Electrodynamics - Web course

NP-TEL

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Physics

Pre-requisites:

1. Introductory course on Electricity and Magnetism at the level of D. J. Griffiths, “Introduction to Electrodynamics”.

Additional Reading:

1. W. Greiner, Classical Electrodynamics, Springer (2009).
2. R. Resnick, “Introduction to Special Relativity”, Wiley (1992).

Coordinators:

Prof. Amol Dighe
Theoretical PhysicsTIFR

COURSE OUTLINE

The course is a one semester advanced course on Electrodynamics at the M.Sc. Level.

It will start by revising the behaviour of electric and magnetic fields, in vacuum as well as matter, and casting it in the language of scalar and vector potentials.

Writing Maxwell equations in the same language will lead to the analysis of electromagnetic waves, their propagation, scattering and radiation.

Special relativity will be introduced, which will allow the covariant formulation of Maxwell's equations and the Lagrangian formulation of electrodynamics.

Relativistic motion of charges in electromagnetic fields, and the motion of electromagnetic fields through matter will be covered, with plenty of examples.

COURSE DETAIL

Lectures	Topics
Module I: Electromagnetic waves	
Lecture 1: Maxwell's equations: a review	Maxwell's equations in vacuum, Maxwell's equations inside matter
Lecture 2: Solving static boundary value problems	Uniqueness theorems, Separation of variables for Poisson's equation
Lecture 3: Time-dependent electromagnetic	Relaxation to a stationary state, Propagating plane electromagnetic (EM) wave, Decaying plane EM wave

fields	
Lecture 4: Energy in electric and magnetic fields	Energy in static electric field, Energy in static magnetic field, Energy stored and transported by EM waves
Lecture 5: EM waves with boundaries	EM waves at dielectric boundaries: reflection, refraction, EM waves in conductors: inside and at the boundary
Lectures 6-7: EM waves in confined spaces	Rectangular waveguides, Circular cylindrical waveguides, Coaxial cable, Cavities
Lecture 8: EM wave equations with sources	Wave equation for scalar and vector potentials with sources, Solving the wave equation with sources
Lecture 9: EM radiation	Electric and magnetic fields: radiation components, Radiation energy loss, Radiation from antennas
Lectures 10-11: Multipole radiation	Multipole expansion, Electric dipole radiation, Magnetic dipole and electric quadrupole radiation
Lecture 12: Problems	
Module II: Relativity and electrodynamics	
Lecture 1: From electrodynamics to Special Relativity	Faraday's law and Lorentz force, Motivations for Special Relativity, Lorentz transformations
Lecture 2: Lorentz transformations of observables	Length, time, velocity, acceleration, EM wave: aberration and Doppler effect, Transformations of electric and magnetic fields

Lecture 3: Relativistic energy and momentum	Defining momentum in Special Relativity, Defining relativistic energy
Lecture 4: Covariant and contravariant 4-vectors	Covariance and contravariance, Examples of 4-vectors: x, del, p, J, A, u, A
Lecture 5: Metric and higher-rank 4-tensors	Metric and invariant scalar products, Second rank 4-tensors: symmetric and antisymmetric, Higher-rank 4-tensors
Lecture 6: Tensor calculus	Length, area, 3-volume and 4-volume in 4-d, Gauss's law and Stokes' theorem in 4-d
Lecture 7: Relativistic kinematics	Two-body scattering, Decay of a particle
Lecture 8: EM field tensor 'and Maxwell's equations	The electromagnetic field tensor F, Maxwell's equations in terms of F and F-tilde
Lectures 9-10: Lagrangian formulation of relativistic mechanics	Lagrangian, Hamiltonian, energy, equations of motion, Non-relativistic particle in a potential, Relativistic free particle, Relativistic particle in EM fields
Lecture 11: Lagrangian formulation of relativistic electrodynamics	Volume distribution of changes in EM fields, Field-field interaction and Maxwell's equations
Lecture 12: Problems	

Module III: Relativistic electrodynamics: applications	
Lectures 1-2: Motion of charges in E and B fields	Relativistic equations of motion, Particle in a unifrm electric field, Particle in a uniform magnetic field, Particle in combinations of electric and magnetic fields
Lecture 3: EM potentials from a moving charge	Lienard-Wiechert potentials: without relativity and using relativity
Lectures 4-5: EM fields from a uniformly moving charge	E and B fields from Lienard-Wiechert potentials, E and B fields from Lorentz transformations, Force between two uniformly moving charges
Lectures 6-7: Cherenkov radiation	Cherenkov: intuitive understanding and applications, Cherenkov radiation: formal calculations
Lecture 8: Radiation from an accelerating charge	From Lienard-Wiechert potentials to EM fields, Calculating relevant derivatives, Calculating E and B fields including their radiative components
Lecture 9: Radiation from linear motion: Bremsstrahlung	Radiated power from an accelerating charge, Bremsstrahlung radiation: large velocities
Lectures 10-11: Radiation from circular orbits: Synchrotron	Radiation from a circular orbit, Time variation of the radiation signal, Instantaneous pattern of radiated power, Synchrotron radiation for producing X-rays
Lectures 12-13: radiation reaction force	Force of an accelerating charge on itself: small acceleration, Radiation damping in ultra-relativistic case
Lectures 14-15: EM radiation	Interactions of EM fields with electrons, Scattering of EM wave by a free electron,

passing through matter	Scattering of EM wave by a bound electron, Absorption by a bound electron, Refractive index: collective polarization by electrons
Lecture 16: Problems	

Total lectures: 12 (module I) + 12 (module II) + 16 (module III) = 40

References:

1. Panofsky and Phillips, Classical Electricity and Magnetism, 2nd Ed., Dover (2005) .
2. Landau and Lifshitz, “The Classical Theory of Fields”, 4th Ed., Pergamon (1989).
3. J. D. Jackson, “Classical Electrodynamics”, 3rd Ed., Wiley (2007).