

Learning Goals

Phys 3310 E&M1

CHAPTER SCALE

CHAPTER 1: Vector analysis

TOPICS

- Div, grad, curl
- Line, surface, volume integrals
- Curvilinear coordinates
- Dirac delta function
- Vector fields (potentials)

OBSERVATIONS

- Some mix this chapter in with Chapter 2
- Some skip this chapter (except for Dirac delta function)
- Some assign the first HW from Ch 1, but do not discuss deeply in class
- Students have seen most of this material before, but are not comfortable with it.

PREREQUISITES: Students should already be able to...

1. Be able to compute correctly div, grad and curl in rectangular coordinates for any test function
2. Do a path integral along a specific path -- eg. Griffiths 2.20
3. Be able to expand $1/1+e$ and $1/1-e$ when e is very small (Taylor series).

Students should be able to:

1. Evaluate the integral from negative infinity to infinity of the delta function, $\delta(x)$
2. Evaluate the 3-dimensional divergence of $1/r^2$ in the \hat{r} direction [$4\pi d^3(\mathbf{r})$]
3. Evaluate the integral of a function times the delta function
4. Be able to evaluate the integral of $1/(x-r)^{3/2}dx$
5. Give a geometrical description of the divergence theorem, and fundamental theorem for curls.
6. Change a multidimensional integral in Cartesian coordinates to one in another coordinate system using the Jacobian.

CHAPTER 2: Electrostatics

TOPICS

- Electric field, Coulomb's law
- Gauss' Law, divergence and curl of E
- Potential
- Poisson & Laplace equation
- Work & energy
- Conductors

COMMENTS

PREREQUISITES: Students should already be able to...

1. State Gauss' Law and construct the 3 Gaussian surfaces (sphere, cylinder, pillbox).
2. Use Cartesian, spherical and cylindrical coordinates appropriately when constructing integrals and surface and volume elements.

Electric Field

1. Students should be able to state Coulomb's Law and use it to solve for E above a line of charge, a loop of charge, and a circular disk of charge.
2. Students should be able to solve surface and line integrals in curvilinear coordinates (when given the appropriate formulas, as in the inner-front cover of Griffiths).

Divergence and Curl of E ; Gauss' Law

1. Students should recognize when Gauss' Law is the appropriate way to solve a problem (by recognizing cases of symmetry; and by recognizing limiting cases, such as being very close to a charged body).
2. Students should be able to recognize that E comes out of the Gaussian integral only if it is constant along the Gaussian surface.
3. Students should be able to recognize Gauss' Law in differential form and use it to solve for the charge density ρ given an electric field E .

Electric Potential

1. Students should be able to state two ways of calculating the potential (via the charge distribution and via the E -field); indicate which is the appropriate formulation in different situations; and correctly evaluate it via the chosen formulation.
2. Students should be able to calculate the electric field of a charge configuration or region of space when given its potential.
3. Students should be able to state that potential is force per unit charge, and give a conceptual description of V and its relationship to energy.
4. Students should be able to explain why we can define a vector potential V (because the curl of E is zero and E is a conservative field).

5. Students should be able to defend the choice of a suitable reference point for evaluating V (generally infinity or zero), and explain why we have the freedom to choose this reference point (because V is arbitrary with respect to a scalar – its slope is important, not its absolute value).

Work & Energy

- Students should be able to calculate the energy stored in a continuous charge distribution when given the appropriate formula
- Students should be able to explain in words what this energy represents.

Conductors

- Students should be able to sketch the induced charge distribution on a conductor placed in an electric field.
- Students should be able to explain what happens to a conductor when it is placed in an electric field, and sketch the E field inside and outside a conducting sphere placed in an electric field.
- Students should be able to explain how conductors shield electric fields, and describe the consequences of this fact in particular physical problems (e.g., conductors with cavities).
- Students should be able to state that conductors are equipotentials, that $E=0$ inside a conductor, that E is perpendicular to the surface of a conductor (just outside the conductor), and that all charge resides on the surface of a conductor.

CHAPTER 3: Special Techniques

TOPICS:

- Laplace's equation
- Boundary conditions and uniqueness
- Method of images
- Separation of variables in Cartesian and spherical
- Multipole expansion

COMMENTS:

- *AH: A standard (and often easiest) way to solve an electrostatic problem is to take the known solution of the homogenous Laplace equation and put all physics into the boundary conditions.*
- *TdG: This is a good laboratory for acquiring the tools to learn to solve long problems with several steps (course-scale learning goal 6), allowing students to understand at a deep mathematical level a wide swath of physical phenomena and that having these tools allows students to understand at a deep mathematical level a wide swath of physical phenomena.*
- *WH: I honestly don't think most students get that, I'm willing to bet that most of them become good calculators without the insight.*

PREREQUISITES: Students should already be able to...

1. Recognize the wave equation is in Cartesian coordinates, and state that e^{ikx} is a solution
2. Recognize the solution to separation of variables in Cartesian coordinates.
3. Recognize that a function can be expanded in terms of a complete basis, such as sin and cos.
4. State that conductors are equipotentials.

Laplace's equation

1. Students should recognize that the solution to Laplace's equation is unique.

Method of Images.

1. Students should realize when the method of images is applicable and be able to solve simple cases.

2. Students should be able to explain the difference between the physical situation (surface charges) and the mathematical setup (image charges).

Separation of variables/boundary value problems

1. Students should recognize where separation of variables is applicable and what coordinate system is appropriate to separate in.
2. Students should be able to outline the general steps necessary for solving a problem using separation of variables.
3. Students should be able to state what the basis sets are for separation of variables in Cartesian and spherical coordinates (i.e., exponentials, sin/cos, and Legendre polynomials.)
4. Students should be able to apply the physics and symmetry of a problem to state appropriate boundary conditions.
5. Students should be able to solve for the coefficients in the series solution for V , by expanding the potential or charge distribution in terms of special functions and using the completeness/orthogonality of the special functions, and express the final answer as a sum over these coefficients.

Multipole expansions

1. Students should be able to explain when and why approximate potentials are useful.
 2. Students should be able to identify and calculate the lowest-order term in the monopole expansion (i.e., the first non-zero term).
 3. Students should be able to sketch the direction and calculate the dipole moment of a given charge distribution.
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CHAPTER 4: Electric Fields in Matter

TOPICS

- Polarization & dielectrics
- Field of polarized object (bound charges, field inside dielectric)
- Electric displacement
- Linear dielectrics: Susceptibility, permittivity, dielectric constant
- Boundary value problems with dielectrics

COMMENTS

- *AH: This chapter uses the same methods as Chapter 3, and reinforces that math.*

Polarization and dielectrics

1. Students should be able to name 4 similarities and differences between a conductor and a dielectric (both shield E, conductor shields E completely, dielectric shields via fixed dipoles, conductor shields via mobile electrons).
2. Students should be able to predict whether a particular pattern of polarization will result in bound surface and/or volume charge
3. Students should be able to explain the physical origin of bound charge.

Field of a polarized object

1. Students should be able to sketch the E field inside and outside a dielectric sphere placed in an electric field.
2. Students should be able to explain what happens to a dielectric, when it is placed in an electric field.
3. Students should be able to explain the difference between free and bound charge.

Electric displacement

1. Students should be able to sketch the direction of D, P, and E for simple problems involving dielectrics
2. Students should be able to calculate the E field inside a dielectric when given epsilon and the free charge on the dielectric.
3. *What else do we want students to know about D?*

Linear dielectrics

1. Students should be able to articulate the difference between a linear and nonlinear dielectric.
2. Students should be able to write down Maxwell's equations (for electrostatics) in matter, when given the appropriate equations in vacuum.
3. Students should be able to state the differences in boundary conditions for fields (D) in matter versus a conductor (D).

CHAPTER 5: Magnetostatics

TOPICS

- Currents and charge density
- Magnetic fields and forces (Lorentz force law)
- Biot-Savart law
- Divergence and curl of B (Ampere's Law)
- Magnetic vector potential

COMMENTS

1. The concept that a magnet does not work as it lifts an object is hard.

PREREQUISITES: Students should already be able to...

1. Write down Lorentz force law
2. Know the right-hand rule and how to apply it

Currents and charge density

1. Students should be able to calculate current density J given the current I , and know the units for each.
2. Students should be able to explain, in words, what the charge continuity equation $\frac{\partial \rho}{\partial t} + \nabla \cdot J = 0$ means.
3. Students should be able to state the vector form of Ohm's Law ($J = \sigma E$) and when it applies.
4. Students should be able to calculate the current I , K and J in terms of the velocity of the particle or in terms of each other.

Magnetic fields and forces

1. Students should be able to describe the trajectory of a charged particle in a given magnetic field.
2. Students should be able to sketch the B field around a current distribution, and explain why any components of the field are zero.
3. Students should be able to explain why the magnetic field does no work.

Biot-Savart Law

1. Students should be able to state when the Biot-Savart Law applies (magnetostatics; steady currents, $dp/dt=0$).

2. Students should be able to compare similarities and differences between the Biot–Savart law and Coulomb’s Law.
3. Students should be able to choose when to use Biot–Savart Law versus Ampere’s Law to calculate B fields, and to complete the calculation in simple cases.

Divergence and curl of B (Ampere’s Law)

1. Students should be able to draw appropriate Amperian loops for the cases in which symmetry allows for solution of the B field using Ampere’s Law (ie., infinite wire, infinite plane, infinite solenoid, toroids), and calculate I_{enc} .
2. Students should be able to make comparisons between E and B in Maxwell’s equations (what exactly do we want?)

Magnetic vector potential

1. Students should be able to explain why the potential A is a vector for magnetostatics, whereas it’s a scalar (V) in electrostatics. Ie., that the source of magnetic fields is a vector, not a scalar.
2. Students should recognize that A does not have a physical interpretation similar to V.

CHAPTER 6: Magnetic Fields in Matter

TOPICS

2. Magnetization – diamagnets, paramagnets, ferromagnets
3. Field of magnetized object (bound currents)
4. Auxiliary field H
5. Linear and nonlinear media: susceptibility, permeability

COMMENTS

PREREQUISITES: Students should already be able to...

CHAPTER 7: Electrodynamics

TOPICS

- Electromotive force (Ohm's Law, emf)
- Electromagnetic induction (Faraday's Law)
- Maxwell's equations

COMMENTS

- There is not a general consensus on whether this chapter should be covered in 3310.
- Most students from 3310 go on to take 3320 and will see Maxwell's equations there
- If this material is covered in 3310, it may still be prudent to review in 3320

PREREQUISITES: Students should already be able to...