About Exam 3

- **When and where (same as before)**
  - Monday Nov. 22\textsuperscript{rd} 5:30-7:00 pm
  - Bascom 272: Sections 301, 302, 303, 304, 305, 311, 322, 327, 329
  - Ingraham B10: Sections 306, 307, 312, 321, 323, 324, 325, 328, 330

- **Format (same as before)**
  - Multiple choices
  - Close book
  - One 8x11 formula sheet allowed, must be self prepared.
  - Bring a calculator (but no computer). Only basic calculation functionality can be used.

- **Special needs:**
  - No early test before Monday Nov 22\textsuperscript{rd} possible.
  - One alternative session (Monday afternoon) in our lab room.
Chapter 30: Sources of the Magnetic Field
  All chapters covered.

Chapter 31: Electromagnetic Induction and Faraday’s Law
  All sections covered.

Chapter 32: Inductance
  All sections covered.

Chapter 33: AC Circuits.
  Section 33.1 -- 33.7

Chapter 34: EM Waves
  All sections covered
  (Displacement Current (34.1) only conceptual level.
  Solving differential equations (for Maxwell’s eqs.) not required.)

Past related materials:
- Chapter 16: Wave Motion helps for Ch. 34
- Section 28.4: RC circuit will be part of RLC circuit.
**Disclaimer**

- This review is meant as supplements to your own preparation.

- Exercises presented in this review do not form a problem pool for the test.
Exam Topics (1)

- Concepts: Understanding all key concepts in the covered chapters.

- Basic Quantities:
  - Magnetic Field, Magnetic (electric) Flux
  - Electromotive Force (emf)
  - Inductance (self & mutual)
  - Time Constants (RC, L/R)
  - Phase Angles, Phasors
  - Resonance Frequency \((1/\sqrt{LC})\)
  - Waves speed \((v)\), wave length \((\lambda)\), amplitude \((A)\), frequency \((f, \omega)\), period \((T)\), phase \((\varphi)\)
  - EM wave spectrum, energy, radiation pressure, Poynting Vector.
Exam Topics (2)

- Magnetic Fields can be produced by:
  - moving charge (Biot-Savart law)
  - change of $E$ field
    (displacement current, not in this exam.)

- Ampere’s Law
  - Ampere’s law simplifies the calculation of B field in some symmetric cases.
    - (infinite) straight line, (infinite) current sheet, Solenoid, Toroid

- Gauss’s Law in Magnetism $\rightarrow$ no magnetic charge.

- Forces between two currents
  - Can be attractive/repulsive
  - No force if perpendicular
Exam Topics (3)

- **Magnetic Induction**
  - Faraday’s Law emf: \( \varepsilon = -d\Phi_B/dt \)
  - Field emf: electric field produced due to change of \( \Phi_B \)
    \( \rightarrow \) no circuit/conductor is required.
  - Motional emf: emf due to magnetic force.
  - Lenz’s Law.
  - **Important**: identify direction of emf

- **Self and Mutual Inductance.**
  - \( e = -Ldl/dt \)
  - \( e_2 = M \, dl_1 / dt, \, e_1 = M \, dl_2 / dt \)
Exam Topics (4)

- Timing circuits:
  - RC ($t=RC$)
  - RL ($t=L/R$)
  - LC ($\omega=1/\sqrt{LC}$)

- RCL series circuit (AC powered)
  - Phasor relationship for R, L, C
  - Voltage and current of RLC circuit. Impedance
  - Resonance.
  - Power Consideration

- Electromagnetic waves
  - Speed of EM Wave = speed of light $c$
  - $E_{\text{max}}$, $B_{\text{max}}$, $f$, $\omega$, $\lambda$, $\phi$, directional relationship of E, B, S
  - Wave energy, Intensity
  - Radiation pressure
  - Maxwell’s equation at conceptual level (no derivation)
Chapter 30: Two Ways to Calculate Magnetic Field

- **Biot-Savart Law (first principle):**

\[
\vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{ds \times \hat{r}}{r^2}
\]

- **Ampere’s Law:**

(Practical only for settings that are highly symmetric)

\[
\oint \vec{B} \cdot ds = \mu_0 I
\]

any closed path
example 1: Biot-Savart Law

Use Biot-Savart to find the magnetic field at the point P.

Solutions: (See board)

\[ \vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{ds \times \hat{r}}{r^2} \]

Answer:

segment 1 contribution: \( B = 0 \)

segment 3 contribution: \( B = 0 \)

segment 2:

\[ \vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{ds \times \hat{r}}{R^2} = \frac{\mu_0 I}{8R} \]
example 2: Ampere’s Law

- An infinite straight thin wire is at the center of two concentric conducting cylinders of radius \( R \) and \( 2R \).

  The currents are \( I \) (into the page), \( 2I \) (out), and \( I \) (in), respectively for the center wire and the two cylinders. (as color coded).

Find \( B \) as function of \( r \).

- Solution:

\[
\oint \mathbf{B} \cdot d\mathbf{s} = 2\pi r B = \mu_0 I_{\text{enclosed}}
\]

\[ 
\Rightarrow B = \frac{\mu_0 I_{\text{enclosed}}}{2\pi r}
\]

Answers:

- \( r < R \), \( B = \frac{\mu_0 I}{2\pi r} \) (Clockwise)
- \( R < r < 2R \), \( B = \frac{\mu_0 I}{2\pi r} \) (counter-clockwise)
- \( r > 2R \), \( B = 0 \)
Chapter 31

- Faraday’s Law
  - How to calculate magnetic flux
  - from changing $\Phi_B$ to emf
  - motional emf for simply straight wire.
  - directions!

See exercises next page
Reminder: All Those Right-Hand Rules

\[ F = q \mathbf{v} \times \mathbf{B} \]

- For magnetic force on a charged particle: Point a right hand with the fingers in the direction of \( \mathbf{v} \) and the thumb in the direction of \( \mathbf{B} \). The force is perpendicular to both and into the plane of the hand.
- For magnetic force on a current-carrying conductor: Point the fingers of the right hand in the direction of the current \( I \). The thumb points in the direction of the magnetic field \( \mathbf{B} \). The force is perpendicular to both and into the plane of the hand.
- For magnetic force on a magnetic dipole: Point the fingers of the right hand in the direction of the magnetic dipole moment \( \mu \). The thumb points in the direction of the external magnetic field \( \mathbf{B} \). The force is perpendicular to both and into the plane of the hand.
Determine Direction Of emf

- Indicate the direction of emf in the following cases:

  - $|B|$ increases
  - $|B|$ decreases
  - $|B|$ decreases
  - $|B|$ increases
  - $|B|$ decreases
  - path outside $B$
Exercises

More configurations at the end of ch. 31.
Chapter 32

- Inductance (self and mutual):
  - Knowing the definition
  - Calculation for simple settings (solenoid, toroid..)

- LR, (RC) circuit
  - Meaning of time constant
  - Time constant for LR (RC) circuit

- LC circuit
  - Concepts of intrinsic (resonant) frequency
  - $\omega_0$ for LC circuit
  - $\omega \leftrightarrow f$
  - What is Hz?
Reminder: Time Constant

LR circuit

**turning on**

\[ I = \frac{V_0}{R} \left( 1 - e^{-\frac{t}{L/R}} \right) \]

\[ I_{\text{max}} = \frac{V_0}{R} \]

\[ 0.63 I_{\text{max}} \]

**turning off**

\[ I = I_0 e^{-\frac{t}{L/R}} \]

\[ 0.37 I_0 \]

RC circuit: check section 28.4
An LR circuit has a time constant of 1s. Initially, there is no current in the circuit, at t=0, the circuit is being powered by a 3V battery in series.

- How long does it take for the current to ramp up to 80% of maximum?
  - 1.6s (see board)
- If the voltage is doubled to 6V, is the answer to previous question (time to 80%) to be
  - doubled?
  - halved?
  - same?
  - neither?
Chapter 33

- Alternating Circuits (AC):
  - Impedances for R, L, C
  - Simple combination of impedance for series/parallel
  - Resonant condition.
  - (again) \( \omega \leftrightarrow f \).
  - Simple RLC series circuit: \( I, \Delta V \) and \( Z \)
  - Simple phasor relationships
  - Energy consumption for the whole RCL series circuit and at each component.
Reminder:
Summary of Phasor Relationship

$I_R$ and $\Delta V_R$ in phase
$|I_R| = |\Delta V_R|/R$

$I_L$ 90° behind $\Delta V_L$
$\Delta V_L$ 90° ahead of $I_L$
$|I_L| = |\Delta V_L|/X_L$

$I_C$ 90° ahead of $\Delta V_C$
$DV_C$ 90° behind $I_C$
$|I_C| = |\Delta V_C|/X_C$
Reminder
Current And Voltages in a Series RLC Circuit

\[ \Delta v_R = (\Delta V_R)_{\text{max}} \sin(\omega t) \]
\[ \Delta v_L = (\Delta V_L)_{\text{max}} \sin(\omega t + \pi/2) \]
\[ \Delta v_C = (\Delta V_C)_{\text{max}} \sin(\omega t - \pi/2) \]

\[ \Delta V_{\text{max}} = I_{\text{max}} \sqrt{R^2 + (X_L - X_C)^2} \]
\[ \phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) \]

\[ \Delta V_{R\text{-Max}} = I_{\text{max}} R, \quad \Delta V_{L\text{-Max}} = I_{\text{max}} (\omega L), \quad \Delta V_{C\text{-Max}} = I_{\text{max}} / (\omega C) \]
A series RLC AC circuit has $R=425 \, \Omega$, $L=1.25 \, \text{H}$, $C=3.50 \, \text{mF}$, $\Delta V=(150 \, \text{V}) \sin 377t$.

Find the maximum voltage across $R$, $L$, $C$.

### Solution

$$
\Delta V_{R\_Max} = I_{max} R, \quad \Delta V_{L\_Max} = I_{max} (\omega L), \quad \Delta V_{C\_Max} = I_{max} / (\omega C)
$$

$$
R = 425, \quad \omega L = 377 \times 1.25 = 471.3, \quad 1/(\omega C) = 757.8
$$

$$
I_{max} = \Delta V_{max} / |Z| = \Delta V_{max} / \sqrt{R^2 + (\omega L - 1/(\omega C))^2} = 0.29
$$

**Answer:**

$$
\Delta V_{R\text{max}} = 124 \, \text{V}, \quad \Delta V_{L\text{max}} = 138 \, \text{V}, \quad \Delta V_{C\text{max}} = 221 \, \text{V}
$$

Note: It is possible for $\Delta V_C$ (and sometimes $\Delta V_L$) to be greater than $\Delta V_{max}$.

- **Further potential questions:**
  - What is the frequency?, what is the phase between $\Delta V$ and $I$, what is the power consumed by $R$, (or $L$, $C$)?
A Phasor diagram for a certain RCL series circuit is shown below.

- Label all phasors

- Suppose all length are drawn in proportion to SI units (i.e. 1V and 1A will appear to have same length on graph), how big is $R$? (~1 $\Omega$ ?, ~3 $\Omega$ ?, ~4 $\Omega$ ?, can not be determined?)
Chapter 34

- Electromagnetic Waves
  - Knowing general concepts: e.g. can EM waves travel in vacuum? Are lights EM waves?
  - Identify wave speed and direction for a traveling wave function. $A \sin(kx-\omega t+\phi)$
  - Understand directional relationship between $E$, $B$ and $S$
  - Conversion between $l$ and $\phi$
  - $E(B) \leftrightarrow u_E \leftrightarrow u_B \leftrightarrow$ flux (intensity) $\leftrightarrow$ Poynting
  - $\frac{1}{2}$ ? (rms vs. max)
  - from source power to field intensity (for point/plane sources.)
EM Wave

- The electric component of an EM wave has the form (in SI units):
  \[ E_x(z,t) = 5.0 \times 10^{-3} \sin(6.28 \times 10^{-3} z + 1.884 \times 10^6 t) \text{ v/m} \]

- What is the speed of the wave, in which direction?
  - \( 3 \times 10^8 \text{ m/s, -z direction. (Why?)} \)

- What are the wavelength and frequency of this wave?
  - \( 1000 \text{ m, 300kHz (why?)} \)

- Write down the function form of the magnetic component of the wave
  \[ B_y(z,t) = -1.67 \times 10^{-11} \sin(6.28 \times 10^{-3} z + 1.884 \times 10^6 t) \text{ T} \]

- Further potential questions (practice yourself):
  - \( E_{\text{max}} \text{?} \ B_{\text{max}} \text{?} \text{, average power? intensity? pressure?} \text{ .....} \)
EM Power And Intensity

A radio station is broadcasting at an average power of 25 kW, uniformly in all direction. What is the signal intensity at 5 km and 10 km? A receiver is capable of being sensitive to an electric field of \( E_{\text{rms}} = 0.020 \text{V/m} \), how far can the receiver be away from the station and still have signal? \( (\mu_0 = 4\pi \times 10^{-7}) \)

- Intensity = \( P/\text{Area} = P/(4\pi r^2) \)
  - @ 5 km, \( I_{5\text{km}} = \frac{25000}{(4\times3.14\times5000^2)} = 8 \times 10^{-5} \text{W/m}^2 \)
  - @ 10 km, \( I_{10\text{km}} = I_{5\text{km}}/4 = 2 \times 10^{-5} \text{W/m}^2 \)

- \( I = \frac{E_{\text{rms}}^2}{(\mu_0 c)} = \frac{(0.02)^2}{(4\pi \times 10^{-7}c)} = 1.06 \times 10^{-6} \text{W/m}^2 \)

\( \Rightarrow I/I_{5\text{km}} = (5\text{km}/r)^2 \Rightarrow r = 43.3 \text{ km} \)