ELECTROMAGNETISM

PART A) Electrostatics and magnetostatics with dielectric and magnetic materials

(0) Introduction: microscopic fields produced by charges and spins *vs* classical field theory

(1) Summary and extension of electrostatics

(1.1) Electrostatic field (**E**), charge density (ρ), electrostatic potential (V): Coulomb, Gauss, and Poisson's laws

(1.2) Electric dipole (**p**): potential and field of the point dipole; induced and permanent dipoles, torque and energy of a permanent electric dipole under an applied field

(1.3) Special dipole distributions: the line dipole and the sphere dipole; multipole expansion for V (and E)

(1.4) Electrostatic properties of metals, surface charge density (σ), boundary conditions for E at a metal surface

(1.5) Uniqueness theorem: capacitance (C) and electrostatic energy; image charge method

(2) Dielectric materials

(2.1) Polarization field (**P**), bound charge density; E-field of polarized dielectrics (depolarizing field)

(2.2) Linear dielectrics *vs* ferroelectric materials (electrets); electric susceptibility & macroscopic electric field in linear dielectrics

(2.3) Electric displacement field (**D**); dielectric constant and capacitance of capacitors with dielectrics

(2.4) Boundary conditions for E and D; relationships between free, bound and total charge densities

(2.5) Electrostatic energy with linear dielectrics and calculation of electric forces in capacitors

(2.6) Microscopic description of linear media (Clausius-Mossotti relation) and of ferroelectrics

(3) Magnetic materials and magnetic field

(3.1) Spin and magnetic moment (**m**); dipolar magnetic field, Coulomb's law for magnetism; torque and energy of a permanent magnetic dipole under an applied field

(3.2) Magnetization field (**M**), magnetic poles and pole densities; auxiliary field (**H**) for magnetized media

(3.3) Linear materials: magnetic susceptibility and permeability, paramagnetism and diamagnetism; demagnetizing H-field, macroscopic H and B fields; saturation magnetization

(3.4) Maxwell's equations for magnetostatics without free currents, boundary conditions for H and B

(3.5) Microscopic description of permanent magnets: exchange interactions, magnetic domains; soft and hard ferromagnetic materials

(4) Summary and extension of electric currents and magnetism

(4.1) Electric current (I) & current densities (**J**, **K**); charge conservation; free and bound currents

(4.2) Ohm's local law: dc conductivity (g), classification of materials; generation of steady currents

(4.3) Calculations of resistance (R); Joule's law; R-C relation in homogeneous media; charge densities at boundaries between media

(4.4) Magnetic field due to free currents: Biot-Savart's and Ampère's laws for B

(4.5) Free currents near and inside linear magnetic media: Ampère law for H; magnetic circuits, reluctance, Hopkinson's law

(4.6) Ampère's equivalence theorem, equivalent currents; multipole expansion; magnetic dipole of a current loop

(4.7) Superconductivity and superconducting currents

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

(5) Magnetic energy & forces, Maxwell's equations, electromagnetic waves

(5.1) Lorentz force and electromotive force; Faraday's law of induction

(5.2) Energy stored in the B-field, self-inductance (L), magnetic energy in linear materials

(5.3) Magnetic forces within solenoids and magnetic circuits

(5.4) Overview of electric technology: electromagnets, generators, transformers, electric motors

(5.5) Displacement current and macroscopic Maxwell's equations; quasi-static approximations

(5.6) Poynting's vector (**S**) and Poynting's theorem; electromagnetic wave equations and speed of light in vacuum; monochromatic waves, irradiance, vacuum wavelength & electromagnetic spectrum

(5.7) Speed of light in perfect dielectrics, refractive index; boundary conditions: constancy of the frequency, Snell's law of refraction; reflectivity for normal incidence

(6) Description and propagation of electromagnetic (e.m.) waves in vacuum, metals and dielectrics

(6.1) Complex notation for planar, spherical, and cylindrical e.m. waves; application to spatial & temporal interference: standing waves, phase velocity *vs* group velocity

(6.2) Attenuation of e.m. waves in lossy media: complex conductivity ($\tilde{\sigma}$), complex dielectric function ($\tilde{\varepsilon}$), and complex refractive index ($\tilde{n}$); skin depth; macroscopic model for $\tilde{\varepsilon}$ and $\tilde{n}$

(6.3) Drude theory for metals, collisionless plasma model; current relaxation and frequency-dependent resistance

(6.4) Electromagnetic properties of dielectrics: Lorentz-Rayleigh model of the complex permittivity & refractive index of insulators; Rayleigh scattering; Debye model of the dipolar relaxation.

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:

Max{EF ; 0.9*EF + 0.1*TE ; 0.55*EF + 0.35*EP + 0.1*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

Textbook : **Gerald Pollack, Daniel Stump, *Electromagnetism*, Pearson (2002)**

Other basic bibliography sources

- J. R. Reitz, F. J. Milford, R. W. Christy, *Foundations of Electromagnetic Theory,* 4th Edition, Addison Wesley (2008)
- D. Griffiths, *Introduction to Electrodynamics*, 3rd Edition, Pearson (2003)
- Theory and problem-solving notes on Atenea

Complementary bibliography

- A. Zangwill. *Modern Electrodynamics*. Cambridge University Press (2012)
- W. J. Duffin, *Electricity and magnetism*, 4th Edition, McGraw-Hill (1990)
- W. H. Hayt, Jr., y J. A. Buck. *Teoría electromagnética, 8ª Ed.* Mc Graw Hill (2012)
- P. Lorrain, D. R. Corson, *Campos y ondas electromagnéticas*, 5ª Ed., Selecciones Científicas (1990)
- R. K. Wangsness, *Campos electromagnéticos*, Limusa (2001)

"Informal" resources

- Videolectures of the Electromagnetism course taught at MIT in 2002 by Prof. Walter Lewin: https://www.youtube.com/playlist?list=PLUdYlQf0_sSsfcNOPSNPQKHDhSjTJATPu /
- J. Peatross, M. Ware, *Physics of Light and Optics*, 2011c edition, available at http://optics.byu.edu/textbook.aspx
- R. Feynman, R. B. Leighton, M. Sands, *The Feynman Lectures on Physics,* Vol 1 and 2, Addison Wesley (1964, latest edition in 2005)