PC2031 Electricity and Magnetism I

Course Description and Syllabus

Term: 2024 Sem1	**Lecture days:** Mon. & Thurs.
Instructor: Li Xinwei	**Lecture time:** 10 am – Noon
Email: xinweili@nus.edu.sg	**Venue:** M: LT29, T: LT27
Office hour: Wed. 11 am - noon	**TA:** Yang Hengxing (hengxing@u.nus.edu)

Course description and learning outcomes:

The subject of electricity and magnetism forms one of the most crucial pillars in physics. Among the four fundamental forces in nature, the electromagnetic force is not only most ubiquitous but most relevant to understanding and engineering our surrounding world. Being accepted as a well-established theoretical framework in modern physics, the subject can naturally be extended to advanced theoretical frontiers including the theory of special relativity and quantum field theory. On the technological front, developing a solid understanding of electric and magnetic phenomena is also crucial for a wide range of engineering disciplines and emerging technical areas with important applications. For these reasons, the course is mandatory for Physics majors and highly recommended for all Engineering majors.

Topics to be covered within this course include: vector calculus; electrostatic fields, Coulomb's law, and electric potential; electric fields in matter; magnetostatic fields, Biot-Savart's law, and magnetic vector potential; magnetic fields in matter; time-varying electric and magnetic fields, Faraday's and generalised Ampere's laws; Maxwell's equations and electromagnetic waves in vacuum. Knowledge from PC2032 is desirable.

By the end of the course, students should be able to:

1. Apply vector analysis, including vector algebra, vector products, and vector transformation, with proficiency
2. Quantitatively work out gradient, divergence, and curl of fields and can interpret the physics picture of them
3. Analyze vector integrals using the fundamental theorems for gradients, divergence and curl
4. Explain the concept of Dirac Delta function and their basic properties in integral calculus

5. Distinguish system geometries and pick appropriate curvilinear coordinates for simplification of problems
6. Demonstrate usage of differential and integral calculus in spherical coordinates and cylindrical coordinates
7. Apply Coulomb's law to derive electric fields induced by discrete and continuous charge distributions
8. Derive electric fields using the Gauss's law and symmetry arguments
9. Explain the physics picture of electric scalar potential
10. Derive the electric potential from a known electric field distribution
11. Derive the electric field distribution from a known electric potential
12. Interpret boundary conditions of electric field and electric potential
13. Calculate energy associated with a given point charge distribution
14. List conditions that uniquely applies to conductor electrostatics
15. Explain the two uniqueness theorems
16. Use the method of images combined with uniqueness theorems to derive electric potentials and electric fields
17. Use separation of variables combined with boundary conditions to solve Laplace equations (of potential) for certain high-symmetry geometries
18. Explain the merit of multipole expansion of electric potential
19. Derive electric fields and potentials induced by electric dipoles
20. Explain the concepts of polarization, induced dipoles, surface charge density, volume charge density, and displacement field in dielectrics
21. Calculate volume charge density and surface charge density of a dielectric from a given polarization distribution
22. Use Gauss's law in the presence of dielectrics to calculate displacement fields and electric fields
23. Interpret boundary conditions of electric field, displacement field, and electric potential on the surface of a dielectric
24. List the relations between displacement field, electric field, polarization, susceptibility, and permittivity, that hold for linear dielectrics
25. Explain the working principle of a parallel-plate capacitor
26. Calculate energy stored in dielectric systems
27. Distinguish conditions that need to be met for electrostatics and magnetostatics
28. Explain the Lorentz force law and its implication on the impact of magnetic forces on moving charges
29. Explain the concepts of line current, surface current density, and volume current density
30. Apply the Biot-Savart law to calculate magnetic fields induced by steady currents (line current, surface current density, and volume current density)
31. Derive magnetic fields using the Ampère's law and symmetry arguments

32. Explain the concept of magnetic vector potential and common assumptions adopted for it
33. Derive the magnetic field from a known vector potential
34. Derive the vector potential from a known current distribution
35. Interpret boundary conditions of magnetic field and vector potential
36. Explain the merit of multipole expansion of vector potential
37. Explain the concept of magnetization in diamagnets, paramagnets, and ferromagnets
38. Calculate the force and torque on a magnetic dipole in a magnetic field
39. Explain the concepts of bound currents in magnetic media
40. Calculate bound currents from a given magnetization
41. Use the Ampère's law in magnetic materials to calculate the magnetic field and auxiliary field
42. List the relations between magnetic field, auxiliary field, magnetization, magnetic susceptibility, and permeability, that hold for linear magnetic media
43. Explain scenarios where magnetic media exhibit nonlinear responses
44. Explain the magnetic hysteresis loops for ferromagnets
45. Explain the concept of electromotive force and its alternative interpretation
46. Explain the flux rule for motional electromotive force
47. Explain how the Faraday's law is derived
48. Explain Maxwell's correction to Ampère's law in the Maxwell's equation
49. Write down the full Maxwell's equations in vacuum (differential form)
50. Write down the Maxwell's equations in vacuum assuming conditions for electrostatics and magnetostatics (differential and integral forms)
51. Derive the electromagnetic wave equation using the Maxwell's equations
52. Explain the basic properties of the solution to wave equations

Textbooks:

Main:

- David J. Griffiths. *Introduction to Electrodynamics*. 4th ed., Pearson Education, Inc., 2013. ISBN: 978-0-321-85656-2

Supplementary:

- John David Jackson. *Classical Electrodynamics*. New York, John Wiley & Sons, Inc., 1998. ISBN: 978-0-471-30932-1
- Landau and Lifshitz. *Electrodynamics of continuous media*., Oxford: Pergamon Press Ltd., 1961.

Course materials:

Course materials consist of (1) slides and (2) handwritten notes, both of which will be uploaded to Canvas site ahead of the lecture. Handwritten notes serve the purpose of showing detailed steps of derivation that contributes to understanding important example problems in the slides.

Assessment components:

Component	Weight	Description
Quizzes/attendance	15%	3 – 5 times, randomly called upon throughout semester
Homework	25%	4 – 6 sets
Final exam	60%	Closed book test (with one A4 help sheet), in the exam week

Quizzes/attendance (15%): Unannounced quizzes will be held during the regular lecture window and to be turned in at the end of lecture before the class is dismissed. A total of 3 – 5 quizzes will be randomly distributed throughout the semester. The quizzes serve to (1) take attendance and (2) evaluate the student's understanding of recently covered topics. Attendance of all lectures (tutorials aside from lectures, if held, are optional) is expected. All papers turned in with the student's name properly signed will count towards half of the quizz score, while the other half depends on the quality of the answer to the quizz question(s). Excused absence to a lecture due to medical/academic/personal reasons can be considered only if the student submits an email application to the instructor (with reasonable explanations and supporting materials) prior to the lecture. For approved absences, make-up quizzes are available.

Homework (25%): A total of 4 – 6 sets of assignment questions will be given in accordance with the lecture progress. They will be announced on Canvas, and are turned in by student through Canvas before the deadline. The student must submit their work in .pdf format, which can either be typed work or scanned copy of their handwritten answer sheet. Books, online searches, reference materials, AI tools, and discussions among students are allowed in completing the homework, but copying others' work is considered plagiarism and therefore strictly prohibited. Late submissions are assessed with a 10% penalty each day they are late. The penalty linearly increases with lateness.

Final exam (60%): The final exam, which takes place in the exam week, covers all course contents taught throughout the semester. The exam is a closed book test. No reference material is allowed except for one A4 sized help sheet (front and back sides). A list of equations that the instructor deems important will be recommended for students to include in their own help sheets. Non-programmable electronic calculators are allowed. Any communication between students is strictly prohibited during the exams.

Academic integrity:

All students enrolled in this course are expected to follow the ethical guidelines defined in the NUS code of student conduct, in which the writings on academic integrity read as follows.

“The University is committed to nurturing an environment conducive for the exchange of ideas, advancement of knowledge and intellectual development. Academic honesty and integrity are essential conditions for the pursuit and acquisition of knowledge, and the University expects each student to maintain and uphold the highest standards of integrity and academic honesty at all times.”

“The University takes a strict view of cheating in any form, deceptive fabrication, plagiarism and violation of intellectual property and copyright laws. Any student who is found to have engaged in such misconduct will be subject to disciplinary action by the University. Such misconduct will include, but is not limited to, the misuse of content or language generated by artificial intelligence (AI) computer programmes.”

“It is important to note that all students share the responsibility of protecting the academic standards and reputation of the University. This responsibility can extend beyond each student’s own conduct, and can include reporting incidents of suspected academic dishonesty through the appropriate channels. Students who have reasonable grounds to suspect academic dishonesty should raise their concerns directly to the relevant Head of Department, Dean of Faculty, Registrar, Vice Provost, or Provost.”