Name ____________________  
Test 3  
April 9, 2014

This test consists of three parts. Please note that in parts II and III, you can skip one question of those offered.

Possibly useful formulas:

**EM waves**

\[
E_0 = cB_0 \\
S = \frac{1}{\mu_0} (E \times B) \\
\langle S \rangle = cB_0^2 / 2\mu_0 \\
P = \langle S \rangle / c
\]

**Inductor**

\[
L = \mu_0 N^2 A / \ell \\
U = \frac{1}{2} LI^2
\]

**LC Circuits**

\[
\omega = 1/\sqrt{LC} \\
Q = Q_0 \cos(\omega t)
\]

**Impedance**

\[
X_C = 1/C\omega, \quad X_L = L\omega \\
Z^2 = R^2 + (X_L - X_C)^2 \\
\phi = \tan^{-1}[ (X_L - X_C) / R ] \\
\omega_0 = 1/\sqrt{LC}
\]

**RLC Circuits**

\[
\omega = \frac{1}{\sqrt{LC - \frac{R^2}{4L^2}}} \\
Q = Q_0 e^{-R/(2L)} \cos(\omega t)
\]

**AC Circuits**

\[
\Delta V = \Delta V_{\text{max}} \sin(\omega t) \\
I = I_{\text{max}} \sin(\omega t - \phi)
\]

**RMS values**

\[
\Delta V_{\text{rms}} = \frac{\Delta V_{\text{max}}}{\sqrt{2}} \\
I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}}
\]

**Faraday’s Law**

\[
\oint E \cdot ds = -\frac{d\Phi_E}{dt}
\]

**Ampere’s Law**

\[
\oint B \cdot ds = \mu_0 I + \varepsilon_0 \mu_0 \frac{d\Phi_E}{dt}
\]

**Part I: Multiple Choice [20 points]**

For each question, choose the best answer (2 points each)

1. In an AC circuit with an ideal resistor, capacitor, and inductor, which component(s) actually consume power
   A) Resistor (only)  
   B) Capacitor (only)  
   C) Inductor (only)  
   D) Resistor and capacitor  
   E) Capacitor and inductor

2. Magnetic fields can be made by electric current, as well as by
   A) Constant electric fields  
   B) Changing electric fields  
   C) Constant magnetic fields  
   D) Changing magnetic fields  
   E) Loops of wire in motion
3. According to Lenz’s law, if you move a loop of wire in a region with a magnetic field, currents will appear in the wire that try to keep the __________ constant through the wire
A) Magnetic field
B) Magnetic flux
C) Electric field
D) Electric flux
E) Current

4. The electronic component that resists changes in current is a
A) Resistor  B) Capacitor  C) Diode  D) Inductor  E) Switch

5. Suppose you have 240 V AC going into a transformer, and you want to get 120 V AC out. If there are 200 turns on the primary winding, how many should there be on the secondary?
A) 800  B) 400  C) 200  D) 142  E) 100

6. Suppose I had an air-core inductor, and I decided I wanted to increase the inductance. Which of the following would be a bad way to do this?
A) Increase the number of turns
B) Increase the cross-sectional area
C) Increase the length (while leaving the number of turns the same)
D) Add an iron core
E) Actually, all of these would be a good idea

7. In a steady state, an ideal inductor acts like
A) A wire, no resistance
B) An open circuit, no current
C) A capacitor
D) A switch
E) None of the above

8. Which of the following describes the physical meaning of wavelength $\lambda$?
A) How many times it repeats in a meter
B) How many times it repeats in a second
C) The distance between one peak of a wave and the next
D) The time between one peak of a wave and the next
E) The velocity of the wave

9. What type of signals tend to be blocked by a capacitor?
A) High voltage
B) Low voltage
C) High current
D) High frequency
E) Low frequency

10. If $V_{\text{max}} = 100$ V for an AC source, what is $V_{\text{rms}}$?
A) 200 V  B) 141 V  C) 100 V  D) 71 V  E) 50 V

Part II: Short answer [20 points]
Choose two of the following questions and give a short answer (1-3 sentences).

11. An ideal transformer can, in principle, increase the voltage by a large factor. Since $P = I (\Delta V)$, doesn’t this mean that the power increases a lot? Doesn’t this mean that energy is being created for free?

12. Explain what it means when the current lags or leads the voltage in an AC circuit. When you have a capacitor, which of these does it do?

13. Place the following in order from longest wavelength to shortest: gammas-rays, infrared, microwaves, radio, ultraviolet, visible, X-rays.

Part III: Calculation: [60 points]
Choose three of the following four questions and perform the indicated calculations (20 points each)

14. A loop of wire or radius $R$ is in the shape of a circle with $N = 500$ loops in a region with a magnetic field of $B = 1.30$ T, pointing perpendicular to the loop, as sketched at right. The circle is expanding its radius at a velocity of 2.00 m/s, so that at time $t$, the radius is $R = 2t$.

(a) Calculate the magnetic flux through a single loop, and through all 500 loops, as a function of time.

(b) Calculate the EMF around the 500 loops as a function of time.

(c) At what time is the EMF equal to 150 V? At this time, which direction is the EMF generated, clockwise or counter-clockwise?
An inductor with $L = 0.120$ H is connected via a switch to a capacitor with $C = 32.00 \ \mu F$, as shown at right. Initially, there is a charge $Q_0$ on the right hand side of the capacitor. At $t = 0$, the switch is closed (ignore the dashed figure for now)

(a) Find the angular frequency $\omega$, the frequency $f$, and the period $T$ over which this oscillator will oscillate. Also find a formula for the charge $Q$ as a function of time.

(b) What is the first positive time $t$ when the capacitor has no charge on it? At this moment, the inductor is measured to have a current $I = 0.200$ A running through it. Find the energy in the inductor at this moment. Is there any energy in the capacitor at this moment?
16. A certain circuit consists of a $\Delta V_{\text{rms}} = 120.0$ V at $f = 60.0$ Hz source fed into a heater with a resistance of $R = 20.0$ $\Omega$. Initially, boxes $A$ and $B$ contain simple wires, as shown.

(a) Calculate the current $I_{\text{rms}}$ through the resistor. This is the amount of current our heroes need to keep from freezing.

(b) Horrible Henry sneaks in and replaces box $A$ with an inductor with $L = 0.500$ H. Find the impedance $Z$ of the resulting circuit, and the current now passing through the resistor.

(c) Friendly Fred then replaces box $B$ with a capacitor that exactly cancels out the effects of the inductor, thereby restoring the current to the value found in part (a). What capacitance did he use?
17. An electromagnetic wave has a wavelength of 457 nm and an electric field given by

\[ \mathbf{E} = (324 \text{ V/m}) \hat{i} \sin(kz - \omega t) \]

where the \( \hat{i} \) denotes the direction of the electric field.

(a) What is the value of \( k \) and \( \omega \) for this wavelength?
(b) What is the magnitude and direction of the magnetic field \( \mathbf{B} \) for this wave?
(c) What is the time-averaged intensity \( \langle S \rangle \)?