OPTI 447: Optical Physics (updated 12/21/11)

OPTI 447. Optical Physics (3). Review of linear algebra and classical mechanics, atomic models, Lorentz model, EM propagation, optical properties of dielectrics and metals, magneto- and electro-optics, concepts of nonlinear optics. P, PHYS 241, MATH 223, MATH 254, MATH 322, OPTI 280, 310 & 330.

1. Review of linear algebra: 3D vectors, orthonormal Cartesian basis vectors, Cartesian components and representation as a column vector, linear vector spaces, linear operators and matrices, important types of matrix and the matrix inverse, systems of linear equations, eigenvalue problems and the characteristic equation, calculation of eigenvalues and eigenvectors, completeness and orthonormality of the eigensolutions of a Hermitian matrix, diagonalization of Hermitian matrices, tensors and their matrix representation. A physical example, the Jones calculus for field polarization, eigen polarizations for optical systems and materials.
2. Review of classical mechanics: Newton's equation for a particle moving in 1D, kinetic and potential energies, conservation of energy, equations of motion for multiple particles and one particle moving in 3D, Hooke's law for small oscillations, the 1D harmonic oscillator, general solution and eigensolutions, physical examples including the pendulum, the mine-shaft problem, and molecular vibrations, the damped harmonic oscillator and complex harmonic eigensolutions, coupled harmonic 1D oscillators and eigensolutions, 3D harmonic oscillator and the force constant tensor, symmetry of the force constant tensor and the principal axes system, example of the principal axes system for coupled 1D harmonic oscillators.
3. Models of the atom: Historical overview, Bohr model of the hydrogen atom and energy levels, principal quantum number, emission and absorption spectra of hydrogen, time-dependent and time-independent Schrödinger equations, one-dimensional examples of a quantum particle in a box and the quantum simple harmonic oscillator, Schrödinger equation for the hydrogen atom, ground state properties n=1, quantum numbers n,l,m,s for the energy levels, properties of the atomic orbitals, optical interactions and selection rules, spontaneous emission and energy level lifetime, time-energy uncertainty principle and real versus virtual transitions.
4. Lorentz electron oscillator model: Classical model for a displaced electron cloud, restoring force and resonant frequency, Lorentz model with damping, Lorentz force due to an applied EM field, dipole approximation and the driven Lorentz model, solution of the Lorentz model for a harmonic field, dipole moment and the atomic polarizability, optical polarization for a gas of atoms, mechanical effects of light, dipole interaction energy, optical trapping of particles in a laser beam, optical tweezers and optical molasses.
5. Electromagnetic propagation: Maxwell equations and the constitutive relations, Maxwell's wave equation, Helmholtz equation for a monochromatic field, transverse electric field solution for an isotropic medium, the complex refractive-index, refractive-index & absorption, matrix form of the Helmholtz equation.

6. Optical dispersion: Optical spectra of dielectric media, oscillator strengths, static dielectric constant, near resonance approximation, absorption and refractive-index spectra, notion of transparent media, Sellmeier and Cauchy formulae, dielectric constant of conducting media or metals, frequency dependence of optical properties and the plasma frequency, reflection from a metal for normal incidence & skin depth.
7. Crystal optics: The Lorentz electron oscillator model in crystals, principal axes system and the principal (complex) refractive-indices, susceptibility and dielectric tensors in crystals, matrix forms for the macroscopic polarization and electric displacement for a crystal, crystal symmetry and the susceptibility and dielectric tensors, isotropic, uniaxial, and biaxial crystals, matrix form of the Helmholtz equation for propagation of a plane-wave in a crystal, propagation of a plane-wave along a principal axis in a crystal, (2x2) matrix formulation and the Jones calculus, dichroism and polarizers, birefringence and wave-plates, propagation along a general direction in a transparent biaxial crystal, (3x3) matrix formulation, the wave-vector surface and optic axes, eigenpolarizations, ordinary and extraordinary waves in a uniaxial crystal, double refraction at an interface.
8. Magneto-optics & optical activity: Description of the magneto-optical Faraday effect, cyclotron motion in the presence of a static magnetic field, Lorentz electron oscillator model and the optical polarization, circularly polarized eigenpolarizations, magneto-optical Zeeeman effect, Faraday rotation and optical isolators, description of optical activity.
9. Electro-optics: Description of the electro-optical Pockels and Kerr effects, electron motion in the presence of a static electric field, simplified Lorentz model for electro-optics (EO lite), anharmonic electron motions, the first- and second-optical polarizations, the EO Pockels effect, general formulation of the first- and second-order optical polarizations, index contraction of the second-order susceptibility, matrix Helmholtz equation for propagation along the optic axis of a KDP crystal, eigenpolarizations and the EO Pockels effect, EO modulation of radiation.
10. Acousto-optics: Sound or acoustic waves in an acousto-optic (AO) cell, refractive-index modulations and spatially varying optical polarization due to an acoustic wave, Helmholtz equation for field optical propagation in an AO cell, the slowly-varying envelope approximation (SVEA), Raman-Nath or Debye-Sears diffraction, the Klein-Cook parameter Q, Bragg diffraction, acousto-optic modulators.
11. Introduction to nonlinear optics: Simplified Lorentz model for nonlinear optics (NLO), anharmonic electron motions, the first- and second-optical polarizations, second- and higher-order NLO, second-harmonic generation (SHG), optical rectification, sum and difference frequency generation, generalization of the first- and second-order polarizations, Helmholtz equations, solution for SHG, phase-matching for efficient SHG and the coherence length, Maker fringes, index phase-matching in uniaxial crystals, quasi phase-matching.

12. Topics in NLO: Third-order nonlinear optics, THG, the nonlinear Kerr effect, self-focusing and self-defocusing, simple model for self-trapping and the critical power, self-focusing collapse, arrest of collapse by plasma generation, filamentation in media, light strings in the atmosphere, self-phase modulation, supercontinuum generation, high harmonic generation.