Physics 106b-2011 Exam 2 Coverage

Coverage:
The exam <u>is</u> cumulative, but will emphasize material covered since the last exam:
Last part of class 8 (2-4-11) through first part of class 23 (3-29-11)
Wolfson & Pasachoff:

- Ch. 25 through Ch. 31 [*omitting pp. 720-722, 760-761, and section 31-5.*]
- plus pp. 872-873;
- 34.1 through 34.3

Assignments 4-8

Critical concepts covered since the last exam (Red = we covered these in the most recent lecture, Blue = we covered these in an earlier lecture; updated 3-29-11)

Capacitors
- Definition of capacitance
- Parallel plate capacitors
- Energy storage in capacitors
- Energy density of the electric field
- Calculating capacitance from known **E** (e.g. problem 26-36)
- Connecting capacitors in series and parallel:
- Formulas for computing equivalent capacitance of series/parallel connections
- Capacitors in series have same charge, those in parallel have same voltage
- Dielectrics:
  - Capacitance is multiplied by the dielectric constant
  - Microscopic picture of how this happens, including reduction of **E** by dielectric

Electric current:
- Definition
- meaning/definitions of current density, resistivity, drift velocity
- Drude model for conductivity in metals and metal-like materials (i.e. connection between resistivity and typical time between collisions)
- Current-carrying wires need not have a net charge (and usually have little, if any), even though they have a high density of mobile charge carriers

Ohm's Law
Calculating power in circuits; when to use $P = IV$, $P = I^2R$, $P = V^2/R$
Internal resistance of a battery or other voltage source
Connecting resistors in series and parallel: Formulas for equivalent resistance
Kirchoff's Loop Rule & Junction Rule
RC circuits:
- How to go from the differential equation for the charge on the capacitor to an equation for the charge as a function of time.
- Meaning of exponential growth & decay
- Meaning of RC time constant; why it's reasonable that time constant should be proportional to R and to C

Magnetic forces:
- how the direction of the magnetic field is defined
- Lorentz force on a moving point charge and the associated right hand rule
- Why this leads to motion in circles and helices; how to find the radius
- Magnetic force on a current element $I\,d\vec{\ell}$
- Hall effect: qualitative understanding
- How motors work

Production of magnetic fields:

- Field due to a moving point charge: equation and qualitative picture, including associated right hand rule
- Biot Savart law and how to use it for simple geometries

Ampère's law for **E** constant in time:

- What it means
- What the left side describes
- Fact that it works for any path
- How to use it to find **B** for highly symmetrical currents

Solenoids

- How to use Ampère's law to find the field
- What the field looks like in a linear or toroidal solenoid

No Magnetic Monopoles Law:

- What it means
- Connection to the fact that magnetic field lines form closed loops
- connection to Gauss's law
- how it would be modified (qualitatively) if there were monopoles

Induction and motional emf

- What the differences are, what the similarities are
- Definition of magnetic flux
- Motional emf equation: what it means & how to use it
- How generators work
- Faraday's law:
  - What it means, including meaning of the left side
  - Fact that it works for any path
  - The **B** is total **B** from all sources, including induced current (if any)
  - How to use it to calculate **E** for symmetrical changing **B**
  - What it means to have a non-conservative **E**
  - Lenz's law: how to use it, why it's needed to avoid non-conservation of energy
- Eddy currents: qualitative

Transformers

Correction to Ampère's law

- Derivation
- Definition of displacement current
- How to use it to calculate **B** for symmetrical changing **E**
- Be able to tell qualitatively whether a particular loop has non-zero circulation of **E** or **B** around it, given **E** or **B**

You are expected to be able to integrate and differentiate the following functions:

x^n (where n may be positive or negative, and may or may not be an integer), $\sin ax$, $\cos ax$, $\frac{1}{x}$, e^{ax}

Equations to internalize for exam 1
(Not the format that they will be given in on the exam; for that, see the following pages.)

Ch. 23:

Coulomb's law: The force between two point charges: $\mathbf{F} = \frac{kq_1q_2}{r^2}\hat{\mathbf{r}}$

Relation between the electric force and the electric field: **F = E**q

Electric field of a point charge: $\mathbf{E} = \frac{kq}{r^2}\hat{\mathbf{r}}$ (This is really a variant form of Coulomb's law.)

Principle of superposition: $\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 + \ldots$

Electric field of a continuous charge distribution: $\mathbf{E} = \int \frac{k\,dq}{r^2}\hat{\mathbf{r}}$ (Again, this is really a variant form of Coulomb's law.)

Ch. 24:

Definition of electric flux: $\phi_E \equiv \int \mathbf{E}\cdot\hat{\mathbf{n}}\,dA$ (for flat surface, uniform field, $\phi_E = \mathbf{E}\cdot\hat{\mathbf{n}}\,A$)

Gauss's law: $\oint \mathbf{E}\cdot\hat{\mathbf{n}}\,dA = \frac{q_{\substack{net\\enclosed}}}{\varepsilon_o}$

Ch. 25:

Definition of voltage: $V \equiv \frac{U \text{ of a point charge}}{\text{charge of that point charge}}$

Relation of voltage to electric field: $\Delta V_{AB} = -\int_A^B \mathbf{E}\cdot d\vec{\ell}$

Voltage due to a point charge: $V = \frac{kq}{r}$

Superposition of voltages: $V_{TOT} = V_1 + V_2 + \ldots$

Voltage of a continuous charge distribution: $V = \int \frac{k\,dq}{r}$

Relation of electric field to voltage: $\mathbf{E} = -\vec{\nabla}V$, where $\vec{\nabla} \equiv \hat{\mathbf{x}}\frac{\partial}{\partial x} + \hat{\mathbf{y}}\frac{\partial}{\partial y} + \hat{\mathbf{z}}\frac{\partial}{\partial z}$

(Note: variants of this would include, for example, $E_\ell = -\frac{dV}{d\ell}$.)

Definition of capacitance: $Q = CV$ $\quad \frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} \Leftrightarrow C_{series} = \frac{C_1C_2}{C_1 + C_2}$ $\quad C_{parallel} = C_1 + C_2$

Energy density of the electric field: $u_E = \frac{\varepsilon_0 E^2}{2}$ $\quad U = \int_{all\ space} u_E\, dV$

Dielectric constant: $\kappa \equiv \frac{E_{plates}}{E_{Tot}}$ $\quad C_{\substack{parallel\\plate}} = \frac{\kappa\varepsilon_0 A}{d}$ $\quad U = \frac{1}{2}CV^2$

Ohm's Law: $V = IR$ $\quad \frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{r_2} \Leftrightarrow R_{parallel} = \frac{R_1R_2}{R_1 + R_2}$ $\quad R_{series} = R_1 + R_2$

Definition of resistivity: $R = \frac{\rho L}{A}$ **Resistivity in the Drude model:** $\rho = \frac{m}{ne^2\tau}$ **Drift velocity:** $I = nqAv_d$

Electrical power: $P = VI$ $P = I^2 R$ $P = V^2 / R$ **Output voltage of a real battery:** $V_{out} = \varepsilon - Ir$

RC charging: $V_C = \varepsilon\left(1 - e^{-t/RC}\right)$ **RC discharging:** $V_C = V_0 e^{-t/RC}$

Hall voltage: $V_H = \frac{IB}{nqt}$ **Gauss's Law for magnetic fields:** $\oint \mathbf{B} \cdot \hat{\mathbf{n}}\, dA = 0$

Lorentz force: $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$

Force on a current-carrying wire: $d\mathbf{F} = I\, d\vec{\ell} \times \mathbf{B}$ **If wire is straight and B uniform:** $\mathbf{F} = I\, \vec{\ell} \times \mathbf{B}$

Biot-Savart Law: $d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{\mathbf{r}}}{r^2}$

Ampère's Law: $\oint \mathbf{B} \cdot d\vec{\ell} = \mu_0 I_{\substack{net \\ threading}} + \mu_0 \varepsilon_0 \frac{d}{dt} \int \mathbf{E} \cdot \hat{\mathbf{n}}\, dA$ $B_{solenoid} = \mu_0 n I$

Motional emf and/or induction: $\varepsilon_{loop} = -\frac{d\phi_B}{dt}$, where $\phi_B \equiv \int \mathbf{B} \cdot \hat{\mathbf{n}}\, dA$

Faraday's law: $\oint \mathbf{E} \cdot d\vec{\ell} = -\frac{d}{dt} \int \mathbf{B} \cdot \hat{\mathbf{n}}\, dA$ **Transformers:** $\varepsilon_s = \varepsilon_p \frac{N_s}{N_p}$ $I_s V_s = I_p V_p$

On the exam, you will be provided with the following numerical values:

$k = 8.99_9$ Nm^2/C^2	$\varepsilon_o = 8.85_{-12}$ C^2/Nm^2 = $1/(4\pi k)$	Charge of electron = -e, where e = 1.60_{-19} C
$c = 3.00_8$ m/s	$\mu_o = 4\pi_{-7}$ N/A^2	Mass of electron = $m_e = 9.11_{-31}$ kg
		Mass of proton = $m_p = 1.67_{-27}$ kg

Equations that will be provided on the exam
IMPORTANT: you are expected to know the conditions under which each of these can be applied!!!

$\mathbf{E} = \frac{\mathbf{F}}{q}$ $\quad \mathbf{E}_{\text{point charge}} = \frac{kq}{r^2}\hat{\mathbf{r}}$ $\quad \mathbf{E} = \int \frac{k\,dq}{r^2}\hat{\mathbf{r}}$ $\quad E_{\text{due to sheet charge}} = \frac{\sigma}{2\varepsilon_0}$ $\quad E_{\text{total, at metal surface}} = \frac{\sigma}{\varepsilon_0}$

$\oint \mathbf{E}\cdot\hat{\mathbf{n}}\,dA = \frac{q_{\text{net, enclosed}}}{\varepsilon_0}$ $\quad k = \frac{1}{4\pi\varepsilon_0}$ $\quad \phi_E \equiv \int \mathbf{E}\cdot\hat{\mathbf{n}}\,dA$ $\quad \phi_E = EA\cos\theta$

$V \equiv \frac{U_{\text{point}}}{q_{\text{point}}}$ $\quad \Delta V_{AB} = -\int_A^B \mathbf{E}\cdot d\ell$ $\quad \mathbf{E} = -\nabla V$ $\quad \vec{\nabla} \equiv \hat{\mathbf{i}}\frac{\partial}{\partial x} + \hat{\mathbf{j}}\frac{\partial}{\partial y} + \hat{\mathbf{k}}\frac{\partial}{\partial z}$ $\quad \Delta V_{AB} = -\mathbf{E}\cdot\ell$

$E = -\frac{dV}{dx}$

$V_{\text{point charge}} = \frac{kq}{r}$ $\quad V = \int \frac{k\,dq}{r}$

$v = v_0 + at$ $\quad s = \Delta x = x - x_0 = v_0 t + \frac{1}{2}at^2$ $\quad v^2 = v_0^2 + 2as$ (and similar equations for y and z.)

$\mathbf{v}_{AC} = \mathbf{v}_{AB} + \mathbf{v}_{BC}$ $\quad a_c = \frac{v^2}{r}$ $\quad \mathbf{F}_{\text{net}} = \frac{d\mathbf{p}}{dt}$ $\quad \mathbf{F}_{\text{net}} = m\mathbf{a}$

$F = -kx$ $\quad \mathbf{W} = m\mathbf{g}$ $\quad F_s \le \mu_s N$ $\quad F_k = \mu_k N$ $\quad F_c = \frac{mv^2}{r}$

$F_c = \frac{mv^2}{r}$ $\quad W = \int_{\text{Start}}^{\text{Finish}} \mathbf{F}\cdot d\mathbf{s}$ $\quad W = \mathbf{F}\cdot\mathbf{s} = Fs\cos\theta$ $\quad \mathbf{A}\cdot\mathbf{B} = AB\cos\theta$

$W_{ext} + Q_{ext} = \Delta K + \Delta U + \Delta U_{\text{int}}$ $\quad W_{\text{int}} = \pm\Delta ?$ $\quad U_{\text{grav}} = mgy$ $\quad U_{\text{spring}} = \frac{1}{2}kx^2$ $\quad K = \frac{1}{2}mv^2$

$\Delta U = -\int_{\text{Start}}^{\text{Finish}} \mathbf{F}\cdot d\mathbf{s}$ $\quad \mathbf{F} = -\vec{\nabla}U$ $\quad \vec{\nabla} \equiv \hat{\mathbf{i}}\frac{\partial}{\partial x} + \hat{\mathbf{j}}\frac{\partial}{\partial y} + \hat{\mathbf{k}}\frac{\partial}{\partial z}$ $\quad F = -\frac{dU}{dx}$ $\quad P \equiv \frac{dE}{dt}$

$P = \mathbf{F}\cdot\mathbf{v}$

$\mathbf{F} = -\frac{GMm}{r^2}\hat{\mathbf{r}}$ $\quad U = -\frac{GMm}{r}$ $\quad T^2 = \frac{4\pi^2 R^3}{GM}$ $\quad$ "Equal areas in equal times"

$\mathbf{R} = \frac{\sum m_i \mathbf{r}_i}{M_{\text{tot}}}$ $\quad \mathbf{F}_{\text{net ext}} = M_{\text{tot}}\frac{d^2\mathbf{R}}{dt^2}$ $\quad \mathbf{P} = \sum \mathbf{p}_i$ $\quad \mathbf{F}_{\text{net ext}} = \frac{d\mathbf{P}}{dt}$ $\quad v_{fA} = 2v_{CM} - v_{iA}$

$\text{Impulse} = \mathbf{F}_{\text{av}}\,\Delta t = \Delta\mathbf{P}$

$\omega \equiv \frac{d\theta}{dt}$ $\quad \boldsymbol{\alpha} = d\boldsymbol{\omega}/dt$ $\quad v_t = \omega r$ $\quad a_t = \alpha r$ $\quad \omega = \omega_0 + \alpha t$ $\quad \Delta\theta = \theta - \theta_0 = \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega^2 = \omega_0^2 + 2\alpha\,\Delta\theta$

$\mathbf{A}\times\mathbf{B} \equiv AB\sin\theta\,\hat{\mathbf{n}}$ $\quad I = \sum m_i r_i^2$ $\quad I = I_{\text{CM}} + Mh^2$ $\quad \boldsymbol{\tau} = \mathbf{r}\times\mathbf{F}$

$K = \frac{1}{2}mv_{\text{CM}}^2 + K_{\text{rot}}$ $\quad K_{\text{rot}} = \frac{1}{2}I\omega^2$ $\quad W = \tau\,\Delta\theta$ $\quad v_{\text{CM}} = \omega r$ $\quad \mathbf{L} = I\boldsymbol{\omega} = \mathbf{r}\times\mathbf{p}$ $\quad \boldsymbol{\tau}_{\text{net ext}} = d\mathbf{L}/dt$

$$\omega_0 = \sqrt{\frac{k}{m}} \quad \omega = \sqrt{\frac{g}{\ell}} \quad \omega = \frac{2\pi}{T} = 2\pi f \quad x = A\cos(\omega t + \varphi) \quad \gamma \equiv \frac{b}{m} \quad Q = \frac{\omega_s}{\gamma}$$

$$y = A\cos(kx \pm \omega t) \quad k = \frac{2\pi}{\lambda} \quad v = \frac{\lambda}{T} = \frac{\omega}{k} \quad I \equiv \frac{P}{A} \quad I \equiv \frac{P}{4\pi r^2}$$

$$y = A\cos(kx + \omega t) + A\cos(kx + \omega t) = 2A\cos\omega t\ \sin kx \quad L = \frac{n}{2}\lambda$$

$P \equiv \dfrac{F}{A}$ The equipartition theorem. $P = \dfrac{kA\Delta T}{\Delta x}$ $R \equiv \dfrac{\Delta x}{k}$ $P = e\sigma AT^4$

$$PV = Nk_B T = nRT \quad C \equiv \frac{dQ}{dT} \quad c \equiv \frac{C}{m} \quad C_V = \frac{dU_{INT}}{dT} \quad C_m \equiv \frac{C}{n} \quad C_{mV,\text{solid}} = 3R$$

$$Q = CV \quad \frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} \Leftrightarrow C_{series} = \frac{C_1 C_2}{C_1 + C_2} \quad C_{parallel} = C_1 + C_2$$

$$u_E = \frac{\varepsilon_0 E^2}{2} \quad U = \int_{\text{all space}} u_E\ dV \quad \kappa \equiv \frac{E_{plates}}{E_{Tot}} \quad C_{\substack{parallel\\plate}} = \frac{\kappa\varepsilon_0 A}{d} \quad U = \tfrac{1}{2}CV^2$$

$$V = IR \quad \frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{r_2} \Leftrightarrow R_{parallel} = \frac{R_1 R_2}{R_1 + R_2} \quad R_{series} = R_1 + R_2$$

$$R = \frac{\rho L}{A} \quad \rho = \frac{m}{ne^2\tau} \quad I = nqAv_d \quad P = VI \quad P = I^2 R \quad P = V^2/R \quad V_{out} = \varepsilon - Ir$$

$$V_C = \varepsilon\left(1 - e^{-t/RC}\right) \quad V_C = V_0 e^{-t/RC} \quad V_H = \frac{IB}{nqt} \quad \oint \mathbf{B}\cdot\hat{\mathbf{n}}\,dA = 0 \quad \mathbf{F} = q\mathbf{v}\times\mathbf{B}$$

$$d\mathbf{F} = I\,d\vec{\ell}\times\mathbf{B} \quad \mathbf{F} = I\,\vec{\ell}\times\mathbf{B} \quad d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{\ell}\times\hat{\mathbf{r}}}{r^2}$$

$$\oint \mathbf{B}\cdot d\vec{\ell} = \mu_0 I_{\substack{net\\threading}} + \mu_0\,\varepsilon_0\,\frac{d}{dt}\int \mathbf{E}\cdot\hat{\mathbf{n}}\,dA \quad B_{solenoid} = \mu_0 nI$$

$$\varepsilon_{loop} = -\frac{d\phi_B}{dt} \quad \phi_B \equiv \int \mathbf{B}\cdot\hat{\mathbf{n}}\,dA \quad \oint \mathbf{E}\cdot d\vec{\ell} = -\frac{d}{dt}\int \mathbf{B}\cdot\hat{\mathbf{n}}\,dA \quad \varepsilon_s = \varepsilon_p\frac{N_s}{N_p} \quad I_s V_s = I_p V_p$$