On the following problems show all your work. Partial credit will be given, if earned. Write your answers in the blanks provided.

12

(12 pts) 1.

a) The de Broglie wavelength of an electron is $6.00 \times 10^{-11}$ m. What is the momentum $p$ of a photon that has the same energy as the electron? Express your results in units of $\text{kg} \cdot \text{m/s}$.

Ans ________________

b) A photon of wavelength 0.01800 nm scatters from a free electron that is initially at rest. After the collision the linear momentum of the electron has magnitude $4.0 \times 10^{-23} \text{ kg} \cdot \text{m/s}$. What is the wavelength of the photon after it has scattered from the electron? (Note: The scattering angle $\phi$ is not $180^\circ$.)

Ans ________________
1. An object 6.0 mm tall is placed to the left of a convex mirror that has focal length \( f = -12.0 \text{ cm} \). The image is 2.0 mm tall.

a) Is the image upright or inverted?  
Ans ____________

b) Is the image to the left of the mirror or to the right of the mirror?  
Ans ____________

c) How far is the object from the mirror vertex?  
Ans ____________

(10 pts) 3. A long straight wire carries current \( I = 8.0 \text{ A} \) in the direction shown in the sketch. A small object with charge \( q \) is moving away from the wire with speed \( v = 3.0 \times 10^4 \text{ m/s} \). When the object is 0.200 m from the wire, the force on it is \( F = 5.0 \times 10^{-6} \text{ N} \), in the direction shown in the sketch.

a) What are the magnitude and direction of the magnetic field \( \vec{B} \) that is due to the wire at the location of the charged object?  
Ans \( B = \) ____________  
direction ____________

b) What is the value of \( q \)? Be sure to indicate whether \( q \) is positive or negative.  
Ans ____________
(12 pts) 4. Consider the capacitor network shown in the sketch. All three capacitors have attained their final charges. \( C_1 = 6.0 \times 10^{-9} \text{ F} \), \( C_2 = 3.0 \times 10^{-9} \text{ F} \) and \( C_3 = 4.0 \times 10^{-9} \text{ F} \). The voltage across capacitor \( C_1 \) is \( V_1 = 12.0 \text{ V} \). Calculate the following:

\[ \begin{align*}
\text{a) The charge } Q_1 \text{ on capacitor } C_1 & \\
\text{Ans } & \\
\text{b) The charge } Q_2 \text{ on capacitor } C_2 & \\
\text{Ans } & \\
\text{c) The voltage } V_3 \text{ on capacitor } C_3 & \\
\text{Ans } & \\
\text{d) The battery voltage } V & \\
\text{Ans } & 
\end{align*} \]
(10 pts) 5. A negative point charge \( q_1 = -5.0 \times 10^{-9} \) C is at the origin and a positive point charge \( q_2 = +8.0 \times 10^{-9} \) C is on the negative x-axis at \( x = -0.400 \) m. Point \( A \) is on the +x-axis at \( x = 0.200 \) m and point \( B \) is on the +x-axis at \( x = 0.300 \) m.

a) What are the magnitude and direction of the resultant electric field at point \( A \) produced by point charges \( q_1 \) and \( q_2 \)?

\[ \text{Ans } E = \quad \text{direction } \]

b) What is the total electric potential at point \( A \) produced by charges \( q_1 \) and \( q_2 \)?

\[ \text{Ans } \]

c) A third charge \( q_3 = -6.0 \times 10^{-4} \) C is placed at point \( A \). What is the direction of the net force exerted on \( q_3 \) by charges \( q_1 \) and \( q_2 \)?

\[ \text{Ans } \]

d) How much work does the resultant electric field of \( q_1 \) and \( q_2 \) do on charge \( q_3 \) when it moves on the x-axis from point \( A \) to point \( B \)? (Be sure to indicate whether the work is positive or negative.)

\[ \text{Ans } \]
(10 pts) 6. The circuit shown in the sketch consists of a battery with internal resistance \( r \), a resistor \( R = 6.00 \, \Omega \) and a switch. An ideal voltmeter \( V \) is connected to the terminals \( a \) and \( b \) of the battery. When the switch is open the voltmeter reads 4.22 V. When the switch is closed the voltmeter reads 4.08 V. Calculate

\[
\text{\begin{center}
\begin{tikzpicture}
\draw (0,0) -- (4,0) -- (4,1) -- (0,1) -- cycle;
\draw (0,0) -- (0,1);
\draw (4,0) -- (4,1);
\draw (2,0) -- (2,1);
\draw (1,0) -- (1,1);
\draw (3,0) -- (3,1);
\node at (0.5,0.5) {\text{Switch}};
\node at (1.5,0.5) {a};
\node at (2.5,0.5) {\text{\}}};
\node at (3.5,0.5) {b};
\node at (0.5,1.5) {V};
\node at (1.5,-0.5) {R};
\end{tikzpicture}
\end{center}
\]

a) the emf of the battery

\[ \text{Ans.} \quad \frac{4.22 - 4.08}{0.5} \]

b) the internal resistance \( r \) of the battery

\[ \text{Ans.} \quad \frac{4.22 - \frac{4.08}{2.0}}{0.5} \]

(8 pts) 7. Two radio antennas \( A \) and \( B \) emit electromagnetic waves in phase and with the same frequency \( f \). Antenna \( B \) is 6.0 m to the right of antenna \( A \). Point \( P \) is 2.0 m to the right of antenna \( B \). What is the smallest value of the frequency \( f \) for which the interference at point \( P \) is destructive?

\[
\text{\begin{center}
\begin{tikzpicture}
\draw (0,0) -- (4,0) -- (4,1) -- (0,1) -- cycle;
\draw (0,0) -- (0,1);
\draw (4,0) -- (4,1);
\draw (2,0) -- (2,1);
\draw (1,0) -- (1,1);
\draw (3,0) -- (3,1);
\node at (0.5,0.5) {A};
\node at (2.5,0.5) {B};
\node at (3.5,0.5) {P};
\node at (1.5,0) {6m};
\node at (2.5,0) {2m};
\end{tikzpicture}
\end{center}
\]

\[ \text{Ans} \quad \frac{6 - 2}{2} \]
8. In a series ac circuit, \( R = 300 \, \Omega \) and \( C = 4.00 \times 10^{-5} \, \text{F} \). There is no inductor. The angular frequency of the voltage source is 200 rad/s. The amplitude of the voltage across the capacitor is 400 V.

- a) What is the amplitude of the voltage across the resistor?
  Ans.

- b) What is the amplitude of the source voltage?
  Ans.

- c) Does the source voltage lead the current or does it lag the current?
  Ans.

- d) What is the average power provided to the circuit by the voltage source?
  Ans.
9. In the circuit shown in the sketch a conducting bar 0.20 m long slides toward the right on frictionless rails. The speed of the bar is \( v = 20.0 \, \text{m/s} \) and is constant. The 5.00 \( \Omega \) resistor is the only resistance in the circuit. There is a uniform magnetic field \( B = 0.400 \, \text{T} \) directed out of the page, as shown.

- a) Is the induced current in the circuit clockwise or counterclockwise? Ans. ______________

- b) What is the magnitude of the external force \( F_{\text{ext}} \) that must be applied to the bar to keep its speed constant?
  Ans. ______________

- c) What is the rate at which the external force \( F_{\text{ext}} \) does work on the bar? Ans. ______________