Please attempt ALL problems.

This is a “closed-book” examination.

You may NOT use your notes, nor any textbooks.

You must work independently. NO collaboration is allowed.

You may ask Dr. Curtright questions, however, especially if you think something is unclearly stated.

GOOD LUCK !!

“On my honor, I have neither received nor given aid on this exam.”

Name: _____________________________________________

Signature: __________________________________________

ID #: _____________________________________________
Multiple choice total score (60 possible, 10 questions, 6 points each):

Essay problem scores (40 possible, 1 question):

Exam total score (100 possible):

Please Note: In all of the following, vectors are indicated either by bold letters or else by letters with arrows (for example \( \vec{r} \)). Unit vectors along the \( x \), \( y \), and \( z \) axes are denoted by \( \mathbf{e}_x \), \( \mathbf{e}_y \), and \( \mathbf{e}_z \), respectively. A unit vector pointing radially away from the origin is denoted by \( \mathbf{e}_r \).
“Essay” Problem. Show all your work on this problem. A copper conducting sphere of radius \( a \) carries a charge \(-Q\). Let the variable \( r \) measure distance from the center of this sphere. This conducting sphere is surrounded by a concentric spherical shell of radius \( b \), as shown in the Figure below. The shell carries a total charge of \(+Q\) spread uniformly on it.

(a) Sketch a few electric field lines for this distribution of charge, clearly indicating the direction of \( \mathbf{E} \) and whether the lines spread or perhaps start and stop.

(b) In terms of the strength of the electric field \( E(r) \) at a distance \( r \) from the center of the solid sphere, calculate the flux through an imaginary concentric spherical shell (not shown in the Figure) of radius \( r \).

(c) How much charge \( Q_{\text{inside}} \) is inside the imaginary shell for all three cases: \( r < a \), \( a < r < b \), and \( b < r \)?

(d) Use Gauss’ law and your answers to (b) and (c) to determine \( E(r) \) for all three cases: \( r < a \), \( a < r < b \), and \( b < r \).

Recall the volume of a sphere of radius \( R \) is \( 4\pi R^3/3 \), and the surface area is \( 4\pi R^2 \).
(extra page for essay problem)
Multiple Choice Questions  
Circle or underline the correct answer.

Sometimes by accident or by design, none of the given answers may be correct. If you believe that to be the case, you should write-in what you believe to be the correct answer.

[1] Three equal positive point charges, \( Q \) Coulombs each, are located on the corners of an equilateral triangle, each of whose sides is of length \( L \). The magnitude of the force on each charge due to the other two charges is \( 8 \) Newtons. What will be the magnitude of the force if all the sides of the triangle are doubled in length?

- (a) 2 Newtons
- (b) 4 Newtons
- (c) 8 Newtons
- (d) 16 Newtons
- (e) There’s no way to figure this out unless \( Q \) and \( L \) are given!

[2] Two charged parallel metal plates, inside the evacuated tube of a television, are separated by 1.00 cm and have a potential difference of 1000 volts. An electron is released at rest from the negative plate and accelerates towards the positive plate. What will the electron’s kinetic energy be when it reaches the positive plate?

- (a) 1000 volts
- (b) \(-1.6 \times 10^{-16}\) Joules
- (c) \(1.6 \times 10^{-16}\) Joules
- (d) \(1.6 \times 10^{-19}\) Joules
- (e) \(-1.6 \times 10^{-19}\) Joules

[3] A copper wire (with resistivity \( \rho = 1.7 \times 10^{-8} \) Ohm-meters) is 74 meters long. If the total resistance of the wire is 1.60 Ohms, what is the radius of the wire?

- (a) 0.5 mm
- (b) 1.0 mm
- (c) 2.0 mm
- (d) 1.6 mm
- (e) 4.0 mm

[4] Determine the power dissipated in the top-most resistor in the circuit shown below.

\[ \text{6 volts} \]

- (a) 0 Watts
- (b) 6 Watts
- (c) 9 Watts
- (d) 12 Watts
- (e) 24 Watts
[5] A 6.00 $\mu$F capacitor is charged up to 12.0 Volts. Then (at $t = 0$) it is connected at each end to a 10.0 $M\Omega$ resistor. How long does it take for the charge on the capacitor to drop to 36.0 $\mu$C?

(a) It never drops to that value!
(b) 1.00 seconds
(c) 86.6 seconds
(d) 41.6 seconds
(e) 60.0 seconds

[6] In the Figure above, the current in the long, straight wire is $I_1$ and the wire lies in the plane of the rectangular loop which carries current $I_2$. What is the magnitude and direction of the net force exerted on the loop by the magnetic field created by the wire?

(1) $\mu_0 I_1 I_2 \left( \frac{1}{2\pi c} + \frac{1}{2\pi(a+c)} \right) \vec{F}_{\text{right}}$
(2) $\mu_0 I_1 I_2 \left( \frac{1}{2\pi c} + \frac{1}{2\pi(a+c)} \right) \vec{F}_{\text{left}}$
(3) $\mu_0 I_1 I_2 \left( \frac{1}{2\pi c} - \frac{1}{2\pi(a+c)} \right) \vec{F}_{\text{left}}$
(4) $\mu_0 I_1 I_2 \left( \frac{1}{2\pi c} - \frac{1}{2\pi(a+c)} \right) \vec{F}_{\text{right}}$
(5) $\mu_0 I_1 I_2 \left( \frac{1}{2\pi c} - \frac{1}{2\pi(a+c)} \right) \vec{F}_{\text{right}}$
[7] A conducting bar of length 1.0 meters is being moved at a constant velocity of 5.0 meters/sec from left to right on a track by an external force of 1.0 Newtons as shown in the Figure. A uniform magnetic field of strength 1.0 Tesla is directed out of the plane of the track and bar as shown. The bar makes good electrical contact with the tracks on which it slides without friction. A current of 1.0 Ampere is observed to flow through a resistor at the end of the track. The track, bar, and resistor form a closed circuit. Neglect the electrical resistance of the bar and of the track. What is the resistance $R$ of the resistor (in Ohms)?

(1) 5 \hspace{1cm} (2) 1 \hspace{1cm} (3) 2 \hspace{1cm} (4) 0 \hspace{1cm} (5) 10

[8] A powerful electromagnet has a field of 1.6 Tesla and a cross-sectional area of 0.20 m$^2$. If we wrap around the electromagnet a coil of (insulated!) wire having 100 turns and a total resistance of 10 $\Omega$, and then turn on the power to the electromagnet in 20 ms, what is the current induced in the coil?

(1) 80 A \hspace{1cm} (2) 160 A \hspace{1cm} (3) 80 mA \hspace{1cm} (4) 160 mA \hspace{1cm} (5) 1600 A

[9] A capacitor $C$ is connected to a power supply that applies a voltage $V(t) = \sqrt{2}V_{rms} \sin(\omega t)$. What is the charge $Q(t)$ on the capacitor plates as a function of time $t$?

(1) $Q(t) = CV_{rms}$
(2) $Q(t) = 0$
(3) $Q(t) = CV_{rms} \sin(\omega t) / \sqrt{2}$
(4) $Q(t) = \sqrt{2} (V_{rms}/C) \sin(\omega t)$
(5) $Q(t) = \sqrt{2}CV_{rms} \sin(\omega t)$

[10] A 10.0 mH inductor carries a current $I = I_{max} \sin(\omega t)$ with $I_{max} = 5.00$ A and $\omega / (2\pi) = 60.0$ Hz. What is the back emf in the inductor as a function of time (in volts, of course)?

(1) $9.4 \cos(377t)$
(2) $9.4 \sin(377t)$
(3) $18.8 \cos(377t)$
(4) $1.5 \cos(60t)$
(5) $3.0 \sin(60t)$