Lecture Plan

The book for the course is:

Griffiths, David J. 2023. *Introduction to Electrodynamics*. 5th ed. Cambridge: Cambridge University Press.

The 4th edition is also fine:

David J. Griffiths - *Introduction to Electrodynamics*, 4th ed., (2012). *Addison-Wesley*. ISBN 978-0-321-85656-2.

The book contains for each chapter many exercises whose solutions can be found in:

- David J. Griffiths (2014) Instructor’s Solution Manual Introduction to Electrodynamics, Fourth Edition

Notice that this is the solution manual for the 4th edition. In the 5th edition book you may find addition exercises, but unsolved.

For further study, clarification and (solved) exercises, please consult:

- Edward M. Purcell, David J. Morin - Electricity and Magnetism, 3d ed., (2013). Cambridge University Press.

- David Halliday, Robert Resnick, Jearl Walker - Fundamentals of Physics, (2018). Extended-Wiley

WEEK 1

Lecture 1: Introduction & Mathematical preliminaries

Contents: Introduction to the course. Scope of the course. Topics covered. General tips and advices. Mathematical preliminaries: scalar and vector fields, gradient, divergence and their geometrical interpretations.

To read:

- Sections 1.1 and 1.2

Lecture 2: Mathematical preliminaries - Part II

Contents: Solenoidal fields. Curl of of a vector field and its geometrical interpretation. Irrotational fields. Product rules. Second derivatives: Laplacian, divergence of the curl and curl of the gradient. Integrals involving scalar and vector fields: line integrals, surface integrals (flux through a surface).

To read:

- Sections 1.2, 1.3

Lecture 3: Mathematical preliminaries - Part III

Contents: Volume integrals. Divergence theorem. Solenoidal fields: consequences of the divergence theorem. Stokes' theorem and its consequences for irrotational fields. Divergence of $\frac{\hat r}{r^2}$

To read:

- Sections 1.3, 1.4, 1.5 and 1.6
- [Subleties of estimating the divergence by looking at pictures]

WEEK 2

Lecture 4: Introduction to Electrostatics - Part I

Contents: 1D Dirac delta function and its properties. 3D Dirac delta function. Change of coordinates: spherical and cylindrical coordinates. Introduction to electrostatics. Charge and its measurement (electroscope). Conservation and quantization of charge. "Source" and "test" charges, principle of superposition. Coulomb's law. Comparison between gravitational and electric forces. Electric fields of point charges with exercises.

To read:

- Section 1.5, "Advertisement" and Section 2.1

Lecture 5: Introduction to Electrostatics - Part II

Contents: Electric field generated by a continuous distribution of a charge: line, surface and volume densities of charge. Exercises on the electric field generated by continuous distributions of charge: electric field of a infinite uniformly charged wire, uniformly charged ring, uniformly charged disk, uniformly charged plane.

Lecture 6: Introduction to Electrostatics - Part III

Contents: Gauss's law. Exercises on Gauss's law with spherical, cylindrical and plane symmetry. Electric field generated by a uniformly charged sphere, uniformly charged wire, uniformly charged plane. Divergence of the electric field. The curl of the electric field.

To read:

- Section 2.2

WEEK 3

Lecture 7: Electric Potential & Boundary conditions

Contents: General considerations on why is useful to know the divergence and curl of a vector field (Helmholtz theorem). Electric potential; potential of a point charge and of a spherical shell. Electric potential of a plane: how to choose the reference point. General expression of the potential of a continuous charge distribution. Poisson and Laplace's equations.

To read:

- Section 2.3

Lecture 8: Boundary conditions and the electric dipole

Contents: Boundary conditions of the electric field and of the electric potential. Electric dipole: Electric potential generated at large distances, dipole moment, electric field at large distances. Hints at the multipole expansion: form of the potential for a continuous charge distribution when look from far away; "monopole" and "dipole" terms. Electric dipole moment vector for continuous charge distributions. Potential and potential energy of the electrostatic field. Review of conservation of energy.

To read:

- Section 2.3.5, Section 2.4.1

Lecture 9: Energy of discrete and continuous charge distributions

Contents: Energy of a system of two particles. Energy of a general point charge distribution. Energy of a continuous charge distribution. Energy density. Energy stored in a uniformly charged spherical shell, different ways of computing the same thing.

To read:

- Section 2.4

WEEK 4

Lecture 10: Conductors

Contents: Conductors and insulators. Electric field inside a conductor. Electrostatic induction. Properties of the electric field and of the potential of a conductor. Induced charge distribution. Conductors with a cavity: screening and Faraday cage.

To read:

- Section 2.5.1, 2.5.2
- Radio inside a metallic cage
- Benjamin Franklin hit by a thunderstorm

Lecture 11: Capacitors

Contents: Conductors with high curvature. Capacitors and capacitance: parallel plate, spherical and cylindrical capacitors. Series and parallel capacitors: equivalent capacitance. Electrostatic energy stored in a capacitor. Force on the plates of a capacitor. General expression of the force on a conductor. Electrostatic pressure.

To read:

- Section 2.5.3, 2.5.4

WEEK 5

Lecture 12: Intro to Poisson and Laplace equations

Contents: Uniqueness theorem for Poisson's equation (with proof). General formulation of an electrostatic problem. Laplace's equation in one dimension. Mean value theorem for Laplace's equation (with proof).

To read:

- Section 2.5.3

Lecture 13: Image charge method

Contents: Image charges method: surface charge induced by a point charge on a grounded conducting plane; total induced charge induced; force exerted by the plane on the point charge. Exercises.

To read:

- Section 3.2 (not in the exam)

Lecture 14: Dielectrics I

Contents: Electric fields inside insulators. "Stretching" mechanism, atomic polarizability.

To read:

- Section 4.1

Lecture 15: Dielectrics II

Contents: Polarization of dielectrics composed of polar molecules: total force and torque on a dipole immersed in an electric field. Potential energy of a dipole inside an electric field. Polarization vector. Potential generated by a polarized dielectric. Bound charges.

To read:

- Section 4.2.1, 4.2.2, 4.3

Lecture 16: Dielectrics III

Contents: Electric displacement and Gauss's law in presence of dielectrics. Linear and homogeneous dielectrics: electric susceptibility, relative permittivity.

To read:

- Section 4.4.1, 4.4.3

Lecture 17: Exercise Session I

Lecture 18: Exercise Session II

Lecture 19: Exercise Session III

WEEK 6

Lecture 20: Electric Current I

Contents: Electric current. Steady electric current. Drift velocity. Current density.

Lecture 21: Electric Current II

Contents: Conservation of charge: continuity equation. Ohm's law, resistors. Microscopic derivation of Ohm's law. Conductivity. Joule's "heating" law.

To read:

- For some reason Griffiths postpones Ohm's law to Section 7.1.1 and 7.1.2

Lecture 22: Electric Current III

Contents: Batteries. Electromotive force definition. Kirchhoff's laws. Resistors in series and in parallel. Discharge of a capacitor. Exercises on circuits with steady currents. Electromotive force definition. Kirchhoff's laws. Resistors in series and in parallel. Recap on the topics related to the electric current. Discharge of a capacitor. Exercises on circuits with steady currents.

WEEK 7

Lecture 23: Introduction to Magnetic fields I

Contents: Lorentz force. Examples: motion of a particle in uniform magnetic field. Exercises on Lorentz force: velocity selector and mass spectrometer. Work due to magnetic fields. Forces on current-carrying wires: one- and three-dimensional wires.

To read:

- Section 5.1, 5.2
- Force on current-carrying wires in a magnetic field

Lecture 24: Introduction to Magnetic fields II

Contents: Lifting up a weight using a battery. Electrostatics and Magnetostatics. Biot-Savart law. Biot-Savart law for 3D circuits. Exercise: Magnetic field generated by a long straight wire.

To read:

- Section 5.2, 5.3

WEEK 8

Lecture 25: Divergence and Curl of the magnetic field

Contents: Force between wires. Magnetic field generated by a loop-carrying current. Magnetic dipole moment. Equivalence between electric field produced by a tiny dipole and magnetic field produced by a small circuit. Divergence of the magnetic field. Line integral of the magnetic field of a infinitely long current-carrying wire. Concept of "current enclosed by a path", sign of the current.

To read:

- Section 5.3

Lecture 26: Ampere's law

Contents: Ampere's law in integral and differential form. Sketch of the proof of Ampere's law for a generic magnetic field. Applications of Ampere's law: magnetic field of a long straight wire and of a long and tightly wound solenoid. Electrostatics and Magnetostatics equations. Magnetic vector potential. Hints to Poisson's equation for the magnetic vector potential. Boundary conditions for the magnetic field.

To read:

- Section 5.4.2
- Optional Sections: 5.4.1, 5.4.3

WEEK 9

Lecture 27: Magnetic Fields in Matter I

Contents: Introduction to magnetic fields in matter: phenomenology of diamagnets, paramagnets and ferromagnets. Magnetic moment due to the orbit of the electron around the nucleus and intrinsic magnetic moment of the electron. Torque and forces on magnetic dipoles due to external magnetic fields, paramagnetism.

To read:

- Section 6.1

Lecture 28: Magnetic Fields in Matter II

Contents: Effects of external magnetic fields on the orbit of the electron. Why paramagnetic/diamagnetic materials are attracted/repelled by a solenoid? Definition of magnetization. Finding the bound currents from the magnetization.

To read:

- Section 6.2 (equations (6.13) and (6.14) stated without proof, but take a look especially to section 6.2.2)
- 6.3.1, 6.3.2
- Levitating a frog using diamagnetism (Ig-nobel prize award, 2000)
- Superconducting magnetic levitation

Lecture 29: Ferromagnetism

Contents: Linear media, magnetic susceptibility. The susceptibility is positive for paramagnets and negative for diamagnets. Ferromagnetism: hysteresis and phase transition. Exercise: bound currents and magnetic field of a long magnetized cylinder. Exercise on rod filled with diamagnetic material.

To read:

- Section 6.4

WEEK 10

Lecture 30: Faraday's Law I

Contents: Electrostatic and magnetostatic fields are decoupled. Magnetic and electric fields are relative quantities. Faraday's experiments: 1) conducting loop moved in a magnetic field generated by a circuit with stationary current; 2) Same as 1) but the circuit with stationary current is now moved and the conducting loop is stationary; 3) circuit stationary with time-dependent current and a stationary conducting loop. Faraday-Lenz law. Justification of experiment 1); derivation of the induced fem in the conducting loop by using Faraday's law and the Lorentz force. Examples of Lenz's law (i.e. sign of the current).

To read:

- Section 7.1
- Not in the exam, but good (theoretical) reading: Purcell-Morin, chapter 5, that shows how electric and magnetic phenomena are relative quantities

Lecture 31: Faraday's Law II

Contents: General proof of experiment 1). Local form of Faraday's law. Exercises.

To read:

- Section 7.2.1

Lecture 32: Eddy Currents & induced electric field

Contents: Eddy currents. Simple demonstration of eddy current in class. Induced Electric field. Exercises.

To read:

- Section 7.2.2, 7.2.3
- eddy currents video

Lecture 33: Inductance

Contents: Inductance: Mutual inductance and self-inductance. Neumann formula. Self-inductance of a long solenoid + a toroidal coil (to do at home). Circuits involving inductance: the simple example of the RL circuit.

To read:

- Section 7.2.2, 7.2.3, 7.2.4

Lecture 34: Energy of Magnetic fields I

Contents: Energy analysis of a RL circuit. Energy stored in the magnetic field. Energy density. Computation of the self-inductance using the energy stored in the magnetic field. Recap of electrodynamics before Maxwell. Problems related to Ampere's law.

To read:

- Section 7.3.1

WEEK 11

Lecture 35: Maxwell's equations

Contents: How Maxwell fixed Ampere's law. Displacement current: a changing electric field induces a magnetic field. Simple examples where displacement current pops up. Recap on Maxwell's equations in vacuum.

To read:

- Section 7.3.2, 7.3.3, 7.3.4, 9.1

Lecture 36: Electromagnetic Waves (Not in the exam)

Contents: Definition of wave. Waves in one dimension. Wave equation. Wave equation from the motion of a string with tension. Sinusoidal waves. Hints to the Fourier theorem. Polarization of a wave. Electromagnetic waves in vacuum. Wave equation for the electric and magnetic fields. Velocity of light. Plane wave solution of Maxwell's equations.

To read: Section 9.1, 9.2.1, 9.2.2

Lecture 37: Exercise Session IV

Lecture 38: Exercise Session V