Name:

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Physics 7B Final – Fall 2019
Professor A. Lanzara

TOTAL POINTS: 100

Show all work, and take particular care to explain what you are doing. Partial credit is given. Please use the symbols described in the problems. Define any new symbol that you introduce and label any drawings that you make. All answers should be in terms of given variables. If you get stuck, skip to the next problem and return later.

Problem 1 (19 pts.)

A real heat engine working between heat reservoirs at T_1 and $T_2=2T_1$ produces W of work in one cycle for an heat input of Q_{in}. The heat output is labeled Q_{out}.

a) **(3 pts.)** What is the efficiency of this real engine?
b) **(3 pts.)** If the engine were a Carnot engine operating between the same two heat baths, what would the efficiency be?
c) **(5 pts.)** Calculate the total entropy change of the universe for a cycle of the real engine
d) **(4 pts.)** Calculate the total entropy change of the universe (for each cycle) for a Carnot engine operating between the same two temperatures. Do not simply assert the answer, but provide a proof.
e) **(4 pts.)** Find the difference in work done by these two engines per cycle, assuming they have the same Q_{in}.

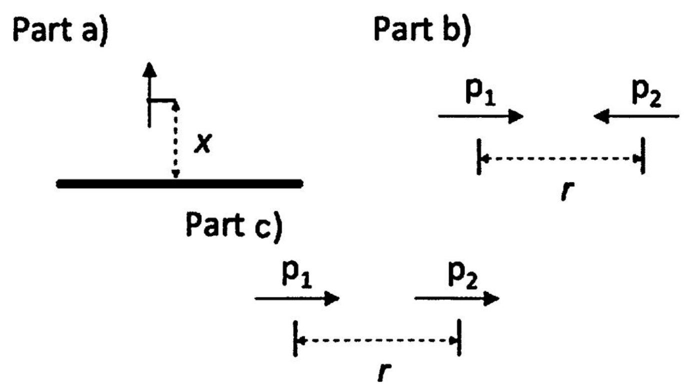
Problem 2 (12 pts.)

a) **(4 pts.)** What is the force on an electric dipole placed a distance x above an infinite sheet of charge with surface charge density σ, (see part a of the figure below)

Two electric dipoles with dipole moments p_1 and p_2 are in line with one another as shown below.

b) **(5 pts.)** Find the potential energy U of one dipole in the presence of another dipole with the dipoles are anti-aligned (see part b of the figure below). Assume the distance r between the dipoles is much greater than the length of either dipole.

c) **(3 pts.)** Now assume that the dipoles are aligned with one another. What is U?

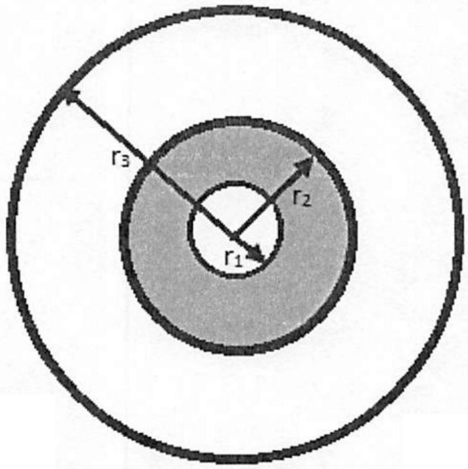


Problem 3 (10 pts.)

Consider a spherical resistor in series with a spherical capacitor which consists of three concentric metal spheres of radii r_1, r_2, and r_3. The space between the spheres $r_1 < r < r_2$ is filled with a material with resistivity ρ. The charge on the middle conductor is $-Q_0$ and the charge on the outer conductor is $+Q_0$.

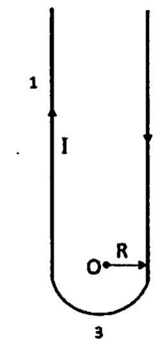
a) **(5 pts.)** What is the capacitance of the spherical capacitor?

b) **(5 pts.)** What is the resistance between the inner and middle conductors?

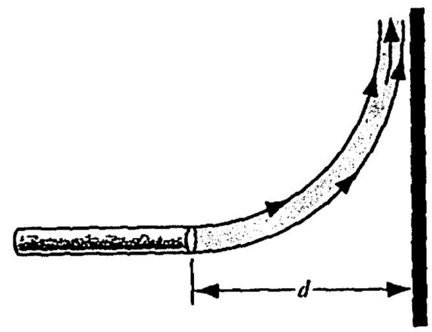


Problem 4 (15 pts.)

a) **(10 pts.)** Two long parallel wires are separated by a distance $2R$ and are connected at one end by a semicircular wire of radius R. A current I runs through the setup, as shown below. Find the magnetic field generated by the setup at the point O.



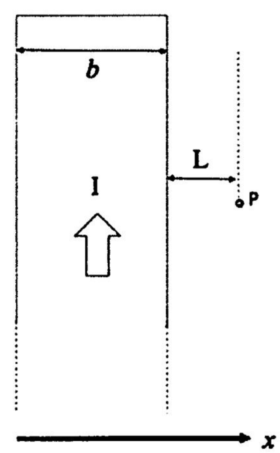
b) **(5 pts.)** A beam of electrons (charge e and mass m) whose kinetic energy is K emerges from a thin-foil window at the end of an accelerator tube. There is a metal plate a distance d from this window and at right angles to the direction of the emerging beam, as shown below. A uniform magnetic field B is applied in the region outside of the window. Find the minimum magnetic field (magnitude and direction) such that the emerging beam does not hit the metal plate.



Problem 5 (14 pts.)

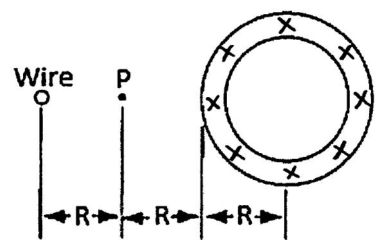
a) **(4 pts.)** Using relevant physical laws, derive the magnetic field at a distance r away from an infinitely long wire carrying a current I.

b) **(10 pts.)** Consider a very long thin conducting strip of width b. A current I passes through the strip. Find the magnitude and direction of the magnetic field generated by the strip at a point P, as shown in the figure. The point P lies in the same plane of the strip and is at a distance L from the side of the strip.



Problem 6 (15 pts.)

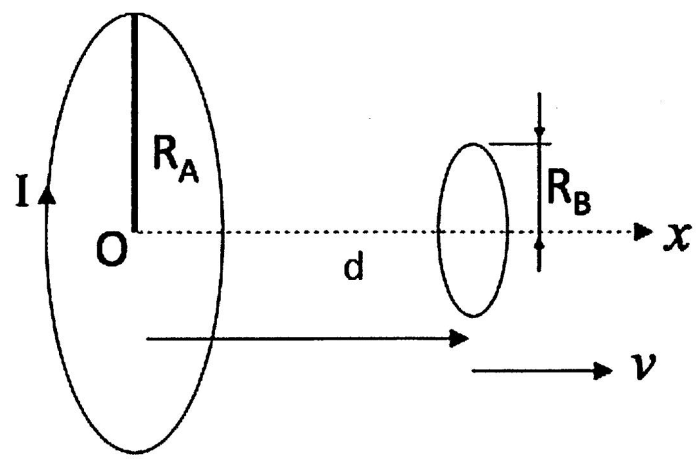
A long, circular pipe, with an outside radius of R, carries a (uniformly distributed) current of I_0 into the paper, as shown below. A wire runs parallel to the pipe at a distance 3R from center to center. Calculate the magnitude and direction of the current in the wire that would cause the resultant magnetic field at the point P to have the same magnitude, but the opposite direction, as the resultant field at the center of the pipe.



Problem 7 (15 pts.)

Two loops of wires of radius R_A and R_B ($R_A>R_B$) are placed at an initial distance d apart from one from the other, as shown in the figure below. The origin of the two loops lies on the same axis. The larger loop is fixed and cannot move. A current I runs in this loop. The smaller loop moves along the x- axis with constant velocity v.

a) **(5 pts.)** Find the magnetic field produced by the larger loop at a point on the symmetry axis a distance x away from the center of the loop.
b) **(7 pts.)** Find the induced emf in the smaller loop when the distance between the two loops is d. Assume that the smaller loop is very small so that the magnetic field across the loop is uniform and equal to the value at its center.
c) **(3 pts.)** Does the larger loop attract or repel the smaller loop? Explain.



Physics 7B Final Equation Sheet Fall 2019

Thermodynamics and Mechanics	Electromagnetism	Constants and Formulas
$\Delta l = \alpha l_0 \Delta T$	$\oiint \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$	$k_B = 1.38 \times 10^{-23}\mathrm{J/K}$
$\frac{dQ}{dt} = -kA\frac{dT}{dx}$	$C = KC_0$	$\frac{1}{4\pi\epsilon_0} \sim 10^{10}\ \mathrm{N \cdot m^2/C^2}$
$dS = \frac{dQ}{T}$	$P = IV$	$q = 1.6 \times 10^{-19}\ \mathrm{C} \sim 10^{-19}\mathrm{C}$
$\Delta S_{syst} + \Delta S_{env} > 0$	$R = \frac{\rho l}{A}$	$\sqrt{2} \sim 1.4$
$\oint dS = 0$	$\Delta V = -\int \vec{E} \cdot d\vec{l}$	$\sqrt{3} \sim 1.7$
$\Delta V = \beta V_0 \Delta T$	$\vec{E} = -\nabla V$	$\ln(2) \sim 0.69$
Adabatic Process: $PV^\gamma = \text{constant}$	$\oiint \vec{B} \cdot d\vec{A} = 0$	$\ln(3) \sim 1.09$
	$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$	$e^x = 1 + x + \frac{x^2}{2} \cdots$
$e = \frac{W_{net}}{Q_{in}}$	$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \hat{r}}{r^2}$	$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} \cdots$
$C_P - C_V = R = N_A k_B$	$\vec{\mu} = NI\vec{A}$	$(1+x)^n = 1 + nx + \frac{x(n-1)}{2}x^2 \cdots$
$COP_{ideal} = \frac{T_L}{T_H - T_L}$	$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$	$\int \frac{1}{(a^2+x^2)^{1/2}}dx = \ln(x + \sqrt{a^2+x^2}) + C$
$\lvert\vec{F}_{cent}\rvert = \frac{mv^2}{r}$	Electric dipole: $V = \frac{1}{4\pi\epsilon_0}\frac{p\cos(\theta)}{r^2}$	$\int \frac{1}{(a^2+x^2)^{3/2}}dx = \frac{x}{a^2\sqrt{a^2+x^2}} + C$
$v = \frac{dx}{dt}$		$\int \frac{x}{(a^2+x^2)^{1/2}}dx = \sqrt{a^2+x^2} + C$
$a = \frac{dv}{dt}$		$\int \frac{x}{(a^2+x^2)^{3/2}}dx = -\frac{1}{\sqrt{a^2+x^2}} + C$
$\omega = \frac{d\theta}{dt}$		$\int_a^b \frac{dx}{\alpha x+\beta} = \frac{1}{\alpha}\ln\left(\frac{\alpha b+\beta}{\alpha a+\beta}\right)$
$\alpha = \frac{d\omega}{dt}$		$\int \frac{xdx}{\alpha x+\beta} = \frac{\alpha x - \beta\ln(\alpha x+\beta)}{\alpha^2} + C$