Physics 223&: Engineering Physics III Final Exam

Answer all questions clearly and completely. Show your work for full credit. Make sure to include units where appropriate. Each question is worth 10 pts. You have 3 hours to complete the exam.

1) Two point charges are placed in vacuum. A charge of +3.00 μC is located at the origin, and a charge of −2.00 μC is located at (0, 0.200) m.
   a) Determine the magnitude and direction of the force on the −2.00 μC charge.
   b) What is the magnitude of the electric field at the midpoint between the two charges?
   c) **Extra Credit:** Explain why the Coulomb is an impractical unit. Some possibly helpful quantities are that Sweden has a population of about 1.05×10^7 with the average mass of one of those people being 74kg.

2) A charged particle with charge −1.50 μC is placed in a uniform electric field of magnitude 2000 N/C pointing upward.
   a) Calculate the force acting on the particle.
   b) If the particle has a mass of 2.00 g, determine its acceleration.

3) A thin spherical shell with radius 0.10 m carries a total charge of 5.00 μC distributed uniformly on its surface.
   a) Using Gauss's Law, calculate the electric field at a point 0.05 m from the center of the shell.
   b) Calculate the electric field at a point 0.20 m from the center of the shell.

4) A parallel-plate capacitor has plates of area 2.00 m^2 separated by a distance of 0.010 m and is filled with a dielectric material with dielectric constant (i.e. relative permittivity) $\varepsilon = 5.00$.
   a) Determine the capacitance of the capacitor.
   b) If a potential difference of 500 V is applied across the plates, calculate the energy stored in the capacitor.

5) A proton is released from rest in a uniform electric field of magnitude $1.00 \times 10^6 \ \frac{N}{C}$ pointing to the right.
   a) Determine the work done on the proton as it moves 0.020 m in the direction of the field.
   b) Calculate the change in the proton's kinetic energy and its final velocity. The mass of the proton is $m_p = 1.67 \times 10^{-27} kg$.

6) A wire of resistivity $1.70 \times 10^{-8} \Omega m$ and cross-sectional area $1.00 \times 10^{-6} m^2$ carries a current of 3.00 A. The wire is 2.00 m long.
   a) Calculate the resistance of the wire.
   b) Determine the potential difference across the ends of the wire.
   c) Calculate the power dissipated in the wire. *Hint:* $P = I^2 R = \frac{V^2}{R}$.

7) A capacitor in an RC circuit has a capacitance of 4.00 μF and is charged to 10.0 V. The circuit has a resistance of 2.00 times 10^3 Ω.
   a) Determine the time constant of the circuit.
   b) Explain the physical significance of the time constant.
   c) Calculate the voltage across the capacitor 6.00 ms after the circuit begins discharging. *Hint:* $Q = CV$

8) A long straight wire carries a current of 10.0 A.
   a) Calculate the magnitude of the magnetic field at a distance of 0.05 m from the wire.
   b) If a second parallel wire is placed 0.05 m away and carries a current of 5.00 A in the opposite direction, calculate the force per unit length between the wires.

9) A rectangular loop of wire with dimensions 0.30 m by 0.20 m is placed in a magnetic field of strength 0.40 T. The field is perpendicular to the plane of the loop and increases at a rate of 0.50 T/s.
   a) Determine the emf induced in the loop.
   b) If the resistance of the loop is 2.00 Ω, calculate the induced current.

10) A resistor of 50.0 Ω, an inductor of 0.100 H, and a capacitor of 2.00 μF are connected in series to an AC source with a peak voltage of 120 V and a frequency of 60.0 Hz.
   a) Calculate the capacitive reactance, inductive reactance, and impedance of the circuit.
   b) Determine the current amplitude in the circuit.
   c) Find the phase difference between the voltage and the current. *Hint: How do you get the current from the charge?*

11) **Extra Credit:** A proton is moving at a speed of $2.00 \times 10^6 \ \frac{m}{s}$ in a region where both electric and magnetic fields are present. In the laboratory frame, the electric field is $\vec{E} = (0, 500, 0)$ N/C, and the magnetic field is $\vec{B} = (0, 0, 0.200)$ T. The laboratory observes the fields to be perpendicular to one another.

   The transformations of the fields into a moving reference frame are given by:

   $E'_{\parallel} = E_{\parallel},$

   $E'_{\perp} = \gamma\Big(E_{\perp} + \vec{v} \times \vec{B}\Big),$

   $B'_{\parallel} = B_{\parallel},$

   $B'_{\perp} = \gamma\Big(B_{\perp} - \big(\frac{1}{c^2}\big)\vec{v} \times \vec{E}\Big),$

   where $\gamma = 1/\sqrt{1 - v^2/c^2}$ is called the *Lorentz factor.*

   a) Transform the electric and magnetic fields into the proton's rest frame.
   b) Discuss how these transformations reveal the relationship between electric and magnetic fields in different reference frames.