PH3007 - Electromagnetism

Credits:	15.0	**Semester:**	2
Number of Lectures:	27	**Lecturer:**	Dr Charles Baily
Academic Year:	2018-19		

Overview

The properties of electromagnetic fields are explored using a variety of mathematical tools (in particular, vector and differential calculus). Topics include: time-independent charge and current distributions, electric and magnetic properties of matter, electrodynamics, conservation laws, electromagnetic waves and radiation.

Aims & Objectives

This module builds on knowledge and skills acquired in prior courses, to develop more sophisticated techniques for solving problems in undergraduate electromagnetism.
The various topics will be presented as part of a coherent theory of classical fields (i.e., as consequences of Maxwell's equations and the Lorentz force law).
The organisation and level of difficulty of the module have been chosen so as to deepen students' understanding of electromagnetic theory, prepare them for practical work in the laboratory, and provide a bridge to more advanced study.
Alongside the development of general problem-solving skills and intellectual maturity, particular emphasis will be placed on conceptual understanding, and deriving physical meaning from mathematical expressions and visual representations.

Learning Outcomes

By the end of this module, students are expected to be able to:

- apply Stokes' theorem and the Divergence theorem to convert equations from differential to integral form (and vice-versa), as well as interpret the physical meaning of the resulting terms. (e.g., What's a flux? What's a divergence? What does the curl tell you about a vector field?)
- write down and explain in words the full set of Maxwell's equations, in both integral and differential form. Students should be able to recognize which equations are relevant for solving a given problem, and apply them correctly to generate a solution. In particular, students should be able to use the integral forms to derive expressions for the fields due to charge/current distributions having planar, cylindrical or spherical symmetry.
- decide when using Coulomb's law and the Biot-Savart law (i.e., direct integration) is the most appropriate method of solution, and apply these integral expressions in rectangular and curvilinear coordinate systems to determine the fields due to basic charge/current distributions. Students should similarly be able to solve for the scalar and vector potentials using direct integration in basic situations.
- explain what conditions must be satisfied in order for the electric potential to be found using the method of images; and apply the method of images to solve for the actual potential in simple cases. Students should be able to explain the differences between the physical situation (surface charges) and the mathematical setup (image charges), and their relation to each other.
- explain when and why approximate potentials are useful; identify and calculate the lowest-order term in the multipole expansion (i.e., the first non-zero term); and calculate the dipole moment for a given charge distribution.
- describe similarities and differences between a conductor and a dielectric material; explain the similarities and differences between free and bound charges, and physically interpret mathematical expressions for bound charges/currents; also, determine bound charge/current distributions for simple situations, and their associated fields.
- translate between **E**- & **B**-fields and the auxiliary fields **D** & **H**, in terms of the polarization and magnetization of a material; and be able to derive (from Maxwell's equations) and apply the boundary conditions on **E**, **B**, **D** & **H** at the interface of two different linear media.

- compute time-dependent electric and magnetic fields from the scalar and vector potentials. When appropriate, students should be able to use the integral form of Faraday's Law to determine induced electric fields; and the Maxwell-Ampere law to find induced magnetic fields.
- state the definitions of the Coulomb and Lorentz gauges, and be able to explain and demonstrate how they lead to solvable wave equations. Students should also be able to explain the meaning of *retarded time*, and interpret potential functions using the retarded time formalism.
- define electromotive force, and be able to compute EMF (either motional or Faraday-induced) for a variety of situations (typically with known or easily computed fields).
- state the continuity equation in differential and integral forms and be able to convert between the two using the divergence theorem; explain how it is an expression of charge conservation, and know its general implications for quantities such as **J** and **E** in steady-state situations.
- recall how Poynting's theorem is derived (what assumptions go into it, and the overall motivation and structure of the derivation); and be able to physically interpret and use **S**, along with the energy density u, to solve basic problems involving the transfer of energy by electromagnetic fields.
- derive the traveling wave equation (and thus its solutions) in free space and in matter, starting from Maxwell's Equations. This would include deriving, understanding, and using the connections between **E** & **B** (and wave speed, wave vector, and polarization directions) as they arise from Maxwell's equations.
- show that a given expression satisfies the wave equation. For traveling waves, students should be comfortable working with the usual elements such as wavelength, wave vector, frequency and angular frequency, period, phase, polarization, and velocity; also, interpret and work with plane wave solutions in complex notation, and translate them into physical solutions.
- identify the terms that contribute to radiation fields; explain and justify both the math and physics of the "three approximations" made when calculating electric or magnetic dipole radiation; use and explain the mathematical forms of **E**, **B** & **S** for electric or magnetic dipole radiation fields, including angular and radial dependence.
- determine the boundary conditions for EM waves at the interface of two different linear media, starting from Maxwell's Equations, and apply them to solve for and interpret the reflected and transmitted waves.

Synopsis
<u>Electrostatics</u>: Charge and current distributions; Coulomb's law; Gauss' law; potential theory; linear dielectrics.
<u>Magnetostatics</u>: Biot-Savart law, Ampere's law; vector potential; magnetic fields in matter.
<u>Electrodynamics</u>: Maxwell's equations; electromagnetic induction; conservation laws for charge and energy; Poynting vector; wave equation; time-dependent potentials and gauge invariance; electric dipole radiation; reflection and transmission.

Pre-requisites
(PH3081 or PH3082 or MT2003 or MT2506) and PH2012 and (MT2001 or MT2501 and MT2503)
Students are expected to have an elementary knowledge of electricity and magnetism and an ability to deal with relevant mathematical techniques.

Anti-requisites
None

Assessment
Continuous Assessment = 40%, 2 Hour Examination = 60%

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

This module is part of the core JH programme, and as such there is a summary of deadlines etc on the School's Students and Staff web pages. There is a class test, likely in week seven, contributing 30% to the module mark, Students have compulsory tutorials every two weeks, with weekly hand-in tutorial work counting for 5% of the module total. Meaningful participation in questions/answers related to lecture content contributes another 5% to the module mark.

Accreditation Matters

This module contains some material that is or may be part of the IOP "Core of Physics". This includes
Electrostatics and magnetostatics
Gauss, Faraday, Ampère, Lenz and Lorentz laws to the level of their vector expression
Maxwell's equations and plane EM wave solution; Poynting vector
Polarisation of waves and behaviour at plane interfaces

Recommended Books

Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph3007.html

General Information

Please also read the general information in the School's honours handbook.