PHY142 Spring 2012 Final Exam

Name:

You have 2.5 hrs to complete this exam. There are 8 questions worth a total of 200 points. You may consult three handwritten sheets of notes during the exam. All working and answers should be completed on the exam sheets. You may use the front and back sides of the paper for your answers. Partial credit will be given for answers which, while finally incorrect, contain sensible, legible, and physically correct working.

Some important (and not so important) constants:

Permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12} \text{m}^{-3}\text{kg}^{-1}\text{s}^{4}\text{A}^{2} \text{or Fm}^{-1}$

Permeability of free space $\mu_0 = 4\pi \times 10^{-7} \text{T m A}^{-1}$

Charge on a electron $e = 1.602 \times 10^{-19} \text{C}$

Speed of light $3.0 \times 10^{8} \text{ms}^{-1}$

Resistivity of copper $\rho_{Cu} = 1.68 \times 10^{-8} \Omega\text{m}$

Resistivity of germanium $\rho_{Ge} = 4.5 \times 10^{-1} \Omega\text{m}$

Resistivity to the Borg $\rho_{Borg} = \text{futile} \frac{4}{7} \Omega\text{m}$
Question 1. (25 points)

A insulating sphere of radius $r_1$ has a uniform charge density $\rho$, except for in the center of the sphere, where there is a spherical cavity of radius $r_0$ which contains no charge. Let $r$ be the distance of a point from the center of the sphere. Write your answers in terms of $\rho$, $r$, $r_1$, $r_0$ and $k$ or $\epsilon_0$.

(a) (5 points) What is the electric field $E(r)$ for points $r < r_0$?
(b) (5 points) What is the electric field $E(r)$ for points $r_0 \leq r < r_1$?
(c) (5 points) What is the electric field $E(r)$ for points $r \geq r_1$?

(d) (5 points) Draw a graph showing the electric field $E(r)$ against $r$. Make sure to label $r_0$ and $r_1$ on your sketch.

(e) (5 points) Draw a graph showing the potential $V(r)$ against $r$, taking the zero of potential to be $r = \infty$. Make sure to label $r_0$ and $r_1$ on your sketch.
**Question 2.** (25 points)

In the circuit shown the switch is initially in the top position so that there is a direct connection from the resistor network to the battery. In this configuration a steady current of 2 A flows from the battery on the left. You should consider the switch to be in the top position for all of (a)-(e). For (f) only the switch position is changed so that the direct connection is broken and replaced by a 1 µF capacitor. The bottom resistor, \( R \), is a square prism of germanium which is twice as long as it is wide.

(a) (4 points) How much current flows through the 36Ω resistor?

(b) (4 points) How much current flows through the 18Ω resistor?

(c) (4 points) How much current flows through the prism? What is the resistance of \( R \)?

(d) (4 points) Find \( d \), the width of the germanium prism, taking the resistivity of germanium as \( 4.5 \times 10^{-1} \) Ωm.

(e) (4 points) How much power is dissipated in the circuit when the switch is in the upright position?

(f) (5 points) The position of the switch is changed and the current flowing from the battery on the left is no longer a steady 2 A, but instead varies with time according to \( I = Ae^{-\frac{t}{\tau}} \). Find \( A \) and \( B \).
Question 3. (25 points)

In a co-axial cable a current density \( j_1 \) flows from left to right down a central wire of radius \( r_1 \) and a current density \( j_2 \) flows in the opposite direction down a hollow cylindrical conductor which has internal radius \( r_2 \) and external radius \( r_3 \).

(a) (5 points) Write an expression for the magnitude of the magnetic field for \( r < r_1 \) in terms of some or all of \( j_1, j_2, r_1, r_2, \) and \( r_3 \).

(b) (5 points) Write an expression for the magnitude of the magnetic field for \( r_1 \leq r < r_2 \) in terms of some or all of \( j_1, j_2, r_1, r_2, \) and \( r_3 \).

(c) (5 points) Write an expression for the magnitude of the magnetic field for \( r_2 \leq r < r_3 \) in terms of some or all of \( j_1, j_2, r_1, r_2, \) and \( r_3 \).

(d) (5 points) If there is no magnetic field outside the coaxial cable write an expression for \( j_2 \) in terms of \( j_1, r_1, r_2, \) and \( r_3 \).

(e) (5 points) Draw a graph showing the magnitude of the magnetic field \( B(r) \) against \( r \) for the case considered in (d) where there is no magnetic field outside the cable. Make sure to label \( r_1, r_2 \) and \( r_3 \) on your sketch.
Question 4. (25 points)

(a) (7 points) A 100 turn solenoid of length 5 cm and radius 3 cm is connected to an AC power supply which supplies a voltage of 220V at a frequency of 50 Hz. If the solenoid has a 50 Ω resistance find the magnitude of the magnetic field produced by the solenoid in its center as a function of time.

(b) (7 points) A closed circular loop of radius 5 cm encloses the solenoid. Find the magnitude of the induced emf in the loop as a function of time.

(c) (7 points) If the loop has a resistance of 10 Ω find the magnitude of the magnetic field it produces at its center as a function of time.

(d) (4 points) If I cut the loop so it is no longer closed will the induced emf change? Will the magnetic field the loop produces change? Explain.
**Question 5.** (25 points)

A crab hunter is hunting crabs from his boat using a rifle with a laser scope. The depth of the water is 10m and it’s refractive index is $n = 1.33$.

(a) (5 points) How deep does the water appear to be to the hunter (looking straight down)?

(b) (4 points) If the wavelength of the laser light in air is 650nm, what is it’s wavelength in the water?

(c) (4 points) What is the speed of the light in the water?

(d) (4 points) What is the frequency of the light in the water?

(e) (8 points) If the angle that the hunter needs to shoot the crab from is $20^\circ$ to the normal of the water surface, how far away from the crab should the laser spot on the sea floor be for the bullet to hit the crab?
(a) (5 points) Draw a ray diagram showing the image that would be formed to the right of the converging lens if the diverging lens was not present.

(b) (5 points) Use the image generated by the converging lens, (which you drew in (a)), as the object for the diverging lens and draw a ray diagram showing how a real image is formed to the right of the diverging lens.

Use the lens equation for the following two questions (ie. do not try to measure from your sketch which is not precisely to scale).

(c) (5 points) If the distance of the original object from the converging lens is 10cm and the focal length of the converging lens is 5 cm find the distance of the image in part (a) from the converging lens.

(d) (10 points) If the diverging lens is placed 5cm to the right of the converging lens and the final image is seen 7.5 cm to the right of the diverging lens what is the focal length of the diverging lens? What is the magnification of the final image with respect to the original object?
The light pattern above was obtained by shining laser light through a double slit. The slits had a separation of 0.1mm and were a distance of 0.85m from the wall on which the pattern was obtained. For the following questions use the scale shown below the pattern to measure the distance between features in the light pattern. You may use the small angle approximation in your calculations. Use the scale shown below the pattern to determine the positions of features in the pattern.

(a) (10 points) From the positions of the interference maxima calculate the wavelength of the light. Calculate the uncertainty in your value based on an estimate of the uncertainty in your measurement of the fringe positions. Try to choose a method of measurement which gives you as accurate a value as possible and say a few words about why you chose that approach.

(b) (10 points) Find the width of the slits. Include an estimate of the uncertainty in your value. Try to choose a method of measurement which gives you as accurate a value as possible and say a few words about why you chose that approach.

(c) (5 points) Make some suggestions for how the experimental setup could be modified to improve the accuracy of your values.
Question 8. (25 points)

Write a brief explanation of one of the following. You may use diagrams and equations to assist your explanation.

(a) Why AC electricity is preferred over DC electricity for long range power transmission.
(b) The difference between ferromagnets, paramagnets and diamagnets.
(c) Resonance in an LRC series circuit.
(d) How Maxwell’s equations predict the existence of electromagnetic waves.
(e) How a third polarizer inserted between two crossed polarizers allows some light to pass through.