1410 W2013 Summary/Review

4/8/13

Try to provide a salient highlight of important concepts introduced in 1410 (winter session) that will be tied to the final exam. Note that this list is not strictly exhaustive (i.e. it may not contain everything). Refer to the class notes and textbook (as well as the HW!!) when preparing for the final

Chapters/Topics covered Overview (Giordano)

- Ch.17 - Electric forces + fields
- ch.18 - Electric Potential
- ch.19 - Electric current + circuits
- ch.20 - Magnetic fields + forces
- ch.21 - Magnetic induction
- ch.11 - Harmonic motion
- ch.22 - AC circuits
- ch.12 - Waves
- ch.23 - Electromagnetic (EM) radiation

4/8/13

- **Charge:** quantized, fundamental base value, protons + electrons
  → opposites attract
- **Coulomb's Law:** $\bar{F} = k \frac{q_1 q_2}{r^2} \hat{r}$ (vector!)

  - superposition
  - dipoles
  - $k = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \frac{Nm^2}{C^2}$
  - $\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$ (permitivity of free space)

- **Electric Field**

  $|F| = q|E| \longrightarrow |E| = \frac{kQ}{r^2}$

  - notion of a 'test charge'
  - analogy to gravity ($F = mg$)
  - lines of force
  - superposition (again and again!)
  - symmetry
  - think about energy!!

- **Electric Flux**

  $\Phi_E = \sum_n \bar{E}_n \cdot \bar{A} = \oint \bar{E} \cdot dA$ (when surface is 'closed')

  - dot product: $\bar{A} \cdot \bar{B} = |A||B| \cos\theta$
  - notion of a 'surface'
  - analogy to water flow through a pipe
  - symmetry (again and again!)
  - geometry: cylinder, sphere, ...

Gauss' Law

4/8/13

$$\Phi_E = \frac{Q}{\epsilon_0} \longleftrightarrow \oint \bar{E} \cdot d\bar{A} = \frac{Q}{\epsilon_0}$$

- notion of a 'closed surface'
- only the total charge inside matters
- symmetry
- various geometries: sheet of charge, parallelsheets, line of charge

Electric Potential + Energy

- notion of work ($W = F\Delta x \leftrightarrow W = \bar{F} \cdot d\bar{r}$)
- potential energy → stored work!!
- $E = K + U = \text{const.}$ (conservation of energy)
- potential vs. potential difference
  ⇝ needs a reference!
- conservative forces: path taken doesn't matter
  (think carefully why this makes sense!)
- superposition
- notion of a 'test charge'
- voltage = electric potential (which is related to but different from notion of elec. pot. energy)
- analogy back to gravity
- key examples: point charge, parallel sheets
- equipotential lines

Conductors vs. Insulators (and semi-conductor)

- notion of valenze electrons (tightly vs. loosely bound)
- polarization

Capacitance

- energy stored in electric field
- parallel plates:

$$\Delta V = \frac{Q}{\epsilon_0 A} d = \frac{Q}{C} \quad \left(C \equiv \frac{\epsilon_0 A}{d} \right)$$

4/8/13

- energy stored in capacitor: $U_c = \frac{1}{2} Q \Delta V = \frac{1}{2} C \Delta V^2 = \frac{1}{2} \frac{Q^2}{C}$
- combinations of capacitors (series vs. parallel)
  → think of analogy to **springs**
- dielectrics → allows more energy to be stored

Electric Circuits (basics)

$I = \frac{dq}{dt}$

- current (electrons moving) → has direction!!
- conductor (e.g. 'ideal wire')
- battery: provides energy to maintain potential difference
- resistance: conduction electrons, drift velocity
  resistivity
- Ohm's Law:
  $V = IR$ (simple version
  $V = IZ$ (complex version) Z-impedance

- circuits are closed (current flows in loops)
- power dissipation through resistance
- combinations of resistors (series vs. parallel)
  → equivalent resistance
- voltmeter, ammeter
- ground

Kirchoff's Laws

- Junction Law: $\sum I_{in} = \sum I_{out}$ (conservation of charge)
- Loop Law: $\Delta V_{loop} = \sum \Delta V = 0$ (conservation of energy)

RC Circuits

- things change w/ time! (exponential, heading towards **steady-st**
- capacitor stores energy, resistor dissipates, battery charges up

4/8/13

- time constant : $\tau = RC$

Magnetism

- history (e.g. compass, Oersted and current-carrying wires)
- all magnets are dipoles (i.e. north and south end)
  → no magnetic monopoles
- magnetic materials (e.g. atomic origins)
- right-hand rule (RHR)
  - different 'versions' depending upon question at hand (pun!)
  - cross-product: $\bar{A} \times \bar{B} = \bar{C}$
    where $|\bar{C}| = |\bar{A}||\bar{B}| \sin\theta$ and $\bar{C}$ is perpendicular to both $\bar{A}$ and $\bar{B}$ via RHR

- visualizing three-dimensionality of things (e.g. ⊗ vs ⊙)
- magnetic field ($\bar{B}$): form closed loops, has both magnitude and direction (just like $\bar{E}$)
  → magnetic fields cause forces
- $\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of free-space)

Ampère's Law

- allows one to determine $\bar{B}$ by considering 'enclosed current' through a '**closed path**'
- put another way, we can use various symmetries to our advantage to determine $\bar{B}$ fields created by currents

$$\sum B_{\parallel} \Delta L = \mu_0 I_{enclosed} \quad \leftrightarrow \quad \oint \bar{B} \cdot d\bar{s} = \mu_0 I_{enclosed}$$

NOTE we saw a slightly modified version of this when dealing w/ Maxwell's Eqns: $\oint \bar{B} \cdot d\bar{s} = \mu_0 I_{enclosed} + \epsilon_0 \mu_0 \frac{d\Phi_E}{dt}$

9/8/13

- important examples: current-carrying wire (radius R, uniform current density), loop of coil

$$B_{loop} = \frac{\mu_0 I}{2R} \qquad B_{coil} = N\frac{\mu_0 I}{2R}$$

- solenoid (length L, radius R, L >> R): $B_{solenoid} = \frac{\mu_0 N I}{L}$
  → uniform field inside (think about why!)

Magnetic Forces

- $\bar{F}_m = q(\bar{v} \times \bar{B})$ ⇝ use RHR ($\bar{B}$ - thumb, $\bar{v}$ - velocity, F_m - index finger)

  Note: sign of q matters!!

  NOTE: combined w/ Coulomb's Law = Lorentz force Law
  $\bar{F} = q(\bar{E} + \bar{q} \times \bar{B})$

- Hall effect
- examples: force between two parallel current-carrying wire

✱ [NOTE: See 2/25/13 notes for additional salient review notes]

Magnetic Induction

- moving charge induces a magnetic field
- moving a magnetic field induces a current

] important duality

→ the notion of induction is a key concept underlying many aspects leading up to electromagnetic radiation

- magnetic flux : $\Phi_B = \bar{B} \cdot \bar{A}$
  (notion of a **surface** is again crucial here!)

- Faraday's Law : $\mathcal{E} = -\frac{d\Phi_B}{dt} \longleftrightarrow \oint \bar{E} \cdot d\bar{s} = -\frac{d\Phi_B}{dt}$

  <u>Note</u>: the induced emf ($\mathcal{E}$) can be thought of as the electric field parallel to an enclosing path (through which Φ_B goes) summed up, ie.:

  $$\mathcal{E} = \oint \bar{E} \cdot d\bar{s}$$

  <u>Note</u>: Φ_B ~~chan~~ can change in a # of ways (B, A, or θ)

- Lenz's Law: induced current <u>opposes</u> changes in magnetic field (this is already built into Faraday's Law via the negative sign)
  → important to realize this essentially amounts to a statement on the conservation of energy

- notion the $\bar{B}$ fields have 'inertia'
- eddy current brake example

RL circuits + Inductance

- like RC circuits, dynamic behavior
- self-induced emf:

  $$\mathcal{E}_{ind} = -L\frac{dI}{dt} = \Delta V_L$$

  (potential 'drop' across an inductor)

- inductance of a solenoid: $L = \frac{\mu_0 N^2 A}{d}$

- inductive time constant: $\tau = L/R$

4/8/13

Energy Stored in Magnetic Fields

- back to the notion of inertia...
- energy stored in an inductor: $U_L = \frac{1}{2} L I^2$
- transformers, ideal transformers equation:

$$\frac{|\Delta V_2|}{|\Delta V_1|} = \frac{N_2}{N_1} = \frac{|I_1|}{|I_2|}$$

Oscillations + Harmonic Motion

- basics: sinusoids, frequency, amplitude, equilibrium, phase
- connection to rotating around a circle fixed at the origin $\quad \dot{x} \equiv \frac{dx}{dt}$
- harmonic oscillator: $m\ddot{x} + b\dot{x} + kx = F(t)$
- notion of energy transfer between kinetic + potential

$$E = K(t) + U(t) = \frac{1}{2} m v^2 + \frac{1}{2} k x^2 = \text{const.}$$

[$v = v(t)$ and $x = x(t)$] (when no damping)

- forced oscillations ⟶ resonance
- natural frequency: $\omega_0 = \sqrt{k/m}$
- trajectories in 'phase space'
- damping: underdamped vs. critical vs. overdamped

NOTE: 'simple harmonic oscillator' (SHO) simply is: $\ddot{x} + \omega_0^2 x = 0$

AC circuits

- RMS values
- instantaneous vs. average values (and diff. re amplitude)
- phasors
- resistance vs. reactance ⟶ impedance

- AC circuit w/ a capacitor
- " " an inductor
- LC circuit → connection to SHO
  (i.e. energy gets transferred back and forth between L and C)
- RLC circuit

☐ Electromagnetic Waves

- induction as a means to transfer energy back and forth between $\bar{E}$ and $\bar{B}$ (think Faraday's Law and Ampère-Maxwell Law)

symmetry — $\left[\begin{array}{l} \frac{d}{dt}\Phi_m \rightarrow \bar{E} \\ \frac{d}{dt}\Phi_E \rightarrow \bar{B} \end{array} \right.$

- wave basics: longitudinal vs. transverse, amplitude vs frequency vs. wavelength, direction of propagation, phase velocity
- 'wave equation': $f(x,t) = f(x \pm ct)$
- different examples of waves (e.g. sound, water, ...)
- ω (angular frequency), k (wave number)
- superposition (i.e. combinations of waves)
- standing waves
- interference (constructive vs. destructive)
- polarization (e.g. Malus' Law: $I_{transmitted} = I_0 \cos^2\theta$)

☐ Maxwell's Equations

- five fundamental equations
- emergence of a wave solution
- speed of light: $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3.00 \times 10^8$ m/s

4/8/13

- intensity: power per unit area ($I \propto E_0^2$)
- EM spectrum
- wave-particle duality

☐ <u>Beyond 1410</u> → while not directly on the test, there is a lot of useful food for thought buried in there!