PART A) Electrostatics and magnetostatics with dielectric and magnetic materials

INTRODUCTION: charge and spin of the constituents of matter, electromagnetic interactions, field description

TOPIC 1) Summary and extension of electrostatics
- Electrostatic field (E): Gauss’s law, scalar potential (V), Poisson's and Laplace's equations, charge density (ρ)
- Electric dipole (p): potential and field of the point and line dipoles, plasma model; induced and permanent dipoles, torque and energy of a permanent electric dipole in an external field, multipole expansion for V (and E)
- Uniqueness theorem: capacitance (C) of conductors and capacitors; image charge method for conductors

TOPIC 2) Dielectric materials
- Polarization: dipole density and polarization field (P), bound charge densities; linear vs ferroelectric materials
- E-field created by a polarized sample; macroscopic electric field inside a polarized dielectric or an electret
- Electric displacement field (D); depolarizing field; linear dielectrics: dielectric constant, effect on capacitance
- Boundary conditions for E and D; relationship between free, bound and total charge in capacitors
- Microscopic description: electrostatic screening; Clausius-Mossotti’s relation; ferroelectrics
- Electrostatic energy with linear dielectrics and calculation of electric forces in capacitors

TOPIC 3) Magnetic materials and magnetic field of magnets
- Spin and magnetic moment (m) of elementary particles; dipolar magnetic field; torque and energy of a magnetic dipole in an external magnetic field
- Magnetization field (M), magnetic scalar potential and vector potential (A) for magnets, auxiliary magnetic field (H)
- Magnetic pole density, magnetizing field, saturation magnetization
- Linear materials: magnetic susceptibility and permeability, paramagnetism and diamagnetism
- Microscopic description of permanent magnets: exchange interactions, magnetic domains
- Boundary conditions for H and B

TOPIC 4) Summary and extension of electric currents and magnetism
- Current density (J) and current (I); charge conservation; free currents and Ohm’s local law: electronic and ionic conductivity, classification of materials; calculations of resistance (R); R-C relationship in a homogeneous medium
- Lorentz force and electromotive force; batteries & generators
- Magnetic field and magnetic vector potential due to currents; Ampère’s law; multipole expansion for A (and B)
- Currents near/inside linear magnetic media
- Ampère’s equivalence theorem; equivalent currents; superconductivity and superconducting currents

PART B) Time-varying fields, electromagnetic energy and waves, optical phenomena

TOPIC 5) Maxwell’s equations, electromagnetic energy, electromagnetic waves
- Faraday’s law and induction, self-inductance, energy stored in the B-field
- Magnetostatic energy with linear materials, calculation of magnetic forces in solenoids and magnetic circuits
- Overview of electric technology: generators, transformers, transmission lines, electric motors
- Displacement current and macroscopic Maxwell's equations; quasi-static approximation
- Relationship between E and B and the scalar and vector potentials
- Poynting’s vector (S), Poynting theorem
- Electromagnetic wave equations in vacuum and in perfectly insulating, transparent dielectrics; speed of light in vacuum and transparent dielectrics; vacuum wavelength

TOPIC 6) Description and propagation of electromagnetic (e.m.) waves
- Linear polarization; planar, spherical, and cylindrical waves in complex notation
- Electromagnetic energy densities in linear media and in vacuum; irradiance
- Overview of e.m. wave phenomena: interference; diffraction; boundary conditions in optics: reflection & refraction
- Constance of the frequency in different media; wavelength inside a medium
- Oscillating e.m. fields in lossy dielectrics, metals, plasmas: complex dielectric function and complex refractive index
- Macroscopic model and Lorentz model of the refractive index; phase velocity vs group velocity
- Maxwell’s equations with sources; Lorenz condition and inhomogeneous wave equation for A and V
- Radiation of the Hertzian (point-like) oscillating dipole: Rayleigh scattering and instability of the classical atom

CONCLUSION: from energy generation and transmission to electromagnetic vectors of information
Requirements
Participants must have passed the exams of the courses "Física 2" and "Càlcul 2". They should have attended some lectures on complex numbers.

Evaluation system
The students' evaluation will consist of a final exam (EF), a midterm exam (EP) towards the end of topic 4, and an evaluation of handed-in homework (TE). The final mark will be given by:

\[ \text{Max} \{ \text{EF} \ ; \ 0.9 \times \text{EF} + 0.1 \times \text{TE} \ ; \ 0.55 \times \text{EF} + 0.35 \times \text{EP} + 0.1 \times \text{TE} \} \]

The students will also receive an English note (A to D), based on their knowledge of written (scientific) English, which will be evaluated based on the handed-in homework.

Bibliography


Other basic bibliography sources

Complementary bibliography

"Informal" resources