, Chapmann-Kolmogorov equation, Markov Chains & Master equation

2. Calculation of mean square displacement.

Relation between dissipation and fluctuation force. Fokker-Planck equation and its solution.

3. Derivation of Master equation for Birth and death process

Derivation of Master equation of Fragmentation Process, Basic features of fragmentation processes, Definition of c(x,t) and of its various moments, Master equation for Aggregation processes: Smoluchowski equation

2. Dimensional Analysis, Similarity & Self-similarity. 12 lect.

Dimension of Physical quantity

Power-monomial law of dimension function, Definition of homogeneous function, Dimension function is homogeneous in character, Definition of generalized homogeneous function, Dependent and independent variables, Dimensional analysis IT-theorem, A few illustrative examples, Similarity Phenomena, A couple of illustrative examples, Self-similarity, Scaling and its different nomenclature, Exercises

3. Application of II-Theorem & Scaling Theory. 6 lect.

Einstein-Smoluchowski theory of Brownian motion: a)Probability approach, b) Rate equation approach Scaling properties of the Brownian motion, Power-law distributions of return time, Random walk follow Diffusion Equation, Heat conduction problem, Fragmentation processes:

Exact solution of Binary fragmentation theory for unified model, Scaling theory of fragmentation processes, Power-law distribution of various Moments, Smoluchowski equation, Exact solution, Scaling theory of Smoluchowski equation, Power-law distribution of various Moments

4. Percolation theory: 6 lect.

Definition of Percolation, Forest fire model, Exact solution in one dimension, Exact solution in Bathe lattice (infinite dimension),Cluster size distribution function,Scaling properties, Hoshem-Kopelman algorithm, Random Graph Theory: Erdos-Renyi model, Small-World Systems: Watts-Strogatz model Scale-Free Network: The Barabasi-Albert model

5. Statistically Self-similar Fractal and Multifractal lect.12

Fractal: General discussions

Hausdorff-Besicovitch Dimension, Similarity dimension, Non-Random Fractal: Cantor set, Kotch Curve, Sierpinski Carpet, Random Cantor set, Power-law,Degree of randomness and its connection to fractal dimension

Multiscaling and multifractality Stochastic Sierpinski carpet and Sierpinski lattice.

Multiscaling and Multifractality:

Simple Example: Cut and Stack Model, Fractal subsets, Various Power-laws, Mass exponent I(q), The Legendre transformation and the fray spectrum, The relation among the $f(a)$, $D(q)$ and $\tau(q)$ and their significance.

6. Nonlinear Dynamics and Chaos: lect.6

Linearity versus Nonlinearity, Driven Damped Pendulum (DDP), Some expected Features of DDP, DDP & Approach to Chaos, Chaos & Sensitivity to Initial Conditions, Bifurcation, Logistic map

7. Deposition and growth processes: lect.6

Definition of random sequential adsorption (RSA) processes, Jamming limit, Reny's random car parking problem.Ballastic deposition, Cooperative ballistic deposition (CBD), RSA of mixture and its connection to random Cantor set

Books recommended

1. G. I Barenblatt, Scaling, self-similarity and Intermediate Asymptotics, (Cambridge University Press, 2002).
2. H. Stanely, Introduction to Phase transition and Critical Phenomena, (Oxford University Press, New York, 1971)
3. N. G. Van Kampen, Stochastic Processes in Physics and Chemistry, (North-Holland, 2004)
4. Radu Balescu, Statistical Dynamics: Matter out of Equilibrium, (Imperial College Press, 1997)
5. R. K. Pathria, Statistical Mechanics, (Pergamon Press, 1977).
6. J, Feder, Fractals, (Plenum, New-York, 1988)
7. D. Stauffer, Introduction to Percolation theory, (Taylor and Francis, 1985)
8. P. M. Chaikin and T. C. Lubensky, Principle of Condensed Matter Physics, (Cambridge University Press, 199B).
9. V Privman, Non-equilibrium statistical Mechanics in one dimension, (Cambridge University Press; 1997)

TGP 531: Introduction to Fluid Dynamics (3 credit)

1. **Ideal Fluids:** **8 lect.**

Equation of continuity. Euler's equations. Hydrostatics. Condition on the absence of convection. Bernoulli's equation - energy and momentum flux. Conservation of circulation. Potential flow. Incompressible fluids. Gravity waves. Internal waves in incompressible fluids.

2. **Viscous Fluids:** **8 lect**

Equation of motion of a viscous fluid. Energy dissipation in an incompressible fluid. Flow in a pipe.The law of similarity - flow with low Reynolds number. Laminar Wake. Exact solutions of equation of motion for a viscous fluid. Oscillatory motion in a viscous fluid. Damping of gravity waves.

3. **Boundary Layers** **4 lect**

Laminar boundary layer, flow near the line of separation. Stability of flow in the laminar boundary layer. Turbulent flow in pipes. The turbulent boundary layer. Flow past streamlined bodies.

4. **Shock Waves** **8 lect.**

Sound waves' and its propagation. Propagation of disturbances in a moving gas. Steady flow of a gas. Surfaces of discontinuity. The adiabatic shock. Weak shock waves. Shock waves in polytropic gas. Shock wave propagation in a pipe. Oblique shock waves. Thickness of shock waves.

5. **One dimensional Gas Flow** **4 lect**

Flow through a nozzle. Flow of a viscous gas through a pipe.One dimensional Similarity flow. One dimensional travelling waves - formation of discontinuities in a sound wave. Characteristics. Riemann invariants.

6. **Two dimensional Gas Flow:** **8 lect**

Potential flow of a gas. Steady simple waves. haplygin's equation. Characteristics in steady two- dimensional flow. The Euler-Tricomi equation: transonic flow. Solutions of the Euler-Tricomi equation near non-singular points on the sonic surface. Flow at the velocity of sound.

Textbooks:

1. L. D. Landau and E.M. Lifshitz - Fluid Mechanics(2nd edition) , Pergamon Press.
2. G.K. Batchelor- Introduction to Fluid Dynamics, Cambridge Univ. Press.
3. Ira M. Cohen, P. Kundu - Fluid Mechanics (3rd ed.) , Academic Press.

TGP 541 : Group Theory and Representation Theory (3 Credits)

Group Theory

a) Definition of Groups, Subgroups,Invariant Subgroups,Cosets. Examples of Finite Groups. 5 lect

b) Representation of Groups, Reducible and Irreducible Representations, Schurs Lemmas. Characters and orthogonality relations. Compact and non-compact groups, Peter-Weyl theorem. 10 lect

c) Lie Groups and Lie Algebras, Adjoint epresentations, tensor product of representations, Application of Young Tableaux. Roots and Weights. Weights and roots of SU(3). Simple roots. 12lect

d) Classification of Lie algebras. Dynkin Diagrams. Classical Groups: SU(N), SO(2N),SO(2N+1), Sp(2N) - definitions and properties. Cartan- Killing metric. Casimir Invariants. 18lect

Textbooks

1. H. Georgi - Lie algebras in Particle Physics, (2nd edition) Westview press, USA.
2. B. Wybourne - Classical Groups for Physicists, Academic Press, NY.

TGP 543 : Differential Geometry and Differential Form (3 Credits)

a) Manifolds, Differentiable Manifolds, Integral curves, diffeomorphisms, Vector fields, coordinate basis, Tangent and Cotangent Spaces, pullbacks and pushforwards. 16lect

b) Commutators and Lie derivatives, Frobenius Theorem, Killing Vector. Properties of Killing vectors. 9lect

c) Dual vector spaces and 1-forms. Higher order differential forms. exterior derivatives, Integration of n-forms, Stokes theorem, Homology and Co-homology, Poincare Lemma. Hodge Dual. Cartan's structure equations. 20lect

Textbooks

1. B. Schutz - Geometrical Methods in Modern Mathematical Physics, Cambridge University Press, 1980.
2. C. Nash and S.Sen - Topology and Geometry for Physicists - Academic Press, 1983.

TPG 550: General Relativity and Cosmology (3 credits)

1. **Preamble:** **3 lect.**

Review of special relativity and its limitations, non-inertial frames. Einstein's equivalence principle.

2. **Elements of Tensor Calculus:** **10 lect.**

Tensor Fields, Metric tensor, Covariant derivatives and connections, parallel transport and Christoffel connection, geodesics. Riemann curvature tensor and its symmetries, Bianchi identities. Ricci and Einstein tensors.

3. **Gravitation:** **9 lect.**

Equivalence principle, gravitational redshift, gravitation as spacetime curvature. Einstein's equation. Energy-momentum tensor.

Weak field limit and linearized Einstein equations.

4. **The Schwarzschild solution and Blackholes:** **8 lect.**

Spherically symmetric metrics and Birkhoff theorem. Schwarzschild solution.Blackholes,

5. **Cosmology:** **15 lect.**

a) Cosmological principle - homogeneity and isotropy. Friedmann-Robertson-Walker metric. Energy-Momentum tensor tensor for various forms of matter. Friedmann equations. Evolution of the scale factor, redshift, Hubble law. Cosmic Microwave Background Radiation.

b) Problems in big bang model. Inflationary Universe.

References:

1. S. Caroll - Spacetime and Geometry: An introduction to General Relativity (Addison Wesley Publishing Co., 2003). [A free version on the web is available as the lecture note gr-qc/9712019]
2. R. D'Inverno - Introducing Einstein's Relativity (Oxford Univ. Press, 1992)
3. R. Wald - General relativity (Chicago University Press, 1984).

TPG 555: Relativistic Quantum Mechanics and QED (4 credits)

1. **Relativistic Quantum Mechanics:** 25 lect.

a) Klein-Gordon equation, Negative energies, Indefinite norm and probability conservation.

b) Dirac equation. Relativistic covariance. Bilinear covariants. Plane wave solution of Dirac equations. Negative energy states, spin sum projectors. Wave packets and Klein's paradox. Electromagnetic minimal coupling. Nonrelativistic limit and Pauli equation. Foldy-Wouthuysen transformation and relativistic corrections. Hydrogen-like atom and Dirac equation. Fine structure and hyperfine splitting. Charge Conjugation. Massless fermions and Chirality. two component spinors.

c) Propagators and hole theory. Feynman propagator. Propagation of Dirac particles in an arbitrary Electromagnetic field. Scattering by Coulomb potential - Rutherford and Mott Scattering formula.

2. **Classical Fields and Its Quantization:** 20 lect.

a) Discrete and Continuous systems. Electromagnetic field as an infinite dynamical system. Gauge invariance and electromagnetic action. Symmetries and Conservation laws. Noether's theorem. Canonical energy-momentum tensor. Generalized angular momentum.

b) Canonical Quantization/Second quantization:
Real Scalar Fields, charged scalar fields. Fock space. Normal ordered and time ordered products. Relation between Feynman propagator and time ordered products. Quantization of the EM field- Gupta-Bleuler formalism. Photon propagator in Feynman gauge. Casimir effect.

c) Quantization of Dirac fields and Anticommutator relation. Fock space for fermions and exclusion principle. Feynman propagator for fermions.

3. **Interaction Between Fields and S-matrix:** 15 lect.

a) Interaction Representation and the general form of the S-Matrix. Dyson formula. Wick's theorem for bosonic and fermionic fields.

b) Calculation of Cross sections and Decay Widths: Compton effect, Pair Annihilation, Bhaba scattering. Four fermi interaction and muon decay width.

References:

1. C. Itzykson and J. Zuber, Quantum Field Theory, McGrawHill (1980).
2. J.J. Sakurai, Advanced Quantum Mechanics, Addison Wesley (1967).

TPG 560: Quantum Field Theory (4 credits)

1. **Introduction:** 8 lect

Relativistic single-particle quantum mechanics: The Klein-Gordon and Dirac equations. Difficulties of antiparticles. Interpretation of the KG and Dirac equations as field equations and necessity of the field view-point. Dirac Matrices and Bi-linear Covariants. Maxwell and Proca equations.

2. **Elements Of Field Theory:** 8 lect

Lagrangian formalism; Real and Complex scalar fields, the electro-magnetic field and Yang-Mills Field. Space-time and internal symmetry: Lorentz and Poncare groups. Tensor Fields and Spinors as representations of Poincare group. Construction of local invariant actions. Noether's theorem and conservation law.

3. **Canonical Quantization and Particle Interpretation:** 5 lect

Klein-Gordon, Dirac, electro-magnetic and massive-vector fields.

4. **Feynman Path Integral and Functional Methods in Field theory:** 12 lect

Path integral formalism of quantum mechanics. Perturbation theory and perturbation Expansion of Green's functions. Generator of connected graphs. Loop expansion. Schwinger-Dyson equations. Wick's theorem. Feynman diagrams. Cross-sections and S-matrix. LSZ reduction formula.

5. **Gauge theories:** 10 lect.

Feynman rules for QED: propagators and gauge conditions. Non-Abelian (Yang-Mills) quantum gauge theories, gauge-fixing and Faddeev-Popov Ghosts. Ward-Takahashi identities in QED. Feynman rules for Yang-Mills theory, BRST transformations.

6. **Renormalization:** 12 lect.

Renormalizibility of a theory. Divergences and dimensional regularization in phi/'A theory, QED and Yang-Mills theories. counter-term method. superficial degrees of divergence. Weinberg's theorem. Renormalization Group: Beta and Gamma functions for QED and QCD; asymptotic freedom. renormalization with spontaneous symmetry breakdown: t'Hooft's gauges. The effective potential and Coleman-Weinberg mechanism for phil'A theory.

7. Anomaly: 7 lect

Slavnov Taylor Identities. Fujikawa treatment of chiral anomalies.

References:

1. L.H. Ryder - Quantum Field Theory (Cambridge Univ. Press, 1985).
2. M.E. Peskin and D.V.Schroeder - Introduction to Quantum Field Theory (Westview Press, 1995)
3. M. Srednicki - Quantum and Statistical Field Theory (Cambridge Univ. Press, 2007)
4. P. Ramond - Field Theory: a modern primer (Addison Wesley, 1990).

TPG (565) Quantum Mechanics -I (3 credit)

1. Review of Fundamental Concepts:

Historical Overview: Failures of Classical Physics and emergence of Quantum Mechanics. Quantum Theory and the Wave Nature of Matter: The Stern-Gerlach Experiment, Kets, Bras and Operators, Base Kets and Matrix Representations, The Principle of Superposition, Wave packets and their Motion, Measurements, Observables and the Uncertainly Relations, The Spreading of Wave-packets, Change of Basis, Position and Momentum Space.

2. Quantum Dynamics:

Time Evolution in Quantum Mechanics. Pictures: The Time Dependent and Independent Schrodinger Equations, The interpretation of the wave function. Pictures: Schrodinger, HeisenbergandInteraction,picturesofQuantumMechanics. Simple Harmonic Oscillator: Dirac's Operator Met hod or Ladder Method.

3. Theory of Angular Momentum

Rotations and Angular Momentum Commutation Relations: Finite Versus Infinitesimal Rotations, Infinitesimal Rotations in Quantum Mechanics. Spin ½ systems and Finite Rotations: Rotations Operator for spin ½ spin precession, Pauli two-component formalism. Rotations in the two-component formalism. O(3), SU(2) and Euler Rotations: Orthogonal Group, Unitary unitary unimodular group, Euler Rotations. Eigenvalues and Eigenstates of Angular Momentum: Commutation Relations and the Ladder Operators, Matrix Elements of Angular-Momentum Operators, Representations of the Rotation Operator. Orbital Angular Momentum: Orbital Angular Momentum as Rotation Generator, Spherical Harmonics as Rotation Matrices. Addition of Angular Momenta: Simple examples of Angular Momentum Addition, Formal Theory of Angular Momentum Addition: The Clebsch-Gordan Coefficients And their Recursion relations, Rotation Matrices.

4. Scattering Theory:

The Lippmann-Schwinger Equation, The Born Approximation, Optical Theorem, Eikonal Approximation, Free Particle States: Plane Waves Versus Spherical Waves, Method of Partial Waves, Low-Energy Scattering and Bound States, Resonance Scattering, Identical Particles and Scattering, Symmetry Considerations in Scattering.

References :

1. Modern Quantum Mechanics, J.J. Sakurai, Addison-Wesley Publishing Company, 1985
2. Quantum Mechanics, Eugen Merzbaher, John Wiley & Sons, 1998
3. Introduction to Quantum Mechanics, Bransden and Joachain, Longman Group UK Ltd 1989

TPG 575: Introduction to The Standard Model-I (3 credits)

Prerequisite: It is assumed that the student has some working knowledge of quantum field theory or at least concurrently enrolled in the quantum field theory course.

1. Introduction: **7 lect**

Hilbert and Fock space, creation and annihilation operators. General properties of interactions. Free field theory. Implications of symmetries.Renormalizable interactions.

2. General Features of The Standard Model: **15 lect**

Vacuum and the idea of spontaneous symmetry breaking. The Goldstone theorem and spontaneous breaking of gauge symmetries,Higgs field .Particle content,The Lagrangian, The perturbative spectrum, Interactions and Symmetry properties.

3. Cross sections and lifetimes: **3 lect**

Scattering states and the S-matrix.Time-dependent perturbation theory. Decay rates and cross sections.

4. Elementary Boson Decays: **4 lect**

ZO decay. W± decays. Higgs decays.

5. Leptonic weak interactions: decays: **8 lect**

Qualitative features. The calculation. The large-mass expansion. Feynman rules.

6. Leptonic weak interactions: collisions: **8 lect**

The Mandelstam variables. Electron-Positron pair- annihilation: calculation. Electron-Positron pair- annihilation: Applications. The Z boson resonance. t-channel processes: crossing symmetry. Interference: Moller scattering. Processes involving photons.

References

1. C.P. Burgess and Guy D.Moore , The Standard Model: A Primer, Cambridge University Press, NY.
2. W.N. Cottingham and D.A.Greenwood, An Introduction To The Standard Model of Particle Physics, Cambridge University Press, NY.
3. J.F. Donoghue, E.Golowich, B.R.Holstein, Dynamics Of The Standard Model, Cambridge University Press, NY.

TPG 562: Introduction to The Standard Model-II(3 credits)

Prerequisite: It is assumed that the student has some working knowledge of quantum field theory or at least concurrently enrolled in the quantum field theory course. Also, he/she has taken or at least concurrently enrolled in the "Introduction To The Standard Model-I" course.

1. Effective Lagrangians In The Standard Model: **8 lect**

Physics below the W-boson mass: the spectrum. The Fermi theory. Physics below the W-boson mass: qualitative features. Running couplings. Higgsless effective theory.

2. Hadrons and Quantum Chromodynamics: **7 lect**

Qualitative features of the strong interactions. Heavy quarks. Light quarks

3. Hadronic interactions: **15 lect**

Quasi-elastic scattering. Hard inelastic scattering: partons. Soft inelastic scattering: low-energy mesons. Neutral-meson mixing.

4. Beyond the standard model: Neutrino masses: **5 lect**

The kinematics of massive neutrinos. Neutrino oscillations. Neutrinoless double-beta decay. Gauge- invariant formulations.

5. Beyond the standard model: Open questions, proposed solutions: **10 lect**

Effective theories. Dimension zero: cosmological-constant problem. Dimension two: hierarchy oblem. Dimension four: triviality, θ**QCD**, flavor problems. Dimension six: baryon-number violation.

Reference

1. CP. Burgess and Guy D.Moore , The Standard Model: A Primer, Cambridge University Press, NY.
2. W.N. Cottingham and D.A.Greenwood, An Introduction To The Standard Model of Particle Physics, Cambridge University Press, NY.
3. J.F. Donoghue, E.Golowich, B.R.Holstein, Dynamics Of The Standard Model, Cambridge University Press, NY.

TPG 570 Introduction to Particle Physics-I (3 credits)

Prerequisite: It is assumed that the student has some working knowledge of quantum field theory or at least concurrently enrolled in the quantum field theory course.

1. **Introductory Overview:** **7 lect.**

Fundamental Particles and their interactions. Hadrons and leptons. Symmetry transformations in particle physics: Conservation laws. QED: U(l) symmetry. C and P invariance - Furry's theorem. Selection rules in positronium decays as examples.

2. **Calculation of Scattering cross-sections and decay widths: 10 lect.**
3. Scattering of electrons by heavy nucleus. Sand T-matrix. Unitarity and optical theorem. Decay rate of unstable particles. Electromagnetic interaction of electrons and QED feynman rules. Electron-proton scattering. Bhabha scattering. Muon pair production from electron-positron annihilation.
4. **Isospin and G-parity:** **8 lect**

U(2) symmetry and isospin transformations. Nucleon - antinucleon system. The G quantum number. Application to Hadronic Systems: Pions, Vector Mesons, Strange Particles. Meson and baryon Octets.

5. **SU(3) symmetry:** **10 lect**

Definition of SU(3) tensors and their representations. Decomposition of product representations. Hadronic states as representations of SU(3): pseudo scalar and spin-112 baryon octet, spin-3/2 decuplet.. Mass formulas. The quark model.

6. **Time Reversal and CPT Invariance:** **10 lect**

Time reversal in Schrodinger and Heisenberg representations. Properties of the T -operator. Examples in QED. T-invariance and S-matrix. CPT-theorem and its applications: Mass, Lifetime equality between particle and antiparticles.

Textbooks:

1. T. D. Lee - Particle Physics: Introduction to Field Theory, Academic Press.
2. F. Halzen and A.D. Martin - Quarks and Leptons, John Wiley.
3. O. Nachtrnann- Elementary Particle Physics, Springer Verlag.
4. L.B.Okun- Leptons and Quarks, North Holland.

TPG 571 Introduction to Particle Physics-II (3 credits)

Prerequisite: It is assumed that the student has some working knowledge of quantum field theory or at least concurrently enrolled in the quantum field theory course. Also, he/she has taken or at least concurrently enrolled in the "Introduction to Particle Physics-I" course.

1. **The Neutral K-Mesons and CP violation:** **10 lect**

Phenomenology of Neutral K-mesons. CP transformations and the Kaon-anti Kaon oscillations. Mass and decay matrices. KL and KS states and their mass difference. Phenomenological analysis of the CP , T and CPT violation in neutral K -meson system.

2. **Weak Interactions** **15 lect**

Neutrino hypothesis, Four-fermion interaction and Phenomenological Fermi Lagrangian. Leptonic decays - Muon decay. Semileptonic decays - pion decay. Parity violation and (V-A) theory. Universality of the weak interactions. Cabbibo mixing. Limitation of Fermi theory - Intermediate vector boson hypothesis.

3. **The Standard Model for Electroweak Interactions** **10 lect**

The SU(2) x U(l) gauge group. Neutral currents. Higgs field and Spontaneous symmetry breaking. Masses of the gauge bosons. Fermions mass from Yukawa couplings. Extension to quarks. CKM matrix. Neutrino-electron scattering. Weinberg angle.

4. **Basics of Parton Model and QCD:** **10 lect**

Inelastic electron-proton scattering. Bjorken scaling. Callan-Gross relation. Gluons and scaling violation-Altarelli-Parisi equation. Electron-positron annihilation into hadrons - color degree of freedom. QCD lagrangian.

Textbooks:

1. T. D. Lee - Particle Physics: Introduction to Field Theory, Academic Press.
2. F. Halzen and A.D. Martin - Quarks and Leptons, John Wiley.
3. O. Nachtmann- Elementary Particle Physics, Springer Verlag.
4. L.B.Okun- Leptons and Quarks, North Holland.

TPG 580:Computational Physics (4 credits)

This course comprise of has two parts: a theoretical part carrying 40 marks-there will be a written exam based on it. The remaining 60marks will be broken up into class assessments whose weight will be 30 marks and the rest 30 marks will be allocated for the Final lab exam.

Only the theoretical syllabus is presented here. Materials to be covered in the lab sessions will also follow the syllabus presented below. Due to the scientific nature of the course the C programming language and the free Unix-like operating system e.g. Linux will be used exclusively.

1. **Preamble:** **6 lect.**
    a) Purpose of scientific computing. Computer arithmetic and errors.
    b) Elementary introduction to the Linux operating system.
    c) Rudiments of C.
    d) Use of a plotting program: gnuplot.
2. **Solution of Nonlinear equation:** **5 lect**
    a) The bisection and secant method.
    b) Method of False Position
    c) Newton-Raphson method
    d) Fixed-point interation.
    e) Logistic maps and Feigenbaum maps. Onset of Chaos.
3. **Numerical Inteqration:** **8 lect**
    a) Trapezoidal and Simpson's rule.
    b) Newton-Coates Integration Formula. Errors and Corrections.
    c) Iterative error correction using Rohmberg Integration technique.
    d) Gaussion quadrature formulas for integration. Gauss-Legendre Quadrature.
    e) Use of random number generators and Monte-Carlo techniques for evaluating integrals in various dimensions.

4. **Solution of ordinary differential equations: 10 lect**
   a) Decay, Growth and Oscillatory equations.
   b) Euler's method. Stability analysis.
   c) Modified and Improved Euler's Method.
   d) 2-point Runge-Kutta method and its stability.
   e) Use of the 4-point Runge-Kutta method
   f) Leap- frog method and its utility.
   g) Systems of differential equations and higher order differential equations.
   h) Numerical solution of Newtons equations under various forces. Falling bodies.
   i) Behavior of Oscillators: Simple harmonic oscillator. Simple Pendulum. Van der Pohl oscillator and Duffing oscillators. Limit cycles and the role of errors.
5. **Partial Differential Equations: 16 lect**
   a) Classification of Second order partial differential equations.
   b) Generic behavior of elliptic, parabolic and hyperbolic PDEs
   c) Initial value problems and advective equation.
   d) Treatment of the wave equation
      i) Forward Time and Centred Space (FTCS) discretization. Von- Neumann Stability analysis Courant condition.
      ii) Lax method and its stability.
      iii) Staggered Leap-frog method and its stability analysis.
   e) Parabolic Equation:
      i) FTCS analysis for parabolic equations.
      ii) Lax-Wendorff method
      iii) Elementary discussion on Crank-Nicholson method.
   f) Elliptic equation:
      i) Boundary Value problems.
      ii) Poisson's equation in 1d. : Inversion of a tri-diagonal matrix.
      iv) Solution of 2d Poisson's equation with dirichlet condition using spectral method
6. **Elements of fourier Analysis 5 lect**
   a) Approximation with functions with Fourier series.
   b) Calculation of Fourier coefficients numerically.
   c) Discrete Fourier transform and the sampling theorem. Nyquist condition of sampling.
   d) Basic idea of Fast Fourier transform.
7. **Simulation of Simple Systems: 10 lect**
   a) Metropolis Algorithm
   b) Importance Sampling
   c) Generation of Random numbers.
   d) Random Walks
   e) 1 D and 2D Ising model. Calculation of Magnetization versus temperature and specific heat vs. temperature curve. absence of phase transition in 1d.

References:

1. C.F. Gerald and P.O. Wheatley - Applied Numerical Analysis, Sixth edition, Addison Wesley.
2. P.De Vries - A first course in Computational Physics (John Wiley and Sons, 1994).
3. W. Press, S. Teukolsky, W. Vellerling and B. Flannery-Numerical Recipes in C: The art of scientific computing (2nd ed.)(Cambridge Univ. Press, 1992).
4. H. Gould and J. Tobochnik- Introduction to Computer Simulation Methods (Addison -Wesley, 1996).

Courses offered by the Department of the Theoretical Physics and credit distribution

Course Number	Course Name	Credits
TPG 501	Introduction to Condensed Matter Physics	4
TPG 502	Advanced Condensed Matter Physics	4
TPG 510	Many Body Quantum Physics	3
TPG 520	Equilibrium Statistical Mechanics-I	3
TPG 521	Equilibrium Statistical Mechanics- II	3
TPG 525	Non-equilibrium Statistical Mechanics	4
TPG 531	Introduction to Fluid Dynamics	3
TPG 541	Group Theory and Representation Theory	3
TPG 543	Differential Geometry and Differential form	3
TPG 550	General Relativity and Cosmology	3
TPG 555	Relativistic Quantum Mechanics and QED	4
TPG 560	Quantum Field Theory	4
TPG 562	Introduction to The Standard Model -II	3
TPG 565	Quantum Mechanics-I	3
TPG 570	Introduction to Particle Physics -I	3
TPG 571	Introduction to Particle Physics -II	3
TPG 575	Introduction to The Standard Model-I	3
TPG 580	Computational Physics	4
TPG 598	General Oral Examination	4
TPG 599	Thesis	6

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