PhD COMPLEX EXAM
QUANTUM THEORY

15. Many-body physics

- Second quantization. Linear response, Green's functions. Kramers-Kronig relation.
- Perturbation theory and diagrammatic techniques. (Feynmann diagrams, Dyson equations, self-energy). Fermi liquids and non-Fermi liquids.
- Interacting one dimensional fermions (renormalization group and basic properties of Luttinger liquids).
- Electron-phonon interactions (polarons, Peierls transition, Cooper instability).
- Superconductivity, Cooper instability. Mean field theory.
- Interacting bosons, Bogoliubov theory, superfluidity.

16. Quantum field theory and particle physics

- Relativistic fields. Canonical quantisation, spin-statistics and CPT theorem.
- Interacting fields, scattering theory, cross sections. Feynman rules. Functional integral methods. Generating functionals. Path integral for fermions.
- Renormalisation. Classification of divergences, counter terms. φ^4 theory and QED at one loop.
- Renormalisation group, Callan-Symanzik equation. Operator product expansion.
- Symmetries, Ward identities. Spontaneous symmetry breaking. Gauge invariance, elements of non-Abelian gauge theory.
- Weak interactions. Parity and CP violation. Charged current Lagrangian, flavour mixing, neutrino oscillations. $SU(2)_L x U(1)_Y$ gauge theory, Higgs mechanism.
- Strong interactions. SU(3) quark model. Fundamentals of quantum chromodynamics, confinement and asymptotic freedom.

17. Quantum physics of electron systems

- Free electrons in Hartree-Fock approximation. Density functional theory. Extensions of DFT: SDFT, self-interaction correction.
- Variational and pseudopotential methods.
- Point group symmetry in band structure. Time reversal symmetry and spin-orbit coupling.
- Surface states, Bychkov-Rashba effect, symmetry analysis of the effective Hamiltonian.
- Green function method in tight-binding approximation. Band structure of alloys, coherent potential approximation.
- Ab initio theory of itinerant magnetism, Stoner model. Method of disordered local moments.

18. Quantum optics and quantum informatics

- Radiation transitions. Photodetection, photon statistics. Hanbury-Brown and Twiss experiment, photon antibunching. Coherent and squeezed states, Wigner functions.
- Resonant atom-light interaction. Atoms in resonators, Purcell effect, strong coupling.
- Ultracold atoms, Bose condensation, optical lattices.
- Entanglement, Bell inequalities, quantum teleportation, quantum cryptography.
- Quantum computing and quantum algorithms.
- Realisation of q-bits, one and two q-bit operations. Mechanisms of information loss: relaxation, dephasing, decoherence.

19. Quantum theory of mesoscopic systems

- Generic properties of metallic grains (random matrix theory, level repulsion, universality classes).
- Conductance through mesoscopic structures (Landauer-Büttiker formula and conductance quantization, random matrix theory of conductance, quantum Hall edge states, universal conductance fluctuations).
- Coulomb blockade in quantum dots and molecules (spectroscopy, co-tunneling, signatures of Kondo effect).
- Superconducting grains and Josephson junctions. Superconducting Q-bits and their manipulation.
- Anderson localization (mobility edge, scaling theory).