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PHYSICS 221 – Section 1

FINAL EXAM

May 2, 2008

Instructions: When you are told to begin, check that this examination booklet contains all the numbered pages from 2 through 9. Read each problem carefully so that you are certain what it is asking. Do not panic or be discouraged if you cannot do every part of every problem. If a part of a problem depends on a previous answer you have not obtained, define a symbol for it and proceed to maximize your credit. Keep moving to finish as much as you can!

You must show your work. The purpose of this exam is to show how well you understood the material we have covered. You must include an adequate explanation, including correct equations where applicable, for full credit. Unless otherwise indicated, a number with no explanation will not get credit. **Show your answer's units**, and give an adequate number of significant digits. Completely numerical solutions showing no equations are not eligible for partial credit. Do not use scratch paper. Indicate any work on the back that you wish to be considered.

Box your answers.

This examination is administered under the Cadet Honor Code. All suspected violations must be reported appropriately. The seat next to you must be unoccupied. No talking is permitted during the examination, apart from questions to the instructor. You may use a scientific calculator, but may not use “advanced features”, including graphing, solving, or equation storage capabilities. Any other electronic devices, including headphones, cell phones, PDAs, and MP3 players, may not be used during the exam in any way. You may use a page of notes.

$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$	$0^\circ\text{C} = 273 \text{ K}$	$R = 8.315 \text{ J/mol} \cdot \text{K}$ $= 0.0821 \text{ atm} \cdot \text{L/mol} \cdot \text{K}$
$1 \text{ atm} = 1.01 \times 10^5 \text{ N/m}^2$	$1 \text{ L} = 10^3 \text{ cm}^3 = 10^{-3} \text{ m}^3$	
$\rho_w = 1000 \text{ kg/m}^3 \text{ (H}_2\text{O)}$	$c_w = 4.186 \text{ J/g (H}_2\text{O)}$	$c_i = 2.090 \text{ J/g (ice)}$
$L_f = 333 \text{ J/g (H}_2\text{O)}$	$L_v = 2260 \text{ J/g (H}_2\text{O)}$	$k_e = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2$
$\epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$	$\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$	$c = 3.00 \times 10^8 \text{ m/s}$

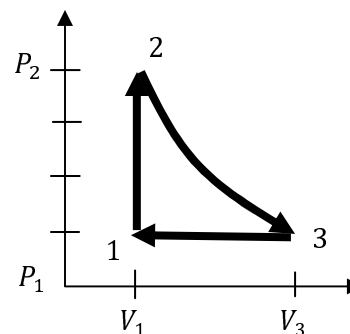
1. **[12pt]** An ideal gas is contained in a 5.00 L vessel at a temperature of 17.0°C and a pressure of 9.00 atm.

(a) [4pt] Determine the number of moles of gas in the vessel.

(b) [4pt] How many molecules are there in the vessel?

(c) [4pt] If the temperature is raised to 80.0°C, how many moles of gas would have to be removed from the container to maintain the original pressure?

2. [14pt] A diatomic ideal gas ($\gamma = 1.40$) confined to a cylinder is put through a closed cycle. Initially the gas is at P_1 , V_1 , and T_1 . First, its pressure is quadrupled to $P_2 = 4P_1$ under constant volume. It then expands adiabatically to volume V_3 at its original pressure, and finally is compressed isobarically to its original volume.



- (a) [4pt] Determine the volume V_3 at the end of the adiabatic expansion in terms of V_1 .

- (b) [4pt] Find the temperature T_2 of the gas at the start of the adiabatic expansion in terms of T_1 .

- (c) [6pt] What is the net work done on the gas for this cycle in terms of P_1, V_1 ?

3. [12pt] A large freezer in a 20°C room contains 2.00 m^3 of water at 0°C .

(a) [4pt] Calculate the change in entropy when 2.00 m^3 is frozen into water at 0°C .

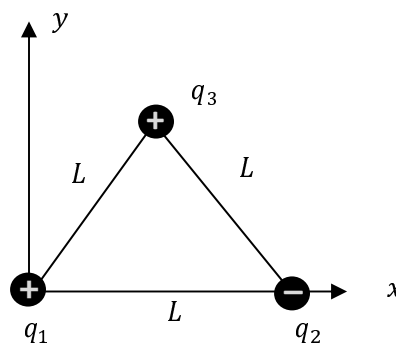
(b) [4pt] What is the minimal amount of heat that the refrigerating system that froze the ice expel into the room at 20°C , according to the Second Law of Thermodynamics?

(c) [4pt] How much energy would an optimal (Carnot) refrigerator require to freeze the ice?

4. [18pt] Three charges

$q_1 = +4.00 \mu\text{C}$, $q_2 = -6.00 \mu\text{C}$, $q_3 = +8.00 \mu\text{C}$
are placed at the corners of an equilateral triangle as shown, with edge $L = 0.650 \text{ m}$.

- (a) [6pt] Calculate the electric field at the position of charge q_1 due to q_2 and q_3 . Give its magnitude and direction relative to the $+x$ axis.



- (b) [4pt] What is the potential energy of the set of three charges (relative to a situation where they are widely separated)?
- (c) [4pt] Suppose charge q_1 is free to move but the other charges are held fixed, and has a mass $m_1 = 1.20 \text{ g}$. Find its speed when far away from the other charges, assuming it is released at rest from the origin.

5. **[18pt]** A coaxial cable of length l has an inner conductor of radius a which carries a charge Q . The surrounding conductor has an inner radius b and a charge of $-Q$. Assume the electrical properties of the material between the conductors are the same as empty space.

(a) [4pt] Find the electric field as a function of r between the conductors, for $a < r < b$.

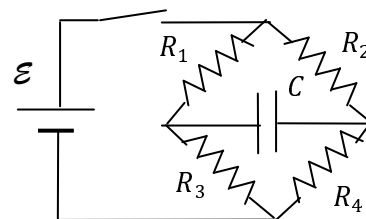
(b) [6pt] Find the potential difference $V_a - V_b$ between the conductors if $Q = 25$ nC, $a = 1.2$ mm, $b = 2.4$ mm, and $L = 30.0$ m.

(c) [4pt] Find the capacitance of this length of cable.

[If you don't have a result for the previous question, assume $\Delta V = 12.0$ V for (c) and (d).]

(d) [4pt] What electrical energy is stored in the cable?

6. [16 pt] In the circuit shown, let $\mathcal{E} = 3.0 \text{ V}$, $C = 25 \mu\text{F}$, $R_1 = 100 \Omega$, $R_2 = R_4 = 200 \Omega$, and $R_3 = 300 \Omega$. Initially, the switch is **closed** and the capacitor is fully charged, and is in a steady state.



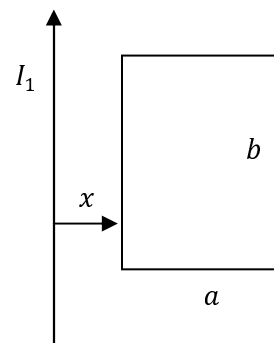
- (a) [4pt] What current flows from the battery in this steady-state situation?

- (b) [4pt] What is the voltage across the capacitor when fully charged?

- (c) [4pt] If the switch is opened at a time $t = 0$, what current flows from the capacitor at that time?

- (d) [4pt] How long does the capacitor take to lose half its charge after the switch is opened?

7. **[18pt]** A long straight wire carries a current I as shown. A square loop of dimensions $a \times b$ is positioned a distance x away as shown.



- (a) [5pt]** What is the magnetic flux inside the square loop? Express it in terms of I_1, a, b, x, μ_0 . Is it into or out of the page?

- (b) [4pt]** If the current is $I_1(t) = I_0 t$ and the square loop has resistance R , what current I_2 is generated in the square loop as a function of time? Give the magnitude and direction (clockwise or counter-clockwise).

- (c) [5pt]** Suppose the current I_1 in the long wire is constant, but the square loop is pulled to the right at a constant speed v . What current I_2 flows in the square loop? Give the magnitude and direction. [Hint: $\frac{d}{dt} = v \frac{d}{dx}$.]

(d) [4pt] What power is needed to pull the loop at speed v when it is a distance x from the long wire?

[Note: You can refer to previous symbolic results without rewriting them, even if you did not solve part of the problem.]

8. [12pt] A red laser beam with a wavelength of 700 nm shines on a dark target which absorbs the beam's energy. The beam has a radius of 1.00 mm and power is absorbed in the target at a rate of 150 mW.

(a) [4pt] What is the frequency of the laser light (in Hz = cycles per second)?

(b) [4pt] What is the amplitude of the electric field in the laser beam?

(c) [4pt] What is the amplitude of the magnetic field in the laser beam?