Final Exam : Physics 2113 Fall 2014

5:30PM MON 8 DEC 2014

Name (Last, First): KEY

Section #________________

Instructor's name:________________________________

Answer all 6 problems & all 8 questions.

Be sure to write your name. Please read the questions carefully.

You may use only scientific or graphing calculators. *In particular you may not use the calculator app on your phone or tablet!*

You may detach and use the formula sheet provided at the back of this test. No other reference materials are allowed.

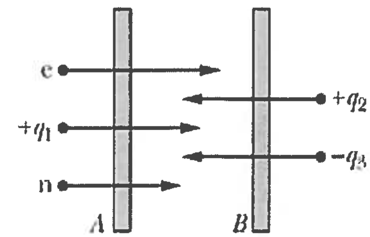
You may not answer or use cell phones during the exam. Please note that the official departmental policy for exams is as follows: "During your test, the only electronic device you may have with you at your seat is a scientific or graphing calculator. You may not have your cell phone, tablet, smartphone, PDA, pager, digital camera, computer, or any other device capable of taking pictures or video, sending text messages, or accessing the Internet. This means not just on your person, but close enough to you that you could reach it during the test. Any student found with such a device during a test will be assumed to be violating the LSU Honor Code and will be referred to the Dean of Students for Judicial Affairs." The simplest remedy is to bring nothing to this test but the calculator, and leave your backpack or purse at home. *If you have brought your cell phone or tablet with you, please leave it at the front of the room under the watchful eye of your instructor.*

Some questions are multiple choice. You should work these problems starting with the basic equation listed on the formula sheet and write down all the steps. Although the work will not be graded, this will help you make the correct choice and to determine if your thinking is correct.

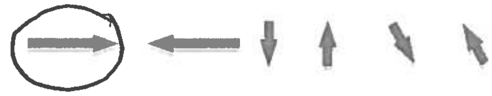
On problems that are not multiple choice, be sure to show all of your work since no credit will be given for an answer without explanation or work. These will be graded in full, and you are expected to **show all relevant steps that lead to your answer**.
Please use complete sentences where explanations are asked for. For numerical answers that require units you must give the correct units for full credit.

YOU GET 120 min (2 hrs)

1.(Question) **[10 points]** In the figure, an electron e travels through a small hole in plate A and then toward plate B. A uniform electric field in the region between the plates then slows the electron without deflecting it. $\Rightarrow \vec{E}$ is $\rightarrow$



(a)[2 points] What is the direction of the electric field?



Four other particles similarly travel through small holes in either plate A or plate B and then into the region between the plates. Three have charges $+q_1$, $+q_2$, and $-q_3$. The fourth (labeled n) is a neutron, which is electrically neutral.

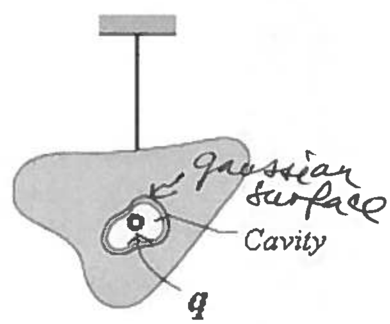
(b)[8 points] Does the speed of each of those four other particles, in the region between the plates (circle the correct answer):

$\vec{a} = \frac{\vec{F}}{m} = \frac{q}{m}\vec{E}$ · if $\vec{v}$ and $\vec{a}$ have the same dir $\rightarrow$ speeding up

· if $\vec{a}$ and $\vec{v}$ have opposite direction $\rightarrow$ slowing down

(i)	$+q_1$	increase	decrease	or remain the same
(ii)	$+q_2$	increase	decrease	or remain the same
(iii)	$-q_3$	increase	decrease	or remain the same
(iv)	n	increase	decrease	or remain the same

2.(Question) **[10 points]** An isolated conductor of arbitrary shape has no net charge. Inside the conductor is a cavity within which is a point charge $q = +3.1 \times 10^{-6}$ C.



(a) [5 points] What is the **charge on the cavity wall**?

$q_{induced} = -q$

(i)+3.10 x 10^{-6} C (ii) +1.0 x 10^{-5} C (iii) -3.10 x 10^{-6} C (iv) -1.0 x 10^{-5} C (v) 0 C

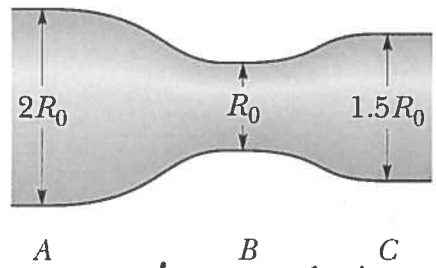
$0 = \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0} = \frac{1}{\varepsilon_0}(q + q_{induced}) \Rightarrow q_{ind} = -q$

(b) [5 points] What is **the charge on the outer surface** of the conductor?

$q_{outer} = q \; (= -q_{induced}) \; \because$ total charge on the conductor $= 0$

(i)+3.10 x 10^{-6} C (ii) +1.0 x 10^{-5} C (iii) -3.10 x 10^{-6} C (iv) -1.0 x 10^{-5} C (v) +1.31x10^{-5} C

3. (Question) **[10 points]** In the figure to the right, a wire that carries a current consists of three sections of the same material but with different radii.



Rank the sections according to the following quantities, **greatest** first:

a) [5 points] current, i, steady-state conditions: i = const throughout the wire (the same)

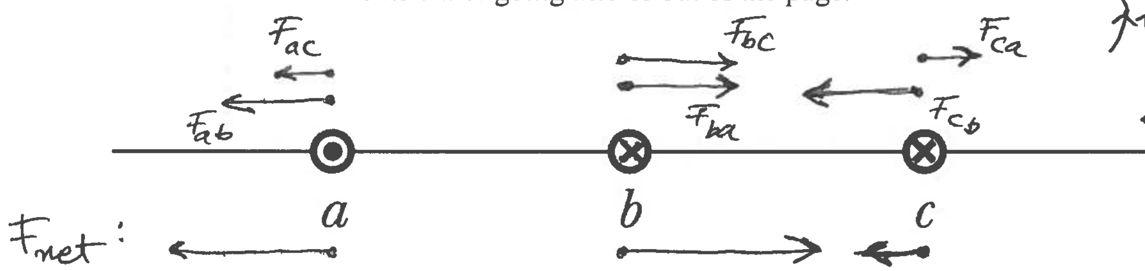
(i) $i_B > i_A > i_C$ (ii) $i_A > i_B = i_C$ (iii) $i_B > i_C > i_A$ (iv) $i_A = i_B = i_C$ (v) $i_C > i_B > i_A$

b) [5 points] magnitude of current density, J, $|\vec{J}| = \frac{i}{A}$ ... for a constant current

(i) $J_B > J_A > J_C$ (ii) $J_A > J_B = J_C$ (iii) $J_B > J_C > J_A$ (iv) $J_A = J_B = J_C$ (v) $J_C > J_B > J_A$

$A = \pi R^2 \Rightarrow |\vec{J}| \propto \frac{1}{R^2}$

4.(Question) **[10 points]** The figure below shows three long straight, parallel, equally spaced wires with identical currents either going into or out of the page.



• parallel attract
• opposite repel

(a) [5 points] Rank the wires according to the **magnitude of the force** on each due to the currents in the other two wires, **greatest** first.

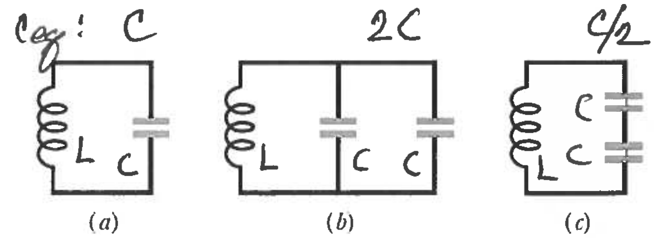
(i) $F_a > F_b > F_c$ (ii) $F_c > F_b > F_a$ (iii) $F_a > F_c = F_b$ (iv) $F_b > F_a > F_c$ (v) $F_a = F_b > F_c$

(b) [5 points] What is the direction of the net force on current a due to the currents in the other two wires?

(i) ← (ii) → (iii) ↑ (iv) ↓ (v) ⊙ (vi) ⊗

see the figure

5.(Question) **[10 points]** The figure to the right shows three oscillating LC circuits with identical inductors and capacitors.



$t \propto T = \frac{2\pi}{\omega} = 2\pi\sqrt{LC_{eq}} \propto \sqrt{C_{eq}}$

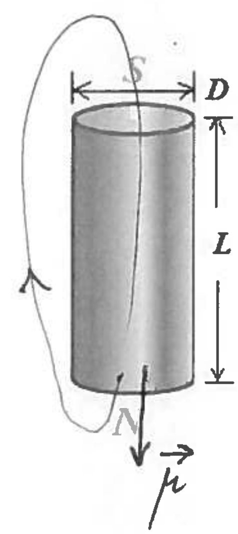
a) [5 points] **Rank** the circuits according to the **time** taken to fully discharge the capacitors during the oscillations, **greatest** first.

time $\propto \sqrt{C_{eq}} \Rightarrow$ b > a > c

b) [5 points] **Rank** the circuits according to the **angular frequency** of the oscillations, **greatest** first.

$\omega = \frac{2\pi}{T} \propto \frac{1}{T} \Rightarrow$ c > a > b

6.(Question) **[10 points]** A magnet, shown in the figure to the right, is in the form of a cylindrical rod. It has a length L = 5.30 cm and a diameter D = 1.00 cm. It has a uniform magnetization of 4.70×10^3 A/m. Circle the correct answer below. $M = 4.7\times10^3 \frac{A}{m}$



(a) [5 points] What is the magnitude of its **magnetic dipole moment**?

(i) 0.0196 J/T (ii) 1.2 J/T (iii) 0.038 J/T (iv) 0.001 J/T

$M = \frac{\mu}{\text{volume}} = \frac{\mu}{\pi \frac{D^2}{4} L} \Rightarrow \mu = M\frac{\pi D^2 L}{4} = \frac{4.7\times10^3 \pi (10^{-2})^2 (0.053)}{4}$

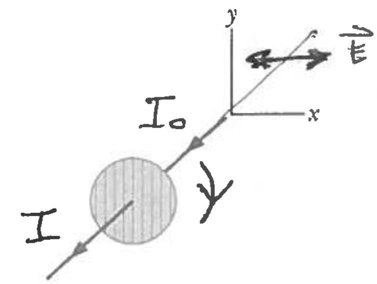
$= 0.0196$ J/T

(b) [5 points] What is the **direction** of its magnetic moment?

(i) Into the page, ⊗ (ii) Out of the page, ⊙ (iii) Down, ↓ (iv) Up, ↑

• magnetic field lines: from N → S outside of the magnet
$\Rightarrow \vec{\mu}$ is ↓ (along the magnetic field line through the center)

7.(Question) **[10 points]** The figure shows light reaching a polarizing sheet whose polarizing direction is parallel to the y axis. We shall rotate the polarizing sheet 40° clockwise about the light's indicated line of travel. During this rotation, does the fraction of the initial light intensity passed by the polarizing sheet increase, decrease, or remain the same if it is initially polarized as follows? (Select all that apply.)



(a) [5 points] unpolarized:

Increases   decreases   remains the same

$I = \frac{I_o}{2}$ regardless of the angle!

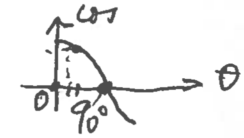
(b) [5 points] polarized parallel to the x axis:

Increases   decreases   remains the same

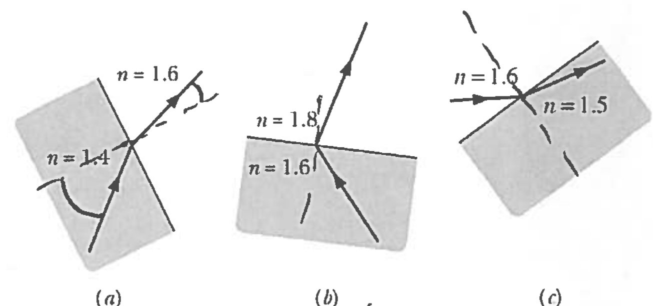
$I = I_o \cos^2\theta_{rel}$

$\theta_{rel,i} = 90°$, θ_{rel} changes from $90° \to 50°$

as θ_{rel} changes from $90° \to 50°$ I increases!



8.(Question) **[9 points]** Consider the figure to the right. **Circle** either True or False.



(a) [3 points] The drawing in part (a) is a physically possible refraction. True or False?

$n = 1.4$ has larger angle!

Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\Rightarrow$ smaller n, larger θ

and vice versa

(b) [3 points] The drawing in part (b) is a physically possible refraction. True or false?

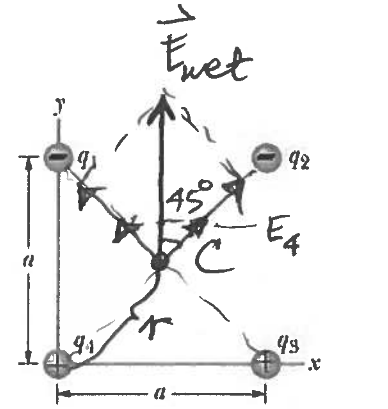
the incoming and reflecting rays cannot be on the same side of the normal

(c) [3 points] The drawing in part (c) is a physically possible refraction. True or false?

$n = 1.5$ has larger θ!

9. Problem **[20 points]** Figure to the right shows an arrangement of four charged particles at the corners of a square. Use that $|q_1| = |q_2| = |q_3| = |q_4| = 2.0 \times 10^{-10} C$, q_1 and q_2 are negative and q_3 and q_4 are positive, and $a = 20$ cm.

$a = 0.2\,m$



(a) [4 points] **Find** the **electric potential** in the center of the square. Show your work to clarify how you arrived at your answer.

$V = \sum V_i = 0$ ... 2 positive and 2 negative charges, at the same distances from the center, same charge magnitudes

$V_i = k \dfrac{q_i}{\frac{a\sqrt{2}}{2}}$ $\quad r = \frac{1}{2} a\sqrt{2}, \; r^2 = \dfrac{a^2}{2}$

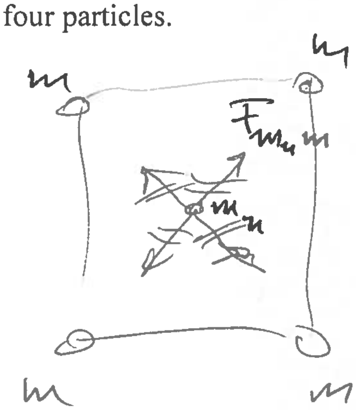
(b) [4 points] **Draw** the direction of **net electric field** in the center of the square and **label** it.

(c) [8 points] **Calculate** the **magnitude of the net electric field** in the center of the square.

$|\vec{E}_{net}| = 4|\vec{E}_4| \cos 45° = 4 k \dfrac{|q|}{r^2} \cos 45° = 4(8.99 \times 10^9) \dfrac{2\times10^{-10}}{0.2^2} 2 \cos 45°$

$|\vec{E}_{net}| = 254 \dfrac{V}{m}$

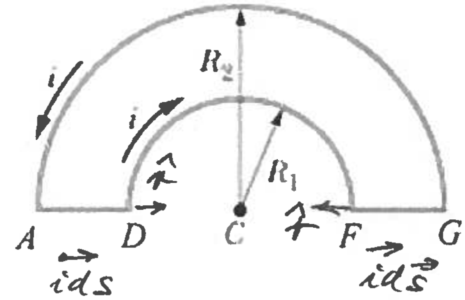
(d) [4 points] All of the four particles in the figure above have mass $m = 0.05$ kg. Now, in addition, assume a neutron in the center of the square ($m_n = 1.68\text{x}10^{-27}$ kg and zero charge).
Calculate the net **gravitational force on the neutron**, due to the other four particles.
NOTE: Only gravitational forces are important now.



The four gravitational forces have the same magnitude and they cancel each other

$\Rightarrow |\vec{F}_{net, q_{neutron}}| = 0$

10. (Problem) **[20 points]** As shown in the figure to the right, two semicircular arcs of radii $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ form part of the circuit ***ADFGA*** carrying current ***i***.



a) [7 points] **Find** an expression for the magnetic field at point C, which is the common center of the semicircular arcs, due to the two straight segments ***AD*** and ***FG***. Explain your answer.

$|\vec{B}(C)| = 0$ because $i d\vec{s}$ and $\hat{r}$ are either in the same or opposite directions along AD and FG $\Rightarrow \sin 0^\circ = \sin 180^\circ = 0$

$d\vec{B} = \dfrac{\mu_0 \, i \, d\vec{s} \times \hat{r}}{4\pi r^2}$, $\quad d\vec{s} \times \hat{r} = ds \sin \theta_{i d\vec{s}, \hat{r}}$ ... Biot-Savart law

b) [7 points] **Derive** an expression for the magnitude of the magnetic field at point C due to the complete circuit ***ADFGA***. Express your answers in terms of $\boldsymbol{R_1}$, $\boldsymbol{R_2}$, $\boldsymbol{i}$, and any constants as needed.

$B = \dfrac{\mu_0 i \phi}{4\pi r}$ ... circular arc, ϕ = opening angle

$R_2 > R_1 \Rightarrow |\vec{B}_2| < |\vec{B}_1|$, $\quad \phi = \pi$

$$|\vec{B}_{net}| = |\vec{B}_1| - |\vec{B}_2| = \frac{\mu_0 i}{4}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

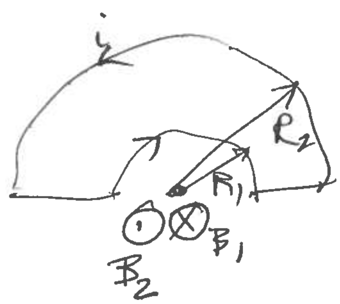
c) [6 points] What is the **direction** of the magnetic field at point C? Explain your choice.

RHR: thumb ≡ dir of i, fingers = direction of $\vec{B}$

$\vec{B}_1$ is ⊗, $\vec{B}_2$ is ⊙

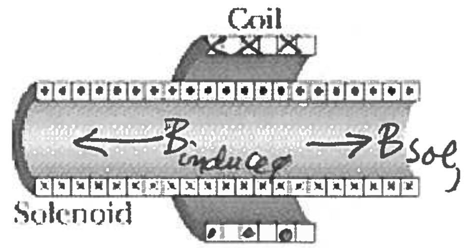
$|\vec{B}_1| > |\vec{B}_2|$

$\Rightarrow \vec{B}_{net}$ is into the page or ⊗



⊗ B_{net}

11.(Problem) **[20 points]** In the figure to the right a 20 turn coil of radius 4.0 cm and resistance 10 Ω is coaxial with a solenoid with 5000 turns/m and radius 2.0 cm. The current in the solenoid increases linearly from 0 A to 50 A in a time interval $\Delta t = 15$ ms. $= 0.015\,s$



a) [4 points] **Calculate** the magnitude of the magnetic field in the interior of the solenoid at the end of the 15 ms interval.

$N_{coil} = 20$
$Radius_c = 4cm$
$R = 10\Omega$

$$B = \mu_0 n i = (4\pi\times10^{-7})(5000)(50) = 0.314\ T$$

B is a homogeneous field inside $\Rightarrow \phi = BA$ $\left(= \int \vec{B}\cdot d\vec{A}\ \text{in general}\right)$

b) [5 points] **Calculate** how much magnetic flux (magnitude) does the current in the solenoid produce, within the interior of the coil, at the end of the 15 ms interval.

$$\phi = B_s A_s = B_s \pi (Radius)_s^2 = (0.314)\pi(0.02)^2 = 3.95\times10^{-4}\ Wb$$

c) [6 points] **Calculate** how much current (magnitude) is induced in the coil during the 15 ms interval.

$$i = \left|\frac{\mathcal{E}_{ind}}{R}\right| = \frac{1}{R}\left(N_{coil}\frac{\Delta\phi}{\Delta t}\right) = \frac{N_{coil}}{R\Delta t}\left(\phi_f - \cancel{\phi_i}^{\,0}\right) = \frac{20\,(3.95\times10^{-4})}{10(0.015)}$$

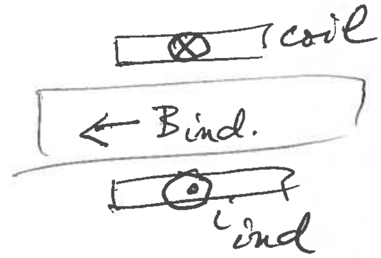
$$\left(\frac{\Delta\phi}{\Delta t}\right)_{coil} = \left(\frac{\Delta\phi}{\Delta t}\right)_{solenoid}$$

$$i = 5.26\times10^{-2} A = 52.6\ mA$$

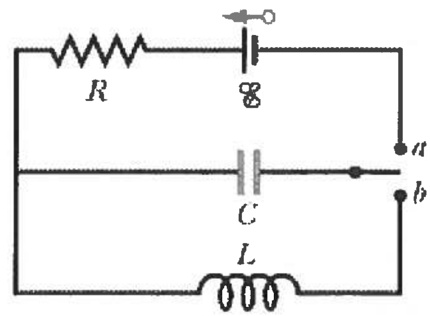
d) [5 points] **Indicate the direction** of the current which is induced in the windings of the coil on the picture. Make sure to show the direction on both top and bottom part of the coil. Explain the reason for your choice.

current increases $\Rightarrow B_{solenoid}$ increases $\rightarrow$ and $\Rightarrow B_{induced}$ opposite dir $\Rightarrow \leftarrow$

RHR: thumb $= B_{ind}$, i_{ind} = fingers



12. (Problem) **[20 points]** In the figure to the right, $\boldsymbol{R} = 14.0\ \Omega$, $\boldsymbol{C} = 6.60\ \mu F$, $\boldsymbol{L} = 54.0$ mH, and the ideal battery has emf $\mathcal{E} = 34.0$ V. The switch is thrown to position ***a***, kept in position ***a*** for a long time, and then thrown to position ***b***.



(a) [5 points] **Calculate** the initial current through the resistor just after the switch is thrown to position ***a***.

$$i_i = i_{max} = \frac{\mathcal{E}}{R} = \frac{34}{14} = 2.43\ A$$

$C = 6.6\times10^{-6}\ F$
$L = 0.054\ H$
$R = 14\ \Omega$
$\mathcal{E} = 34\ V$

(b) [5 points] **Calculate** the charge on the capacitor after the switch is on position ***a*** for a long time.

$$q_{max} = Q = C\mathcal{E} = (6.6\times10^{-6})(34) = 2.24\times10^{-4}\ C$$

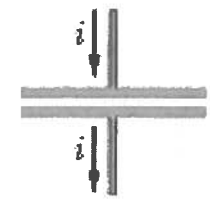
(c) [5 points] **Calculate** the angular frequency of the LC oscillations after the switch is thrown from ***a*** to ***b***.

$$\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(0.054)(6.6\times10^{-6})}} = 1.675\times10^{3}\ \frac{rad}{s} = 1675\ \frac{rad}{s}$$

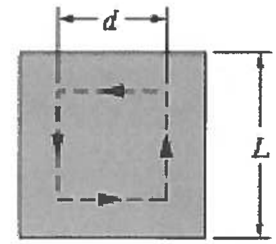
(d) [5 points] **Calculate** the amplitude of the oscillations of the current.

$$I = Q\omega = (2.24\times10^{-4})(1675) = 0.375 A$$

13. (Problem) **[21 points]** In the figure to the right, a parallel-plate capacitor has square plates of edge length L =1.4 m. A current of 2.0 A charges the capacitor, producing a **uniform** electric field **perpendicular** to the plates.



Edge view



Top view

(a) [4 points] **What** is the displacement current i_d through the whole region between the plates?

$$i_d = i = 2.0\,A$$

(b) [6 points] **Calculate** dE/dt in this region.

$$i_d = \varepsilon_0 \frac{d\Phi_E}{dt} = \varepsilon_0 A \frac{dE}{dt}, \quad A = L^2, \quad \vec{E} \text{ is homogeneous}$$

$$\Rightarrow \Phi_E = \int \vec{E} \cdot d\vec{A} = EA$$

$$\frac{dE}{dt} = \frac{i_d}{\varepsilon_0 L^2} = \frac{2.0}{(8.85\times10^{-12})(1.4)^2} = 1.15\times10^{11}\,\frac{V}{m\,s} = 1.15\times10^{11}\,\frac{V}{m\,s}$$

(c) [6 points] **Calculate** the displacement current, $(i_d)_{enc}$, enclosed by the square **dashed** path of edge length d = 0.60 m.

$$\vec{E} \ldots \text{homogeneous} \Rightarrow \frac{(i_d)_{enc}}{i_d} = \frac{A_{enc}}{A} = \left(\frac{d}{L}\right)^2$$

$$\Rightarrow (i_d)_{enc} = i_d \left(\frac{d}{L}\right)^2 = 2.0\left(\frac{0.6}{1.4}\right)^2 = 0.367\,A$$

(d) [5 points] **Calculate** $\oint \vec{B} \cdot d\vec{s}$ around the square **dashed** path.

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 (i_d)_{enc} = (4\pi\times10^{-7})(0.367) = 4.61\times10^{-7}\,T\,m$$

14. (Problem) **[20 points]** An airplane flying at a distance of 40 km from a radio transmitter receives a signal of intensity 30 $\mu W/m^2$. The transmitter radiates uniformly over a <u>hemisphere</u>, it is not a point source.

(a) [5 points] **Calculate** the amplitude of the **electric component** of the signal at the airplane.

$$I = \frac{E_m^2}{2c\mu_0} \Rightarrow E_m = \sqrt{I\,2\mu_0\,c}$$

$$E_m = \sqrt{(3\times10^{-5})(2)(4\pi\times10^{-7})(3\times10^{8})} = 0.15\,\frac{V}{m}$$

(b) [5 points] **Calculate** the amplitude of the **magnetic component** of the signal at the airplane.

$$c = \frac{E}{B} \Rightarrow B_m = \frac{E_m}{c} = \frac{0.15}{3\times10^{8}} = 5.0\times10^{-10}\,T$$

(c) [5 points] **Calculate** the transmission **power** of the transmitter.

$$I = \frac{P}{2\pi R^2} \Rightarrow P = I(2\pi R^2) = (3\times10^{-5})\,2\pi(4\times10^{4})^2$$

$$P = 3.01\times10^{5}\,W$$

(d) [5 points] Given the airplane's tail fin has an area of 10 m^2 and is made of totally reflective metal, **calculate** the **radiation** <u>**force**</u> on the fin due to the incident signal. Assume the fin is perpendicular to the signal.

$$F_r = p_r A = \frac{2IA}{c} = \frac{2(3\times10^{-5})(10)}{3\times10^{8}} = 2.0\times10^{-12}\,N$$

total refl $\Rightarrow p_r = \frac{2I}{c}$