1.) (a) A toaster generates Joule heating at a rate of 855 W when plugged into a 125 volt D.C. power source. This results in a current of \( I = 6.84 \, \text{A} \). The nichrome wire used in the heating element is a high resistance wire, but still the entire heating element only has a resistance of \( R = 18.3 \, \Omega \). The heating element can be unfolded to be a single coil 0.500 cm in diameter and 45.0 cm long, with 480. turns. Find the inductance, \( L \), of this coil. 

**NOTE:** If you do not get an answer to (a), use \( L = 252 \, \text{mH} \) in parts (b) - (e).

(b) If this toaster into an AC wall outlet, with \( V_{\text{rms}} = 125 \, \text{volts} \) and \( f = 60.0 \, \text{Hz} \), find the inductive reactance, \( X_L \), of the heating element.

(c) Sketch a single phasor diagram showing \( v_R \), \( v_L \), and the current, \( i \).

<table>
<thead>
<tr>
<th>“In Use” Equation</th>
<th>“By Geometry” Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V = I , R )</td>
<td>( R = \frac{\mu L}{A} )</td>
</tr>
<tr>
<td>( Q = CV )</td>
<td>( C = \frac{\epsilon}{\mu} \frac{A}{d} ) (Parallel Plate Capacitor)</td>
</tr>
<tr>
<td>( L = \frac{N^2 B L}{I} )</td>
<td>( L = \frac{\mu L}{I} ) (Air-Core Solenoid)</td>
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</table>

(d) The heater element can be thought of as being a resistor and an inductor in series. What is the time constant of this RL circuit?

(e) Use the impedance to find \( I_{\text{rms}} \) for the toaster. There is no capacitive nature to this circuit.

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2.) (a) A current of 4.35 A flows in a long straight wire. Use Ampere’s Law to find \( B \) at point \( P \) which is 15.0 cm (0.150 m) directly below the long straight wire. This is a Star Problem – “Show Me The Integral!” 

(b) The differential equation for an ideal LC circuit is: 

\[
\frac{d^2 Q}{dt^2} = -\frac{1}{LC} \frac{dQ}{dt}
\]

whose solutions are mathematically the same as the Simple Harmonic Oscillator in PHYS-205. Create this equation by starting with the knowledge that the change in the total energy stored in both the inductor and the capacitor is zero, 

\[
\frac{dU}{dt} = \frac{d}{dt}\left(\frac{Q^2}{2C} + \frac{1}{2}LI^2\right) = 0
\]

and remembering that \( I = \frac{dQ}{dt} \).

(c) Starting from the equation for an inductor with \( N \) turns, \( L = \frac{N^2 \mu_0 I}{L} \), show that the right-hand equality of the self-induced emf equation for a coil in a magnetic field 

\[
\xi_L = -N \frac{d\Phi_L}{dt} = -L \frac{dI}{dt}
\]

is true.
(d) Although we don’t want to calculate all the little bits and pieces (we don’t really have the equations),
consider a permanent magnet inside a Gaussian surface of some symmetric shape. What can you say
about the magnetic flux, \( \Phi_b \), such that Gauss’ Law for Magnetism, \( \oint B \cdot d\mathbf{A} = 0 \), holds true?

\[ \oint B \cdot d\mathbf{A} = 0 \]

(e) A 15 turn coil of cross-sectional area 0.00785 m² and length 0.0500 m, experiences a uniform
magnetic field directly down its length of magnitude \( B = 0.0005 + (0.005 T / \text{sec}) t - (0.0005 T / \text{sec}^2) t^2 \). Find
the induced current, if any, in the coil at the time \( t = 5.00 \text{ seconds} \).

Power to the People! (35,000 points)

3.) (a) Two parallel power lines each carry 480 A of current in the same direction. If the cables between
two power poles are 85.0 m long and are separated by a distance of 3.50 meters, find the magnetic force
between the two power lines, and indicate whether they are attracted or repelled. For simplicity’s sake,
treat this as D.C. in this part, even though we know that the power lines are really A.C.

(b) At the house of a mad scientist, Dr. Fyl, the 480 A is used at 118 V A.C. to power his cathedral of
Micron Millennia Pentium computers. The power plant is 25.0 km away, and 50.0 km of wires (\( \ell_{o} \) and
\( \ell_{f} \)) has a total resistance of 22.5 \( \Omega \). If 480 A runs through the wires, find the efficiency of this power
distribution system.

(c) If instead, the electricity is set at 118,000 V A.C. on the power lines, find the new efficiency of the
power distribution system.

(d) The voltage is changed by a step-down transformer from 118,000 volts to 118 volts. The secondary
coil has \( N_2 = 1000 \text{ turns} \). How many turns does the primary loop have?

(e) Our transformer is sketched below – note that both sides have the same number of turns so as not to
suggest an answer for (d)! If at some time \( t_0 \) that the primary current \( I_1 \) is increasing and going to the
right as shown, then explain whether the induced current of the secondary, \( I_2 \), goes to the LEFT or to the
RIGHT.