Electrodynamics - Web course

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

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

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

Additional Reading:


Coordinators:

Prof. Amol Dighe
Theoretical PhysicsTIFR
| 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**

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

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<th>Scattering of EM wave by a bound electron, Absorption by a bound electron, Refractive index: collective polarization by electrons</th>
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Lecture 16: Problems

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

**References**: