1. Shown in the Figure below is a loop of wire that lies in a horizontal plane. You have a standard bar magnet that you will move either up or down and in the process either insert or remove it from the loop. This problem concentrates on knowing which way the current flows in the loop (i.e. all answers are either “clockwise” or “counter-clockwise”). Which way does the current flow if you:

(a) Insert the North end of the magnet into the loop from below.
(b) Insert the South end of the magnet into the loop from below.
(c) Insert the North end of the magnet into the loop from above.
(d) Insert the South end of the magnet into the loop from above.
(e) Remove the North end of the magnet from the loop from below.
(f) Remove the South end of the magnet from the loop from below.
(g) Remove the North end of the magnet from the loop from above.
(h) Remove the South end of the magnet from the loop from above.
2. A coil with 20 turns is placed in a magnetic field whose strength is 0.1 Tesla. The radius of the coil is 0.15 meters and it is turned with a frequency of $f=60$ Hz. This device is called a generator and produces an AC voltage. The output of the generator is fed into a transformer that has 100 turns on the input side and 400 turns on the output side. Finally, the output of the transformer is attached to a 15 $\Omega$ resistor.

(a) What is the peak voltage produced by the generator?
(b) What is the RMS voltage produced by the generator?
(c) What is the peak voltage produced on the output side of the transformer?
(d) What is the RMS voltage produced on the output side of the transformer?
(e) What is the peak current through the resistor?
(f) What is the RMS current through the resistor?
(g) What is the **AVERAGE** power dissipated by the resistor?
(h) What is the average torque required to keep the loop spinning?
3. Shown in the Figure below is a rectangular loop of dimensions 0.20 m by 0.30 m. The loop is partly filled with a magnetic field whose strength is 0.25 T and is directed into the page. The loop has a resistance of 3 Ω. You grab the loop and pull it to the right with a constant speed of 0.4 m/sec.

(a) Which way does the current flow (clockwise or counter-clockwise)?
(b) What is the voltage generated in the loop?
(c) What is the current in the loop?
(d) How much force is required to keep the loop moving at 0.4 m/s?
4. Shown in the figure below is the view from above of a sliding bar of resistance R and length L. The bar is free to slide along the rails without friction. The system is immersed in a magnetic field pointed out of the page (toward you). The bar is given an initial velocity \(v_0\) to the right. Answer all the following:

(a) Write an expression for the flux through the loop formed by the bar and wire slide for the moment when the bar’s position is \(x\).

(b) Using your result from (a) determine an expression for the voltage generated in the loop as a function of the bar’s velocity.

(c) Determine the current through the bar.

(d) Determine the force on the bar as a function of velocity.

(e) What direction is this force (justify your response).
5. A wire with radius $a$ carries a current $I$. The current is uniformly distributed throughout the wire.

(a) Use Ampere's Law to calculate the magnetic field in region i.
(b) Use Ampere's Law to calculate the magnetic field in region ii.
6. Shown in the figure below is a solenoid carrying a current I.

(a) Assume the solenoid is *very long* and then use Ampere's law to determine the magnetic field inside the solenoid.

(b) Calculate the field if this solenoid has 500 coils, is 0.2 meters long, and carries a current of 1 Ampere.

(c) Calculate the energy stored in the solenoid if its radius is 0.01 meters.
7. The circuit below begins with the switch in the open position and the capacitor carrying zero charge. The battery has $V_B = 10\, V$, the resistor has $R = 5\, k\Omega$, and the capacitor has $C = 12\, \mu F$. At time=0, the switch in the circuit is closed.

(a) Determine the time constant of this circuit.

(b) Draw sketches of the time dependence of each of the following:
   i. The voltage on the capacitor as a function of time, $V_C(t)$.
   ii. The charge on the capacitor as a function of time, $Q_C(t)$.
   iii. The voltage on the resistor as a function of time, $V_R(t)$.
   iv. The current through the resistor as a function of time.

To be correct for full credit the vertical axis of each sketch should be labelled with a numerical value indicating either the initial or asymptotic value of the quantity plotted.

(c) Write an equation for each of the following:
   i. The voltage on the capacitor as a function of time, $V_C(t)$.
   ii. The charge on the capacitor as a function of time, $Q_C(t)$.
   iii. The voltage on the resistor as a function of time, $V_R(t)$.
   iv. The current through the resistor as a function of time.

(d) At what time does the voltage on the capacitor reach 3 V?
8. The circuit below begins with the switch in the open position. The battery has $V_B = 8V$, the resistor has $R = 2k\Omega$, and the inductor has $L = 3mH$. At time=0, the switch in the circuit is closed.

(a) Determine the time constant of this circuit.

(b) Draw sketches of the time dependence of each of the following:
   i. The voltage on the inductor as a function of time, $V_L(t)$.
   ii. The voltage on the resistor as a function of time, $V_R(t)$.
   iii. The current through the resistor as a function of time, $I_R(t)$.

   To be counted for full credit the vertical axis of each sketch should be labelled with a **numerical value** indicating either the initial or asymptotic value of the quantity plotted.

(c) Write an equation for each of the following:
   i. The voltage on the inductor as a function of time, $V_L(t)$.
   ii. The voltage on the resistor as a function of time, $V_R(t)$.
   iii. The current through the resistor as a function of time, $I_R(t)$.

(d) At what time is the voltage on the inductor 3 V?
9. Shown below is an RL circuit driven by an AC power source.

(a) Draw a phasor diagram representing this circuit.
(b) Analyze your phasor diagram to determine the magnitude of the impedance, $|Z|$.
(c) Analyze your phasor diagram to determine the phase of the impedance, $\phi_Z$.
(d) Explain in a single sentence what the phase of the impedance means.
(e) Let the resistance be $R = 5k\Omega$, the inductance be $L = 3mH$ and the voltage source have a peak voltage, $V_{peak} = 10V$, at a frequency of $f = 5kHz$. Determine the peak current through the circuit.
(f) Determine the peak voltage across the inductor.
(g) If the voltage across the inductor is used to power another circuit, would this system be considered a high-pass or a low-pass filter? Explain.
10. Shown below is an RC circuit driven by an AC power source.

\[
\begin{array}{c}
\text{R} \\
V_p \\
\text{C}
\end{array}
\]

(a) Draw a phasor diagram representing this circuit.

(b) Determine the magnitude of the impedance, \(|\tilde{Z}|\).

(c) Determine the phase of the impedance, \(\phi_Z\).

(d) Explain in a single sentence what the phase of the impedance means.

(e) Let the resistance be \(R = 1.0k\Omega\), the capacitance be \(C = 0.5\mu F\) and the voltage source have an RMS voltage, \(V_{RMS} = 12V\), at a frequency of \(f = 300Hz\). Determine the RMS current through the circuit.

(f) Determine the RMS voltage across the capacitor.

(g) What circuit element would you add to this circuit (i.e. making a new circuit) such that the result was a resonant circuit with resonant frequency \(f = 30kHz\)? Please specify the type of circuit element (resistor, capacitor, or inductor) and the value (resistance, capacitance, or inductance) required.
11. The “middle” of the AM radio band is at roughly $f=1000$ kHz. The “middle” of the FM radio band is at roughly $f=100$ MHz. Determine the wavelength of each of these two radio stations.
12. You were outside your family spacecraft taking a leisurely spacewalk and your impetulant kid speed off into the cosmos leaving you just floating there, about 150 billion meters from the sun. At your location, the intensity of sunlight is roughly $1000 \text{ W/m}^2$ and the gravity is not completely zero, so you start to fall toward the sun. Even though it would take a long time to reach the sun, you are concerned that if your position changes a lot you’ll never be found.

So you take action:

(a) You calculate the average electric field of the light.
(b) You calculate the average magnetic field of the light.
(c) You calculate the pressure applied to a reflective solar sail.
(d) You calculate the size of a solar sail necessary to exactly balance the sun’s gravity.
(e) What do you write on the sail?

Oh, you and your space suit have a total mass of 100 kg and you happen to remember that the mass of the sun is $2 \times 10^{30}$ kg.
13. Shown in the figure below is a system containing an object, and two lenses. Use the shapes of the lenses in the figure to decide whether they are converging or diverging optical elements.

(a) Find the image location and magnification of the first lens (assuming that only this lens exists). Specify this image location, \( d_{i1} \), as some number of centimeters to the left or to the right of this lens.

(b) The image of the first lens acts as the object for the second. Find the location and magnification of the image produced by the second lens. Specify this image location, \( d_{i2} \), as some number of centimeters to the left or to the right of this lens.

(c) Calculate the total magnification of this entire system.

(d) Is the final image real or virtual?
14. Shown in the figure below is a system containing an object, a lens, and a mirror. This is a 3-pass system in that light goes from the object, through the lens, off the mirror, and back through the lens a second time. Use the shape of the objects in the figure to decide whether they are converging or diverging optical elements.

(a) Find the image location and magnification of the first lens (assuming that only this lens exists).

(b) The image of the first lens acts as the object for the mirror. Find the location and magnification of the image produced by the mirror.

(c) Lastly, the image from the mirror acts as the object for the light’s second pass through the lens. Find the location and magnification of the image produced in this step.

(d) Calculate the total magnification of this entire system. Is the final image real or virtual?
15. A particular person’s nearsighted eye has a near point of 12 cm and a far point of 17 cm. You will place a lens 2 cm in front of their eye. Answer all the following:

(a) Do you use a converging or diverging lens?
(b) What is the focal length of the chosen lens?
(c) What is this person’s new nearpoint?
16. Shown in the figure below is a water glass at two different moments. In the first moment (left figure) the water glass is empty and the light ray strikes the bottom corner as shown. In the second moment, the glass has been filled with water ($n=1.33$). As a result, the light ray has been bent.

(a) Determine the angle $\theta_1$ as shown in the left figure.
(b) Determine the angle $\theta_2$ as shown in the right figure.
(c) Determine the distance $x$ shown in the right figure.
17. As shown in the figure below, a small boy has lost his toy at the bottom of a pool ($n_{\text{water}} = 1.33$). When he shines his flashlight as shown, he can see the toy.

(a) What is the angle of incidence, $\theta_1$, of his light upon the water?
(b) What is the angle of refraction $\theta_2$?
(c) What is the distance from the water’s edge, $x$, to the lost toy?
18. Shown in the figure below is Young’s two-slit experiment. Monochromatic light of wavelength $\lambda = 0.633 \mu m$ comes in from the left and passes through the two (very narrow) slits. The result is a pattern of bright and dark bands visible on a screen 5 meters away from the two slits. **WARNING:** this drawing is not to scale.

(a) Determine the distance, $d$, between the two slits.
(b) If the light is changed to green light, $\lambda = 0.532$, the diffraction pattern will change. What is the location, $y$, of the first dark band using this light.
(c) Make a sketch of the diffraction pattern resulting from single slit interference.
19. A thin film of soap water \((n=1.33)\) appears green when lit from above. Calculate the thickness of the film if it appears green \((\lambda = 500 \text{ nm})\). Assume that this is the thinnest film that can produce green light.
20. Assume that three perfect polarizers are placed in sequence and receive incoming light from one side. The first polarizer has its optic axis oriented vertically. The second is oriented 30 degrees to one side of vertical. The third is oriented horizontally.

(a) What fraction of the incoming light gets through the first polarizer?
(b) What fraction of the incoming light gets through both the first and second polarizer?
(c) What fraction of the incoming light gets through the first, second, and third polarizers?
(d) How much light would get through if the second and third polarizers were exchanged?
(e) Which way are the polarizers in your sunglasses oriented. Explain why.
(f) Explain how polarizing glasses are used to view high quality 3D movies.