

Physics 112

Study Notes for Exam II

Chapter 20 Electric Forces and Fields

Technically, this was covered on Exam I, but you must not forget the basics of electric fields, forces and especially how they relate to electric potential.

Chapter 21 Electric Potential

1. Relation between potential energy and potential; Contour maps
2. Using potential to solve energy conservation problems: Examples 21.2-21.5
3. Potential of Point Charges and Uniform Fields
 - Superposition of Potentials
 - Potential of the Dipole Field (Example 21.8)
5. Relation between Field & Potential
 - Equipotentials, Conductors
7. Capacitors
8. Dielectrics
 - Understand how a dielectric affects field, potential difference and capacitance
9. Energy in Capacitors and Fields
 - Practice Exercises:
 - i. A parallel plate capacitor C_0 with plate separation d is completely charged by a battery of $\text{emf} = V_0$. **The battery is disconnected.** Now a piece of material of dielectric constant κ is inserted between the capacitor's plates, filling the entire gap. Explain what happens (increase, decrease or no change) to each of the following and why: Charge on the metal capacitor plates, electric field strength in the dielectric (compared to that in the initial air gap), capacitance, potential difference between the plates, the energy of the capacitor.
 - ii. A parallel plate capacitor C_0 with plate separation d is completely charged by a battery of $\text{emf} = V_0$. **The battery remains connected.** Now a piece of material of dielectric constant κ is inserted between the capacitor's plates, filling the entire gap. Explain what happens (increase, decrease or no change) to each of the following: Charge on the metal capacitor plates, electric field strength in the dielectric (compared to that in the initial air gap), capacitance, potential difference between the plates, the energy of the capacitor.

Chapter 22 Current and Resistance

1. Model of Current

Little emphasis on this section. Big idea is current (more fundamentally *charge*) conservation.

2. Definition & Description of Current

3. Batteries and EMF

Remember that a battery does whatever it must to maintain a constant potential difference across its terminals. The EMF of the battery is voltage it tries to maintain. Unless otherwise instructed, assume that a battery will deliver whatever current to the circuit it must to maintain this EMF. The battery plays the role of the pump establishing a pressure in the fluid analogy.

4. Potential and Current

Know the definition and units for resistivity.

You may ignore the section on superconductivity

5. Resistors and Ohm's 'Law'

Be aware that most metals have resistivity that varies with temperature.

An *ohmic* resistor is one that has constant resistance over a wide range of currents.

Ohm's law $V = IR$ applies, where V is the potential drop across R and R is independent of I or V .

6. Energy and Power

Be able to use all forms of Eq. 22.14. They're equivalent. Your choice is one of convenience.

Chapter 23 Circuits

1. Symbols in schematic diagrams

You should know these by now just from practice in class, lab and homework.

Remember that ideal wires are resistance-less, and therefore equipotentials.

2. Kirchoff's Rules

Very general. Very powerful. These rules apply to any circuit you will encounter, but simpler equivalent methods exist for specific situations (e.g. series and parallel circuits). Remember that voltage across a resistor always drops as you follow the direction of the current. Be able to set up a set of equations for a circuit that cannot be resolved into series and parallel elements. You will not be asked to solve a complex system of linear equations (that can arise in many of these problems).

3. Series and Parallel Circuits

Equations 23.8 and 23.12 are *derived* from Kirchoff's general rules. When a circuit can be reduced to an equivalent resistance using series and parallel elements, it is usually easier to use 23.8 and 23.12 rather than a full Kirchoff analysis.

4. Measurements

Know how ammeters and voltmeters are connected in circuits. Know what their ideal resistances are and why.

5. Complex Circuits

Be able to analyze a circuit in terms of series and parallel elements where applicable.

Example 23.7 is good.

6. Household Electricity

No exam questions will be based on material in this section

7. Capacitor Combinations

Be able to apply Eqs. 23.17 and 23.19. Remember that they look just like the corresponding ones for resistors, but are reversed wrt series and parallel configurations.

8. RC Circuits

Be able to apply Eqs. 23.22 and 23.25.

9. You may ignore this section.

Chapter 24 Magnetic Fields and Forces

1. Observations of Magnetic Effects

2. Magnetic Field

Compass needles/iron filings align with an external field.

Fields obey superposition (pictures on p. 792 are excellent).

3 & 4. You must be able to compute the magnitude and direction of the magnetic field for three special currents: Long straight wire, center of flat loop and interior of solenoid.

You could be asked to obtain a field that is the superposition of two of these (there was at least one Mastering Physics and one classroom example of this).

5. Forces exerted by Magnetic Field on Moving Charges

Uniform circular motion of charge in field perpendicular to velocity

6. Magnetic Forces on Current Carrying Wires

Forces Between Parallel Current Carrying Wires

Forces Between Current Loops

7. Torques on Magnetic Dipoles in External Fields

Very helpful to keep analogy with simpler case of electric dipole in mind

8. Skip this section

Chapter 25 Electromagnetic Induction

1. Observations. Most of the 'experiments' discussed here were demonstrated in class
2. Motional emf: Moving conductors in magnetic fields can act just like (wimpy) batteries.
3. Magnetic Flux and Lenz' Rule

Flux is a measure of how many field lines cut through an area. $\Phi_B = BA\cos\theta$, where θ is the angle between \mathbf{B} and the normal to the area.

Lenz rule says that induced emf tries to set up a current that opposes whatever *change* in flux is inducing it. Remember that an *electric field* is induced by a changing magnetic flux whether or not a current-carrying loop or circuit is present.

4. Faraday's Celebrated Law:

Induced emf has magnitude equal to the time rate of change of magnetic flux:

$$emf = N \frac{\Delta\Phi_B}{\Delta t}. \text{ The flux may vary due to changing area (motional emf), field strength}$$

or orientation (e.g. rotation in a generator). Use this law for the magnitude of any induced emf, and Lenz' Rule to figure out polarity (direction).

5. Remainder of this chapter will be covered after this exam

Comments on Right-Hand Rules (Optional)

In the formal mathematics of vector algebra, there is an operation called the 'vector product' of two vectors. This product (also known as a 'cross product') of two arbitrary vectors \mathbf{A} and \mathbf{B} is defined to be a vector \mathbf{C} such that $\mathbf{A} \times \mathbf{B} \equiv \mathbf{C}$ where $|\mathbf{C}| = |\mathbf{A}| |\mathbf{B}| \sin\theta_{AB}$ where θ_{AB} is the angle between \mathbf{A} and \mathbf{B} , and the direction of \mathbf{C} is given by a right-hand rule: thumb points to \mathbf{A} , index finger to \mathbf{B} , and middle finger points toward resultant \mathbf{C} which is perpendicular to the unique plane containing \mathbf{A} and \mathbf{B} . In this language, the familiar force on a charged particle in a magnetic field is precisely $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$. Note that the scalar charge q carries an algebraic sign that reflects the reversal of the direction of this force for negative particles. Similarly, the force on a current carrying wire in a magnetic field is $\mathbf{F} = I(\mathbf{L} \times \mathbf{B})$. (In the final case, the vector \mathbf{L} is in the direction of the conventional current.) Note also that this vector product thingy is *anticommutative*, i.e. $\vec{A} \times \vec{B} = -(\vec{B} \times \vec{A})$, so you must do everything in precisely the right order.

The right-hand rule above is in your text's 'language'. For the few of you adopting the old fashioned Gealy rules, the fingers of the right hand point to \mathbf{A} , they swing toward \mathbf{B} and the thumb points toward \mathbf{C} .

Summary of Right-Hand Rules

1. Force of Magnetic Field on moving charged particle or current: Thumb $\rightarrow \mathbf{v}$ or \mathbf{I} , Index Finger (IF) $\rightarrow \mathbf{B}$, Middle Finger (MF) $\rightarrow \mathbf{F}$. Remember to reverse direction for negatively charged particle.
2. Magnetic field of current in long straight wire: Thumb $\rightarrow \mathbf{I}$, fingers curl around the wire in the direction of \mathbf{B} .
3. Magnetic Field of current loop or solenoid: Fingers in direction of current, thumb points along axis in direction of \mathbf{B} .

Worked Problems

There will be three worked problems on the exam. Obviously, there are more than three major topic areas from which they will derive. These major areas include:

- A. Electric Fields and Potentials due to charges
 - \mathbf{E} & V due to one or two point charges
 - \mathbf{E} & V due to uniformly charged parallel plates
 - Remember that \mathbf{E} is a vector and V is a scalar
 - For assemblies of point charges, take $V = 0$ at an infinite distance from the charges. Then $V(P)$ is the superposition (scalar sum) of the potential at point P due to all the source charges
 - Do not assume that field and potential are necessarily zero in all the same places
- B. Energy Conservation Problems
 - In uniform \mathbf{E} field the difference in potential energy of a test charge q at two locations is just $\Delta U = q\Delta V = qE\Delta d_E$ where Δd_E is the component of the distance between the points that is along \mathbf{E} . This is precisely analogous to $\Delta U = mg\Delta h$ in the uniform gravitational field near the surface of the earth
 - In a non-uniform field (such as that of a point charge), you cannot merely multiply E by a difference in distance because E varies in magnitude with position. In this case you must find the difference between the initial and final potential energy of the test particle. Then your old friend $\Delta K = -\Delta U$ works to obtain changes in kinetic energy from changes in potential energy.
 - Electric field \mathbf{E} points in direction of decreasing potential V

C. DC Circuits

- Assume that batteries all do what they must to maintain constant emf. This usually means they 'know' how much current to deliver to a network of resistors and/or capacitors, *e.g.*
- Wires may be considered to have negligible resistance and therefore be equipotential lines.
- Be able to reduce a network of combined series and parallel resistors or capacitors to an effective R or C. You may be asked to find the current/voltage - drop/power through/across/dissipated for any 'interior' resistor or branch.
- Be able to write the Kirchoff loop and junction equations for a network. You will not be asked to solve a complex system of linear equations.
- RC Circuits

D. Magnetic forces/torques on charged particles/current carriers/magnetic dipoles

- Charged particle moving in field \mathbf{B} feels force $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$
- In uniform \mathbf{B} field perpendicular to velocity, a particle executes uniform circular motion with radius $r = \frac{mv}{qB}$.
- Current carrying wire in \mathbf{B} feels force $\mathbf{F} = I(\mathbf{L} \times \mathbf{B})$ (\mathbf{L} in direction of current)
- Magnetic dipole in uniform field \mathbf{B} feels torque $\boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B}$, where:
 $\boldsymbol{\tau}$ is the torque vector whose direction is given by the right-hand rule fingers curve in the direction of the 'twist', thumb points in the direction of the torque
 $\boldsymbol{\mu}$ is magnetic dipole moment of the 'loop'. $|\boldsymbol{\mu}| = IA$. With right-hand fingers pointing in direction of loop current, thumb points in direction of $\boldsymbol{\mu}$

E. Determining Magnetic Fields of Source Currents

- Long straight wire carrying current I creates \mathbf{B} lines circling the wire in the direction RH fingers point with thumb in direction of I . Magnitude of field is $|B| = \frac{\mu_0 I}{2\pi r}$ where r is the perpendicular distance to the wire.
- Field at the center of a current carrying loop of N turns of wire is in a direction given by RHR: fingers curl along the current, thumb points in axial direction of field (same direction of North pole and dipole moment vector) $|B| = \frac{\mu_0 I}{2R}$ where R is the radius of the loop

- Field of ideal solenoid is approximately uniform throughout the interior of the coil, and zero outside the coil. $|B| = \frac{\mu_0 NI}{L}$ where N is the number of turns of wire, I is the current and L is the length of the solenoid. Note that N/L is just turns per unit length which may be the (sufficient) given information about the solenoid's geometry. Also, there is no dependence of this field on coil radius. The direction of this field is along the axis of cylindrical symmetry and the RHR is the same as that for the loop.
- Regardless of geometry of current carrying wires, they always produce fields proportional to $\mu_0 I$.

F. Electromagnetic Induction

- Magnetic flux may be changed by changes in any or all of three things: Area, Field strength or orientation. Any induction problem you encounter in this class will involve only one of these changing at once. More explicitly, expect to use one of the following three variations on Eq. 25.12:

$$\varepsilon = N \frac{\Delta \Phi_B}{\Delta t} = N \frac{\Delta(BA \cos \theta)}{\Delta t}$$

$$\text{Varying Area: } \varepsilon = NB \cos \theta \left(\frac{\Delta A}{\Delta t} \right) \text{ (Works for motional emf problems)}$$

$$\text{Varying Field: } \varepsilon = NA \cos \theta \left(\frac{\Delta B}{\Delta t} \right)$$

$$\text{Varying Orientation: } \varepsilon = NBA \left(\frac{\Delta \cos \theta}{\Delta t} \right) = NBA \omega \sin(\omega t) \text{ (for generator)}$$

G. Logical Combinations of Topics

You should expect to encounter more than three of these topics in the three problems you will be asked to work. Following are a few logical combinations of topics that may appear

- Superposition of electric field and potential of two or more source charges
- Forces on charged particles by both electric and magnetic fields (for example, the mass spectrometer example worked in class)
- Force on a charged particle or current due to another current. Here, you would need to compute the field of the source current that interacts with the other particle or current. The parallel wires of §25.6 are an example of this.
- Faraday problem in which changing B results from time varying current in a source wire or coil.
- Motional emf problem involving Ohm's law