# Topics of Applied Solid State Physics (2019)

**1. Band structure picture of solids.** Methods for calculating energy bands (nearly free electron model, tight binding model), electronic bands in crystals in 1, 2 and 3 dimensions for different valence numbers (1, 2 and higher); metals, semiconductors, insulators; limitations of band structure picture.
(*S. H. Simon: The Oxford Solid State Basics, sections 16.1–16.4.*)

**2. Band structure and optical properties.** Optical excitations in insulators and semiconductors, relation of color and band gap, direct and indirect transitions, energy and momentum conservation; optical excitations in metals (reflectance, color); optical effects of impurities.
(*S. H. Simon: The Oxford Solid State Basics, section 16.5.*)

**3. Semiconductor physics I.** Electrons and holes, effective mass approximation, momentum and velocity of a hole; quasiclassical equation of motion, Drude transport, mobility.
(*S. H. Simon: The Oxford Solid State Basics, section 17.1.*)

**4. Semiconductor physics II.** Intrinsic and extrinsic semiconductors, the effect of doping; donors and acceptors in Si, impurity states, estimation of binding energy; impurity eigenstates.
(*S. H. Simon: The Oxford Solid State Basics, section 17.2.*)

**5. Semiconductor physics III.** Statistical mechanics of semiconductors: density of states, exponential activation, law of mass action, density of conduction electrons and holes in intrinsic and extrinsic semiconductors; conductivity of doped semiconductors as a function of temperature.
(*S. H. Simon: The Oxford Solid State Basics, section 17.3.*)

**6. Semiconductor devices I.** Band structure engineering, semiconductor heterostructures, modulation doping and 2DEG, the unbiased $p$-$n$ junction, estimation of width of depletion region, electrochemical potential, solar cells and photodiodes.
(*S. H. Simon: The Oxford Solid State Basics, sections 18.1–18.2.*)

**7. Semiconductor devices II.** Biased $p$-$n$ junction: the diode, calculating the $I(V)$ characteristics, simplified model, rectification; the transistor, operating principle of a MOSFET.
(*S. H. Simon: The Oxford Solid State Basics, sections 18.2–18.3.*)

**8. Charge transport in mesoscopic systems.** Moore's law, new phenomena at nanoscale; equations of classical diffusive transport, Drude picture; characteristic lengthscales and timescales, typical values in metals and 2DEG; ballistic vs. diffusive regime; resistance of a nanowire, Landauer formalism, conductance quantization.
(e-learning material no. 1.)

**9. Thermoelectric transport in mesoscopic systems.** Bethe-Sommerfeld expansion (motivation). Thermoelectric phenomena: Seebeck effect, heat current, Wiedemann-Franz law, Peltier effect, Kelvin's formula.
(e-learning material no. 2.)

**10. Coherent and incoherent transport.** Four probe resistance, coherent and incoherent serial connection of scattering centers, transmission and reflection probabilities, demonstration of Ohm's law.
(e-learning material no. 3.)

**11. The Boltzmann equation I.** Equilibrium and non-equilibrium distribution functions, derivation of Boltzmann equation without collisions, Lioville's theorem; effect of collisions, incoming and outgoing flux.
(e-learning material no. 4. - Hungarian)

**12. The Boltzmann equation II.** Relaxation time approximation, solution in uniform $E$-field (without temperature gradient); conductivity of empty, fully filled and partially filled band; conductivity of an isotropic system, application for parabolic disperion (Drude's result); temperature dependence of resistivity of metals, Mathiessen rule.
(e-learning material no. 4. - Hungarian)

**13. The Boltzmann equation III.** Solution in the presence of $E$-field and temperature/chemical potential gradient; application: thermoelectric effects, heat conductance, Seebeck coefficient, Peltier coefficient, Kelvin's relation.
(e-learning material no. 4. - Hungarian)

**14. Magnetism I.** Basic types of magnetism: paramagnets, diamagnets, ferromagnets (domains), examples; magnetization ($M$) and magnetic field ($H$), magnetic susceptibility; origin of atomic magnetic moments: Hund's rules.
(*S. H. Simon: The Oxford Solid State Basics, sections 19.1–19.2.*)

**15. Magnetism II.** Why do magnetic moments align? Investigation of a toy model (2 electrons in an atom), symmetry of the wavefunction, Pauli's exclusion principle, exchange energy; Simple models of magnetism: effective model of interacting spins (by Dirac), Heisenberg model, Ising model. Types of spontaneous magnetic order; ferromagnets, antiferromagnets, ferrimagnets; spontaneous symmetry breaking, frustration.
(*S. H. Simon: The Oxford Solid State Basics, section 19.2, chapter 20.*)

**16. Magnetism III.** The mean field theory of ferromagnets, effective (Weiss-)field, self consistency equation, stable and unstable solutions; paramagnetic and ferromagnetic phase, critical temperature (Curie-point); spontaneous magnetization as a function of temperature.
(*S. H. Simon: The Oxford Solid State Basics, chapter 22.*)

**17. Introduction to superconductivity.** Quantum mechanical basics: Schrödinger equation in $\boldsymbol{A}$-field, canonical and kinetic momentum, quantum mechanical current, probabilistic interpretation of wavefunction (Born); discovery of superconductivity, qualitative explanation of electron-electron attraction, Cooper pairs, Bose Einstein condensate, macroscopic wavefunction.
(The Feynman lectures on physics)

**18. Superconductors in magnetic field.** Persistent current, Meissner-effect, penetration depth of magnetic field, boundary condition for $\boldsymbol{B}$-field (image dipole), type I and type II superconductors, vortices and flux pinning (phenomenologically).
(The Feynman lectures on physics)