Planck's constant
\[ h = 6.626 \times 10^{-34} \text{ m}^2 \text{ kg/s} \]

Planck's constant x velocity of light
\[ hc = 1240 \text{ eV x nm} \]

Bohr radius \( a_o = 0.053 \text{ nm} \)

electron mass: \( 9.11 \times 10^{-31} \text{ kg} \)

electron \( c^2 = 511,000 \text{ eV} \)

Reduced Planck constant:
\[ \hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34} \text{ J s} \]

Speed of light in vacuum:
\[ c = 3 \times 10^8 \text{ m/s} \]

Permittivity of free space
\[ \varepsilon_o = 8.85 \times 10^{-12} \text{ C}^2 / \text{N m}^2 \]
\[ k = \frac{1}{4\pi\varepsilon_o} = 9 \times 10^9 \text{ N m}^2 / \text{C}^2 \]

Permeability of free space
\[ \mu_o = 4\pi \times 10^{-7} \text{ T m/A} \]

Magnitude of electron charge
\[ e = 1.6 \times 10^{-19} \text{ C} \]

Problem 1: _____ / 20
Problem 2: _____ / 20
Problem 3: _____ / 20
Problem 4: _____ / 20
Problem 5: _____ / 20
Problem 6: _____ / 10

TOTAL: _____ / 110
1) [20 points, 5 points each]. Explain your reasoning for full credit.

**Multiple choice/short answer questions.**

*i) How many turns of wire a solenoid needs to have to produce a uniform magnetic field of \(2.515 \times 10^{-4}\) T inside it if the current in the turns is 1 A and its length is 5 m? Explain.*

   a. 200  
   b. 1000  
   c. 10000  
   d. not calculable because the diameter of the solenoid is not given  
   e. 100

*ii) A bar magnet is dropped through the conducting loop as shown in the figure. Which is the direction of the induced current in the conducting loop (observed from the top) while the magnet is falling towards the loop and after it has passed through the loop and moves away from it? Explain.*

   a. Counterclockwise when the bar is approaching the loop and counterclockwise when it is falling away from the loop.  
   b. Clockwise when the bar is approaching the loop and counterclockwise when it is falling away from the loop.  
   c. Counterclockwise always.  
   d. Clockwise always.
iii) The light intensity incident on a metallic surface produces photoelectrons with a maximum kinetic energy of 4 eV. The light intensity is doubled. Determine the maximum kinetic energy of the photoelectrons (in eV):

a. 4  
b. 2  
c. \sqrt{2}  
d. 3  
e. it cannot be determined since the work function of the metallic surface is not given.

iv) The wavelength of a 45 kg boy moving at 5 m/s on a skateboard is about:

a. $5 \times 10^{-37}$ m  
b. $3 \times 10^{-36}$ m  
c. $7 \times 10^{-34}$ m  
d. 0.1 m

v) A hydrogen atom is in the $n=2$ excited state. What is the minimum energy needed to ionize the atom?

a. -13.6 eV  
b. -3.4 eV  
c. 3.4 eV  
d. 6.8 eV  
e. -6.8 eV
2) [20 pts, 4 pts each] Short answer.

i) Your Madison oldies radio station broadcasts at 94.9 MHz (1 MHz = 10^6 Hz). What is the wavelength?

\[ \lambda = \] 

ii) A light wave with right-handed circular polarization (looking as it comes toward you, as in the lab) is propagating in vacuum in the \( \hat{z} \) direction. It has a wavelength of 600 nm. At a particular instant in time \( t_0 \) its electric field vector points in the \( \hat{x} \) direction and has magnitude 10 V/m. What is the direction and magnitude of the electric field vector at a later time \( t_1 = t_0 + 5 \times 10^{-16} \) s?

\[ \vec{E} = \] 

iii) A particular metal has a work function of 1.5 eV. What is the maximum wavelength photon that will eject an electron from the metal?

\[ \lambda = \]
iv) An electron is accelerated through a potential difference of 25000 V. What is the de Broglie wavelength of the electron?

\[ \lambda = \text{Value} \quad \text{Units} \]

v) On a bright and sunny day, the intensity of solar radiation on the Earth’s surface is 1000 W/m². If the average wavelength of the sunlight is 500 nm, how many photons are incident on an area A =1 m² of the Earth’s surface per second?

\[ N = \text{Value} \]
3) [20 pts, 5 pts each] Three linear polarizers are arranged as shown, with transmission axes indicated by the thick solid line. The incoming light is **circularly polarized**, and propagating in the \( z \)-direction.

![Diagram of polarizers]

a) The incoming **circularly polarized light** has an electric field vector of magnitude \( E_o \). The electric field vector of the linearly-polarized light in region 1 has an oscillating electric field vector with amplitude (maximum value) of \( E_1 \). What is the ratio \( E_1 / E_o \)? Explain.

\[
E_1 / E_0 = \text{Value}
\]

b) What is the time-averaged power per unit area (intensity) of the incident circularly polarized wave in the case that \( E_o = 10 \, \text{V/m} \)?

\[
S_{ave} = \text{Value} \quad \text{Units}
\]
c) What is the ratio $E_3/E_1$ of the maximum value of the electric field in region 3 (this is the region to the right of the last polarizer) to that in region 1?

\[
E_3 / E_1 = \begin{array}{|c|c|} \hline \text{Value} & \text{Units} \\ \hline \end{array}
\]

\(E_3 / E_1 = \)

\[
\begin{array}{|c|c|} \hline \text{Value} & \text{Units} \\ \hline \end{array}
\]

\(d)\) What fraction of the intensity incident on polarizer 3 is absorbed?

\[
\begin{array}{|c|c|} \hline \text{Value} & \text{Units} \\ \hline \end{array}
\]
4) [20 pts, 5 pts each]
A rectangular coil with resistance $R = 10 \, \Omega$ has $N = 10$ turns each of length $\ell = 5 \, \text{cm}$ and width $w = 2 \, \text{cm}$ as shown in the figure below. The coil moves with constant velocity $v = 1 \, \text{cm/s}$ through a uniform magnetic field $B = 2 \, \text{T}$ entering the page. The magnetic field is $2 \, \text{T}$ only in the region shown, and is zero everywhere else.

A) What is the induced current in the coil as it enters the magnetic field region? Indicate its direction in the loop.
What are the magnitude and the direction of the total magnetic force on the coils:

B) force on the loop from the magnetic field as it enters the magnetic field region;

\[
\begin{array}{c}
\times \times \times \times \\
\times \times \times \\
\times \times \times \times \\
\times \times \times \times \\
\end{array}
\]

\[
W = 2\text{cm}
\]

\[
\ell = 5\text{cm}
\]

\[
F = \\
\begin{array}{c|c|c}
\text{Value} & \text{Units} & \text{Direction} \\
\hline
\end{array}
\]

C) force on the loop from the magnetic field as it moves within the field region;

\[
\begin{array}{c}
\times \times \times \times \\
\times \times \times \\
\times \times \times \\
\times \times \times \\
\end{array}
\]

\[
F = \\
\begin{array}{c|c|c}
\text{Value} & \text{Units} & \text{Direction} \\
\hline
\end{array}
\]
D)  force on the loop from the magnetic field as it leaves the field region.

\[ F = \begin{array}{c|c|c}
\text{Value} & \text{Units} & \text{Direction} \\
\hline
\end{array} \]
5) [20 pts, 5 pts each]
Consider an hydrogen atom with a nuclear charge $e$ and a single electron orbiting.
Answer these questions about the Bohr’s model on this atom:

A) Find the magnitude of the velocity of the electron in the circular orbit with $n = 2$
around the nucleus. [Hint: consider the attractive Coulomb force acting on the electron
due to the proton in the nucleus.]

B) Find the radius of this orbit.

\[
\begin{array}{c|c}
\text{Value} & \text{Units} \\
\hline
\end{array}
\]

$\nu =$

\[
\begin{array}{c|c}
\text{Value} & \text{Units} \\
\hline
\end{array}
\]

$r =$
C) Find the total energy of the electron in this orbit.

\[ E = \begin{array}{|c|c|} \hline \text{Value} & \text{Units} \\ \hline \end{array} \]

D) Find the wavelength of the photon emitted in the transition from the state with \( n_i = 4 \) to the one with \( n_f = 2 \).

\[ \lambda = \begin{array}{|c|c|} \hline \text{Value} & \text{Units} \\ \hline \end{array} \]