Sample Syllabus for one-semester Advanced Computational Physics

3/4/2013

Main text: Cai, *Computational Methods for Electromagnetic Phenomena*: *Electrostatics in salvation, scattering, and electron transport*, Cambridge University Press, 2013.

Reference: Hirsh, Numerical Computation of Internal and External Flows, Vol. II, Chapter 16, for lecture 38-39

Note: All section number below refers to Cai's book except for lecture 37.

- **Lecture 1-4, Section 1.1, 1.2, 1.3.1, 1.5.1**

  1.1 Electrostatics of charges and dipoles
  1.2 Polarization **P** and displacement flux **D**
  1.3.1 Clausius–Mossotti formula for non-polar dielectrics
  1.5.1 Appendix A: Average field of a charge in a dielectric sphere

- **Lecture 5-6 1.4**

  1.4 Statistical molecular theory and dielectric fluctuation formulae

- **Lecture 7-9 2.1.1, 2.3.1, 2.3.2, 2.3.4**

  2.1.1 Debye–Huckel Poisson–Boltzmann theory
  2.3.1 Methods of images for simple geometries
  2.3.2 Image methods for dielectric spheres
  2.3.4 Image methods for multi-layered media

- **Lecture 10-11, 3.1.1, 3.1.2**

  3.1.1 Cauchy principal value (CPV) and Hadamard finite part
  3.1.2 Surface integral equations for the PB equations

- **Lecture 12, 3.1.3, regularization of singular integrals and direct computation of CPV**

  3.1.3 Computations of CPV and Hadamard p.f. and collocation BEMs

- **Lecture 13, 3.2**

  3.2 Finite element methods (FEMs)

- **Lecture 14-15, 4.1, 4.2**

  4.1 Ewald sums for charges and dipoles

4.2 Particle-mesh Ewald (PME) methods

- **Lecture 16-17, 4.3**

  4.3 Fast multipole methods for *N*-particle electrostatic interactions

- **Lecture 18-20, 5.1.1, 5.3.1, 5.3.2**

  5.1.1 Magnetization **M** and magnetic field **H**
  5.3.1 Interface conditions between dielectric media
  5.3.2 Leontovich impedance boundary conditions for conductors

- **Lecture 21-22, 5.4**

  5.4 Absorbing boundary conditions for **E** and **H**

- **Lecture 23-24, 6.1, 6.2.1-6.2.3**

  6.1 Singular charge and current sources
  6.2.1 Dyadic Green's functions for homogeneous media
  6.2.2 Dyadic Green's functions for layered media
  6.2.3 Hankel transform for radially symmetric functions

- **Lecture 25, 6.2.5, 6.3.1**

  6.2.5 Longitudinal components of Green's functions
  6.3.1 Sommerfeld potentials

- **Lecture 26, 7.1.1**

  7.1.1 Integral representations

- **Lecture 27, 7.1.2**

  7.1.2 Singular and hyper-singular surface integral equations

- **Lecture 28-29, 7.4.1-7.4.3**

  7.4.1 Galerkin method using vector–scalar potentials
  7.4.2 Functional space for surface current **J**(**r**)
  7.4.3 Basis functions over triangular–triangular patches

- **Lecture 30-31, 8.1/8.1.1 and 3-D edge element in tetrahedron**

  8.1.1 Finite element method for **E** or **H** wave equations
  8.1.3 Nedelec finite element basis in *H*(curl)

- **Lecture 32-34 10.1.1-10.1.3, 10.1.5**

  10.1.1 Bloch theory for 1-D periodic Helmholtz equations
  10.1.2 Bloch wave expansions
  10.1.3 Band gaps of photonic structures
  10.1.5 Rayleigh–Bloch waves and band gaps by transmission spectra

- **Lecture 35, 10.2.1, 10.2.2**

  10.2.1 Nedelec edge element for eigen-mode problems
  10.2.2 Time-domain finite element methods for periodic array antennas

- **Lecture 36, 9.1-9.3**

  9.1 Weak formulation of Maxwell equations
  9.2 Discontinuous Galerkin (DG) discretization
  9.3 Numerical flux $\mathbf{h}(\mathbf{u}^-, \mathbf{u}^+)$ 230

- **Lecture 37, 9.7, 16.4** (divergence free property of Yee scheme)

  9.7 Finite difference Yee scheme
  16.4 $\nabla \cdot \mathbf{B} = 0$ constrained transport methods for MHD equations

- **Lecture 38-39**, Riemann problem for scalar conservation laws, Burger equation, characteristics, Rankine-Hogoniot condition, etc

  (Hirsh, Section 16.6)

  Reading Wigner-Moyal expansion (12.114) and hydrodynamic equations (15.17)

- **Lecture 40-42, 15.2, 15.3**

  15.2 High-resolution finite difference methods of Godunov type
  15.3 Weighted essentially non-oscillatory (WENO) finite difference methods