

Unit 3 Review

9.1

- The force on a segment of current-carrying wire is $\vec{F} = i\vec{L} \times \vec{B}$

9.2

- The magnetic dipole moment is given by $\vec{\mu} = i\vec{A}$ where the direction of A is given by the right-hand rule: fingers are I , thumb is A .
- The torque on a magnetic dipole in a magnetic field is $\vec{\tau} = \vec{\mu} \times \vec{B}$.
- The potential energy of a magnetic dipole in a magnetic field is $U = -\vec{\mu} \cdot \vec{B}$.

9.3

- The electric dipole moment is defined by $\vec{p} = q\vec{\ell}$ where the direction of ℓ is from $-q$ to $+q$.
- The torque on a magnetic dipole in a magnetic field is $\vec{\tau} = \vec{p} \times \vec{E}$.
- The potential energy of a magnetic dipole in a magnetic field is $U = -\vec{p} \cdot \vec{E}$.

9.4

- Elementary particles have magnetic dipole moments associated with their spin.
- Atoms have dipole moments that arise from spin and the orbital motion of electrons.
- Atomic dipoles tend to align with one another.
- Thermal agitation tends to disalign the dipoles.

9.5-6

- Magnetic susceptibility is defined by $\vec{B}_{\text{int}} = \chi \vec{B}_{\text{ext}}$.

paramagnetic	$\chi = +10^{-5} \text{ to } +10^{-3}$	weakly attracted
diamagnetic	$\chi \approx -10^{-6} \text{ to } -10^{-4}$	weakly repelled
ferromagnetic	$\chi = +10^{+3} \text{ to } +10^{+5}$	strongly attracted

- The relationship between the internal field and external for ferromagnetic materials is described by a hysteresis curve.
- The residual magnetization is the internal field remaining in a magnetic material when the external field is reduced to zero.
- The coercive force is the external field that must be applied to bring the internal field to zero.

10.1

- The larger the velocity of a source particle, the smaller the angle of a head line or tail line becomes.
- When a source particle accelerates, the head line and the tail line go off at different directions.
- For accelerating charges, the length of threads is proportional to r .
- The electric and magnetic fields of accelerating charges fall off as $1/r$ rather than $1/r^2$.
- As the thread moves farther away from the source, its direction becomes perpendicular to the head line.
- The stub is perpendicular to both the head line and the stub.
- The directions are related by $\hat{E} \times \hat{B} = \hat{r}$.

10.2

- We can think of the acceleration as “pulling the tail” of the thread in the direction of the acceleration.
- Electric and magnetic fields can be considered as the sum of “velocity” fields and “acceleration” fields.

10.3

- The electric field is in the direction $\hat{r} \times (\hat{r} \times \hat{a})$.
- The magnetic field is in the direction $\hat{r} \times \hat{E}$.
- The magnitude of the electric and magnetic fields are related by: $E_a = cB_a$ (in SI units).

10.4

- Review the online animations and qualitatively understand these animations.
- Remember that the faster a particle goes, the smaller the head line becomes, but the larger the ray line becomes.
- Oscillating charges lead to oscillating fields and electromagnetic waves.
- The wave travels in the \hat{r} direction.
- The electric and magnetic fields are still perpendicular to \hat{r} , even though they oscillate.

10.5

- When current is increasing, charges accelerate in the direction of the current. When current is decreasing, charges accelerate opposite the direction of a current.
- Know the example of accelerating charges in a wire.
- If current increases or decreases in a wire, an induced electric field points opposite the acceleration.
- If a loop of wire is placed near a wire with changing current, induced current flows around the loop.

- This leads to Faraday’s Law of Induction: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$, $\Lambda_E = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$

10.6

- As current flows in and out of capacitor plates, charges accelerate.
- The electric acceleration fields from charges on the top and bottom plates cancel.
- The magnetic fields add to give looping magnetic fields.
- These magnetic fields are the same as if they were caused by an actual current passing between the capacitor plates. This is called “displacement current” and is given by the equation

$$i_{dis} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}. \text{ Equivalently, the displacement current density is given by } \vec{j}_{dis} = \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}.$$

- This leads to Maxwell’s Term in Ampère’s Law. Maxwell’s Term is the second term in $\nabla \times \vec{B} = \mu_0 (\vec{j} + \vec{j}_{dis}), \quad \Lambda_B = \oint \vec{B} \cdot d\vec{\ell} = \mu_0 (i + i_{dis})$

11.1

- When electric field form loops, the usual ideas of potential energy and energy conservation cannot be applied.
- The line integral of the electric field is called the EMF. EMF is the voltage that is caused by looping electric fields. It behaves in much the same way as the voltage of a battery.

11.2

- Induced current can be produced by “motional EMF” as well as by acceleration fields.
- Motional EMF is the force on charge carriers in a current caused by a wire moving through a magnetic field.

11.3

- Faraday’s Law tells us that the voltage around a loop is minus the rate at which magnetic flux through the loop changes. $\mathcal{E} = -\frac{d}{dt} \Phi_{B,enc}.$

- Faraday’s Law tells us that the curl of the electric field at a point in space is minus the rate at which the magnetic field at the point changes. $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

11.4

- We can create an induced electric field by changing the flux through a loop in a number of ways: change the size of the loop, change the strength of the magnetic field, or change the orientation of the loop with respect to field.
- Lenz’s Law states that the direction of the induced field can be determined from the direction of the induced current that would oppose *change* in the external field.
- Mathematically, Lenz’s Law is represented by the “-“ sign in Faraday’s Law.

11.5

- Be sure you know how to find the direction of induced currents and electric fields by using Lenz’s Law.

11.6

- Be sure you know how to do Faraday's Law problems when 1) the B field varies in time, 2) the loop area varies in time, or 3) the orientation of the loop varies in time.
- Be able to find the electric field inside and outside a circular magnetic field that is changing in time.

11.7

- When the magnetic field through a conductor changes, eddy currents are induced in the conductor.
- Eddy currents produce magnetic fields that oppose the motion of a conductor: if the conductor is moving into a stronger magnetic field, the force is repulsive. If the conductor is moving into a weaker magnetic field, the force is attractive.

11.8

- An electric motor can be made by placing a current loop in an external magnetic field.
- The direction of the current through the loop must be reversed every half cycle to keep the armature of the motor rotating in the same direction.
- AC motors use a double commutator with an AC power supply to reverse the current direction.
- DC motors use a split commutator with a DC power supply to change the current direction.

11.9

- Generators are essentially like motors except that we turn the armature by some mechanical means to induce an EMF in the coil.
- A generator with a double commutator produces an AC voltage.
- A generator with multiple coils and split commutators for each coil can produce a quasi-DC voltage.

12.1

- In a DC circuit, an inductor normally behaves just as a long segment of wire.
- If there is a changing magnetic field in an inductor, current will be induced in the circuit.

12.2

- Inductance is defined by the equation: $V_L = -L \frac{di}{dt}$
- Inductance depends on the geometry of the inductor, not on the current, etc.
- Inductance adds like resistance in series and parallel combinations.

12.3

- The energy stored in an inductor is $U_L = \frac{1}{2} Li^2$.
- The energy density of a magnetic field is $u = \frac{U}{vol} = \frac{1}{2\mu_0} B^2$.

12.4

- In LR circuits, current changes in time either by $e^{-t/\tau}$ or by $1 - e^{-t/\tau}$.
- The LR time constant is $\tau = \frac{L}{R}$.

12.5

- An LC circuit oscillates at an angular frequency $\omega = \frac{1}{\sqrt{LC}}$.
- Energy is transferred back and forth between the electric field of the capacitor and the magnetic field of the inductor as the circuit oscillates.
- ELI the ICE man – and its meaning.
- Know how to derive Kirchoff's loop equation, Eq 12.6. You may be a bit cavalier about signs.

12.6

- A sine wave can be represented by the projection of a phasor onto the y axis.
- The length of a phasor is the amplitude of the sine wave. The angle of a phasor with respect to the x axis is the angular argument (the phase angle) of the sine function.
- Phasors of waves can be added as vectors to produce the sum of two sine functions.
- For AC circuits, the phase angle is ωt , so phasors rotate counterclockwise at an angular speed of ω .
- We usually wish to construct current and voltage phasors for each circuit element.
- For resistors, the current and voltage phasors are in phase.
- For inductors, the voltage phasor is at an angle of $+90^\circ$ from the current phasor.
- For capacitors, the voltage phasor is at an angle of -90° from the current phasor.

12.7

1. If two circuit elements are in series, they have the same current phasor and their voltage phasors add as vectors.
2. If two circuit elements are in parallel, they have the same voltage phasor and their current phasors add as vectors.
3. The sum of current phasors into a junction equals the sum of current phasors out of a junction.
4. The sum of voltage phasors from circuit elements around a loop is the sum of voltage phasors from EMFs around a loop. (Note that they don't sum to zero because of our standard definition of positive voltage. That is, voltage phasors for circuit elements are voltage *drops*, whereas voltages for EMFs are voltage *gains*.)

12.8

- The rms values of voltage or current are the peak values divided by $\sqrt{2}$.
- The average power dissipated by a resistor in an AC circuit is $\bar{P}_R = \frac{1}{2}i_0V_0 = i_{rms}V_{rms}$.
- The average power provided by an AC power source is $\bar{P} = \frac{1}{2}i_0V_0 \cos \phi$.
- $\cos \phi$ is called the power factor.

12.9

- Be able to reproduce the impedance diagram for series LRC circuits, Fig. 12.24. Understand the phase relations that appear in the diagram.
- Know that $Z = \sqrt{(X_L - X_C)^2 + R^2}$ and be able to deduce this from the impedance diagram.
- Know that $\tan \phi = \frac{X_L - X_C}{R}$ and be able to deduce this from the impedance diagram.

12.10

- Resonance is when the impedance of a circuit is minimized so that the current is maximized.
- Resonance in a series LRC circuit is achieved when $X_L = X_C$.
- At resonance $Z = R$.
- The resonant frequency is the natural oscillation frequency, $\omega = \frac{1}{\sqrt{LC}}$.

13.1

- Transformers are devices that change AC voltage by taking advantage of mutual induction between two coils wound around an iron core.
- The voltages in the primary and secondary coils are related by the formula $\frac{V_2}{V_1} = \frac{N_2}{N_1}$.
- The power in the primary and secondary coils is approximately related by the formula $i_1 V_1 = i_2 V_2$.

13.2

- In the United States household power is 120 V (rms), 60 Hz power.
- Transmission lines use high voltages in order to minimize loss of energy in the transmission lines.
- Transformers are used to reduce high voltage power to 120 V for household use.
- Three lines come into a house, 0V and two 120 V that are out of phase by 180°.

13.3

- Three power lines come into a house. One line is at 0 V and two are at 120 V.
- The 120 V lines are out of phase by 180°. By connecting to both 120 V lines, a 240 V circuit is produced.
- Circuit breakers protect against excessive current in a circuit.
- Home circuit breakers have a bimetallic strip switch and a solenoid switch.

13.4

- In home wiring: black and red are hot, white is neutral, and bare or green is ground.
- Copper wire conducts better, is more flexible, and corrodes less than aluminum wire. Aluminum wire is less expensive.
- Larger wire must be used in circuits that draw more current. 6 AWG copper wire is used for stoves, 12 AWG wire is used for most household circuits.

13.5

- Switches are named by the number of wires being switched (poles) and the number of output options (throws).
- Switches are placed in the hot wire of a circuit.
- A white wire with black tape wrapped around it is hot (white hot).
- The hot connection of an outlet is the narrow one. Outlets should be installed with the hot connection down.
- Outlets can be connected in series and parallel.
- Be able to recognize a 3-way switch circuit, and series and parallel outlet circuits.

13.6

- Know why grounding is important.
- Know what a GFCI is how it operates. Know where GFCIs need to be installed and that they need to be installed in series.
- Know why AFCIs are used and where AFCI circuit breakers should be installed.

13.7

- $E(x, t) = E_0 \sin(kx \pm \omega t)$
- This wave moves in the $\mp x$ direction.
- E_0 is the amplitude.
- k is the “wavenumber.” $k = \frac{2\pi}{\lambda}$.
- ω is the angular frequency $\omega = 2\pi f = \frac{2\pi}{T}$.

13.8

- Be sure you understand the terms amplitude, wavenumber, angular frequency, frequency, and period.
- The electric and magnetic fields are perpendicular to each other and perpendicular to the direction the wave travels. The vector $\vec{E} \times \vec{B}$ points in the direction of the velocity.
- The amplitude of the magnetic field is $1/c$ times the amplitude of the electric field.
- The electric and magnetic fields are in phase. That is, if the electric field is large and a given point in space and time, the magnetic field is also large at that point.
- Know that $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$.

13.9

- Know the electromagnetic spectrum. You don’t need to remember the wavelengths listed in the table, but you should remember the names of the different types of electromagnetic radiation and their order in the spectrum.
- $c = \lambda f$.
- Radio communication requires us to modulate a carrier wave with a signal wave, transmit the wave, receive the wave, and then separate the signal from the carrier once again.
- Be qualitatively familiar with the three methods of modulating carrier waves: AM, FM, and PM.

- Center-fed dipole antennas are often used for transmission. Similarly, half-wavelength dipole antennas are often used for reception.
- The length of an antenna is generally on the order of one wavelength.
- A series LRC with a variable capacitor is used to tune the radio. The capacitor adjusts the resonant frequency of the circuit to match the transmission frequency.

13.10

- The maximum rate at which information can be sent on a wave is about the same as the frequency.
- bandwidth is literally the frequency range over which signals can be transmitted. Bandwidth determines the number of signals that can be transmitted simultaneously.

13.11

- Light can be polarized by reflection, scattering, birefringent crystals, or polarizers.
- The direction of polarization for reflection or scattering is along the direction of the intersection of the polarizing planes of the incident and reflected (or scattered) rays.
- Polaroid filters cut out the component of polarized light that is perpendicular to the filter axis.
- Polaroid filters cut half the intensity of unpolarized light.
- The intensity of light is proportional to the square of its electric field.

- Malus's Law: $\frac{I_{out}}{I_{in}} = \cos^2 \theta$