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

**Part I: Multiple Choice [20 points]**
For each question, choose the best answer (2 points each)

1. Which of the following is a property that a transformer would be useful for?
   A) Increasing or decreasing voltage (only)
   B) Increasing or decreasing current (only)
   C) Changing alternating current to direct current (only)
   D) Both (A) and (B), but not (C)
   E) None of the above

2. The unit of inductance is the
   A) Volt       B) Ohm       C) Ampere   D) Farad       E) Henry

3. Which of the following is not a type of electromagnetic radiation?
   A) Ultraviolet B) Alpha rays C) Gamma rays D) Radio       E) Microwaves

**Possibly useful formulas:**

<table>
<thead>
<tr>
<th>EM waves</th>
<th>LC Circuits</th>
<th>RL Circuits</th>
<th>AC Circuits</th>
<th>RMS values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_o = cB_o$</td>
<td>$\omega = 1/\sqrt{LC}$</td>
<td>$I = I_o e^{-i\tau}$</td>
<td>$\Delta V = \Delta V_{max} \sin(\omega t)$</td>
<td>$\Delta V_{rms} = \Delta V_{max} \sqrt{2}$</td>
</tr>
<tr>
<td>$S = \frac{1}{\mu_0} (E \times B)$</td>
<td>$Q = Q_o \cos(\omega t)$</td>
<td>$I = \frac{E}{R} \left(1 - e^{-i\tau}\right)$</td>
<td>$I_{rms} = I_{max} \sqrt{2}$</td>
<td></td>
</tr>
<tr>
<td>$\langle S \rangle = cB_o^2 / 2\mu_0$</td>
<td>$\phi = \tan^{-1} \left(\frac{X_L - X_C}{R}\right)$</td>
<td>$Q = Q_o e^{-\phi / 2} \cos(\omega t)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P = \langle S \rangle / c$</td>
<td>$\omega_o = 1/\sqrt{LC}$</td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inductor</th>
<th>Generator</th>
<th>Faraday’s Law</th>
<th>Ampere’s Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L = \mu_0 N^2 A/\ell$</td>
<td>$\mathcal{E} = N\omega B A\sin(\omega t)$</td>
<td>$\oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$</td>
<td>$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \varepsilon_0 \mu_0 \frac{d\Phi_E}{dt}$</td>
</tr>
<tr>
<td>$U = \frac{1}{2} LI^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Circles</th>
<th>Triangles</th>
<th>Spheres</th>
<th>Cylinders</th>
<th>Cones</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C = 2\pi R$</td>
<td>$A = \frac{1}{2} BH$</td>
<td>$A = 4\pi R^2$</td>
<td>$V = \pi R^2 L$</td>
<td>$V = \frac{1}{3} \pi R^2 L$</td>
</tr>
<tr>
<td>$A = \pi R^2$</td>
<td></td>
<td></td>
<td>$A_{lat} = 2\pi RL$</td>
<td>$A_{lat} = \pi R \sqrt{L^2 + R^2}$</td>
</tr>
</tbody>
</table>
4. Which of the following explains the properties of a diode?
   A) It blocks low frequencies
   B) It blocks high frequencies
   C) It tries to keep voltage constant
   D) It tries to keep current constant
   E) It lets current through one direction, but not the other

5. If we want to induce an EMF in a loop of wire, which of the following methods would work?
   A) Change the size of the loop, so that the magnetic flux through it changes (only)
   B) Change the strength of the magnetic field (only)
   C) Move the loop to a new location, where the magnetic flux is different (only)
   D) All of the above
   E) None of the above

6. Which of the following colors has the longest wavelength?
   A) Red
   B) Blue
   C) Yellow
   D) Violet
   E) Orange

7. Which of the following formulas would give the time averaged power \( \langle P \rangle \) consumed by a resistor with resistance \( R \) in an AC circuit?
   A) \( R I_{\text{max}}^2 \)
   B) \( I_{\text{max}}^2/R \)
   C) \( R I_{\text{rms}}^2 \)
   D) \( I_{\text{rms}}^2/R \)
   E) None of these

8. Electrical power in the US is generated by
   A) Strings of batteries connected in series
   B) Rubbing materials of different types together; triboelectric generators
   C) Loops of wire mechanically rotated in strong magnetic fields
   D) Conductive materials under high pressure pushed through filters that only allow electrons through
   E) Harnessing natural sources of electricity, such as lightning

9. In a perfect LC circuit, power is never lost. This is unrealistic for real circuits because
   A) We want to consume power, so such a circuit is useless
   B) Real circuits, especially inductors, tend to have a lot of resistance
   C) There must be batteries or other sources of power, which have resistance
   D) Real capacitors are also inductors, and inductors are capacitors, so these cancel out
   E) This is only true at one frequency, and you can never match that frequency exactly

10. To construct an inductor, one would typically use
    A) A solenoid; stacked coils of wire
    B) A material of known resistivity and known dimensions
    C) Two parallel plates a fixed distance apart
    D) Doped semi-conductors which allow current through only one way
E) A chemical source of a voltage difference
Part II: Short answer [20 points]
Choose two of the following questions and give a short answer (1-3 sentences).

11. For the simple circuit sketched at right, assume at $t = 0$, there is charge in the capacitor but no current flowing. Explain qualitatively what happens when the switch is closed, giving any relevant equations.

12. Explain qualitatively how the two terms on the right side of Ampere’s Law $\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 l + \varepsilon_0 \mu_0 (d\Phi_E/dt)$ each allow different ways to create a magnetic field.

13. State Lenz’s Law. In particular, tell what would happen if a permanent magnet, with field lines as sketched in, were suddenly withdrawn from a conducting ring, as sketched at right.
Part III: Calculation: [60 points]
Choose three of the following four questions and perform the indicated calculations (20 points each)

14. A loop of copper wire is in the shape of a right triangle of size 30.0 \times 40.0 \text{ cm}, with a hypotenuse of 50.0 \text{ cm}, as sketched at right, with \( N = 125 \) turns. It is in the presence of a magnetic field pointing into the paper, which is changing as a function of time given by:

\[ B(t) = (0.40 \text{ T/s}^2) t^2 \]

(a) Find the flux as a function of time, for the single loop and for the 125 turns.
(b) Calculate the EMF around the 125 loops as a function of time.
(c) If the entire 125 loops have a resistance of 0.78 \( \Omega \), what will be the current at \( t = 2.00 \text{ s} \)? Which direction does it flow?
15. A circuit consists of a 12.0 V battery, an ideal 5.00 H inductor, and two resistors of magnitude 50.0 Ω and 125.0 Ω, as sketched at right. Initially, the switch is closed and has remained closed for a long time.
(a) With the switch closed, in a steady state, which circuit elements will current flow through? Find the initial current $I_0$ flowing through the inductor.
(b) At $t = 0$, the switch is opened. Now which way will the current flow? Calculate the current as a function of time. Find the time when the current drops to 1.0 mA.
(c) Immediately after the switch is opened, at $t = 0$, what will be the voltage across the 125 Ω resistor?
16. A circuit consists of an AC source of unknown frequency and voltage being fed through a resistor with $R = 500 \, \Omega$ and a capacitor of unknown capacitance. A graph of the voltage (solid line, in V) from the source and the current (dashed line, in mA) through the circuit is sketched at right.
(a) From the graph, estimate $V_{\text{max}}$ and $I_{\text{max}}$. What is the approximate impedance $Z$ for the two components?
(b) From the graph, estimate the frequency $f$ and calculate the angular frequency $\omega$.
(c) Estimate the reactance $X_C$ for the capacitor at this frequency. What is the capacitance of the capacitor?
17. The James Webb space telescope has a large sunshield designed to reflect the light coming from the Sun. For purposes of this problem, assume the sunshield is a rectangle $21\,\text{m} \times 14\,\text{m}$ perpendicular to sunlight. The intensity of sunlight is approximately $I = 1361\,\text{W/m}^2$.

(a) What is the light pressure on the telescope, assuming it is perfectly reflecting? What is the total force pushing on this telescope?

(b) The total mass of the telescope is 6500 kg. Calculate the acceleration of the telescope due to sunlight. Calculate how long it would take sunlight to cause it to move 1.00 m, assuming it starts from rest.

(c) Suppose that the mirror surface were mistakenly painted black. How long would it take for the “shield” to absorb one million Joules of energy from the Sun?