Physics 462: EM Waves and Optical Physics

Recommendations for review/study:
- Review the class notes and reading. Work through any derivations or examples that are unclear to you.
- Review the homework solutions, even for problems you got credit for. Often it helps to see other (possibly shorter) ways to do a problem. I will often base a test question on a homework problem.

Basic math literacy
- working with complex numbers: extracting amplitude and phase, taking abs values, conjugation, representing sines and cosines as exponentials.
- representation of waves with real functions(sine, cosine) and with complex exponentials. Amplitude, phase, frequency, wavenumbers, phase velocity.
- Taylor expansion: especially 1^{st} order small angle expansion of sin, cos, $(1+\varepsilon)^n \approx 1 + n\varepsilon$.

For first Midterm:

Maxwell equations
- integral form of Maxwell equations: generally for charges and currents
- electric and magnetic flux integrals, Gauss' law
- continuity equation for charge/current
- scalar and vector potentials: gauge invariance
- energy density and energy flow (Poynting vector), stress-energy tensor

Basic EM wave propagation
- 3-D k-vector, 3-D plane waves, **k**, **E**, **B** are mutually perpendicular for plane waves
- Derivation of wave equation in free space from Maxwell equations
- Calculation of irradiance (intensity), energy density and Poynting vector from the fields
- Cycle averaging to get at mean values of irradiance.
- Faraday and Ampere laws to get **B** from **E** and vice versa.
- Phase and group velocity calculation: calculate vg = $(dk/d\omega)^{-1}$; calculate v_g as a function of index, for guided waves.
- Momentum and pressure in fields

Polarization
- polarization states: linear, circular and elliptical
- representing polarized waves with complex exponential notation with Cartesian vector components
- representing polarization states using either linearly-polarized or circularly-polarized basis states
- optical activity: refractive index depends on R or L circ polarization
- representing polarization states with Jones vector notation
- transformation of polarization states with propagation through birefringent media (waveplates) and through phase changes from Fresnel reflection
- using Jones matrices and rotation matrices to compute changes in polarization states

EM waves at boundaries

- In a region of constant index n, components of wave vector are related by: $\sqrt{k_x^2 + k_y^2 + k_z^2} = nk_0 = n\omega / c$. For plane waves, forward propagation phase is continuous along boundary.
- Boundary conditions for normal and tangential components of the E- and B-fields:
  - Dielectrics: all are continuous for nonmagnetic materials except for the normal component of the E-field
- Reflection from an interface: treat the two polarization directions separately, it is usually easier to solve for the fields that are continuous across the boundary
- Derivation of Snell's law in different ways: phase continuity, Fermat's principle of least time
- Using the Fresnel coefficients as amplitude and phase factors on reflected, transmitted waves.

For Second Midterm:

Standing waves: waveguides and resonators

- Separation of variables to get equations for propagating and standing-wave components of waves.
- Standing waves: bound in transverse direction only (guided beams); 3-D standing waves (as in resonator cavity)
- Geometric/ray picture of guided modes: estimate of number of bound modes using TIR condition
- Qualitative analysis of bound mode profiles in dielectric waveguides by analogy to quantum potentials
- Calculation of modes for dielectric and metallic waveguide, using boundary conditions for normal and tangential components of the E- and B-fields
- TE vs. TM modes
- Modal dispersion: calculation of phase and group velocity of modes

Radiation and antenna theory

- radiation fields come from acceleration and are perpendicular to **a** vector
- understand concept of retarded potentials
- dipole radiation power distribution is proportional to $\sin^2\theta$ (q measured from dipole axis)
- oscillating dipole power is proportional to ω^4 (except near a resonance)
- using Larmor radiation formula for radiated power: $P = 2e^2a^2/3c^3$
- qualitative understanding of radiation power distribution at high velocity: peak moves toward forward velocity direction
- understand differences between near- and far-field
- radiation resistance and role of antenna in circuit

Dispersion: SHO model of the electron response to an EM wave

- Thomson and Rayleigh scattering
- calculate electron motion x(t) under different conditions: forcing, damping, SHO resonant frequency…
- calculate the polarization P, dielectric constant ε from the oscillator amplitude x(t)

- calculating index and absorption coeff from complex dielectric function
- wave propagation with complex index is a damped oscillating wave
- dispersion in plasmas

Fourier transforms (transform sheet will be available on the test)
- Fourier transforms: definitions, symmetries (odd/even etc)
- Delta function and its properties
- Common transforms: rect, triangle, sin, cos, Gaussian, Expon decay.
- Transform theorems: shift, scale, Parseval's theorem
- Convolution and the convolution theorem

You should be able to use transform pairs, theorems and convolution to do transforms. Although the transform sheet will be provided, it is hard to use it properly unless you understand the derivations of basic transforms and the proofs of theorems.

Final exam: all the above plus the following

Interference
- Spatial and temporal coherence
- Conditions for interference: effect of polarization and coherence
- Double slit interference
- Michelson interferometer: interference vs time delay, crossed beam interference
- Double beam interference from a layer: geometric/ray solution
- Other interferometers: Fizeau wedge, Newton's rings, etc
- Fabry-perot etalon: Working with transmission function, free spectral range
- Diffraction gratings and the grating equation

Diffraction
- concept: diffraction integral by integrating over Huygens wavelets
- Fraunhofer diffraction as Fourier transform
- understand spatial frequency coordinates: scaling with wavelength, index, distance
- Diffraction from rectangular apertures