Quantum Condensed Matter Physics 2020-21

1. Classical and Semi-classical models for electrons in solids (3L)
Lorentz dipole oscillator, optical properties of insulators. Drude model and optical properties of metals, plasma oscillations. Semi-classical approach to electron transport in electric and magnetic fields, the Hall effect. Sommerfeld model, density of states, specific heat of; electrons in metals, liquid ^{3} He/^{4}He mixtures. Screening and the Thomas-Fermi approximation.

2. Electrons and phonons in periodic solids (6L)
Types of bonding; Van der Waals, ionic, covalent. Crystal structures. Reciprocal space, x-ray diffraction and Brillouin zones. Lattice dynamics and phonons; 1D monoatomic and diatomic chains, 3D crystals. Heat capacity due to lattice vibrations; Einstein and Debye models. Thermal conductivity of insulators. Electrons in a periodic potential; Bloch's theorem. Nearly free electron approximation; plane waves and bandgaps. Tight binding approximation; linear combination of atomic orbitals, linear chain and three dimensions, two bands. Pseudopotentials. Band structure of real materials; properties of metals (aluminium and copper) and semiconductors. Semi-classical model of electron dynamics in bands; Bloch oscillations, effective mass, density of states, electrons and holes in semiconductors

3. Experimental probes of band structure (4L)
Photon absorption; transition rates, experimental arrangement for absorption spectroscopy, direct and indirect semiconductors, excitons. Quantum oscillations; de Haas-Van Alphen effect in copper and strontium ruthenate. Photoemission; angle resolved photoemission spectroscopy (ARPES) in GaAs and strontium ruthenate. Tunnelling; scanning tunnelling microscopy. Cyclotron resonance. Scattering in metals; Wiedemann-Franz law, theory of electrical and thermal transport, Matthiessen's rule, emission and absorption of phonons. Experiments demonstrating electron-phonon and electron–electron scattering at low temperatures.

4. Semiconductors and semiconductor devices (5L)
Intrinsic semiconductors, law of mass action, doping in semiconductors, impurity ionisation, variation of carrier concentration and mobility with temperature - impurity and phonon scattering, Hall effect with two carrier types. Metal to semiconductor contact. p-n junction; charge redistribution, band bending and equilibrium, balance of currents, voltage bias. Light emitting diodes; GaN, organic. Photovoltaic solar cell; Shockley-Queisser limit, efficiencies. Field effect transistor; JFET, MOSFET. Microelectronics and the integrated circuit. Band structure engineering; electron beam lithography, molecular beam epitaxy. Two-dimensional electron gas, Shubnikov-de Haas oscillations, quantum Hall effect, conductance quantisation in 1D. Single electron pumping, single and entangled-photon emission, quantum cascade laser.

5. Electronic instabilities (2L)
The Peierls transition, charge density waves, magnetism, local magnetic moments, Curie Law. Types of magnetic interactions; direct exchange, Heisenberg hamiltonian, superexchange and insulating ferromagnets, band magnetism in metals, local moment magnetism in metals, indirect exchange, magnetic order and the Weiss exchange field.

6. Fermi Liquids (2L)
Fermi liquid theory; the problem with the Fermi gas. Liquid Helium; specific heat and viscosity. Collective excitations, adiabatic continuity, total energy expansion for Landau Fermi liquid, energy dependence of quasiparticle scattering rate. Quasiparticles and holes near the Fermi surface, quasiparticle spectral function, tuning of the quasiparticle interaction, heavy fermions, renormalised band picture for heavy fermions, quasiparticles detected by dHvA, tuning the quasiparticle interaction. $CePd_2Si_2$; heavy-fermion magnet to unconventional superconductor phase transitions.