Physics 7B Final - Fall 2017
Professor R. Birgeneau

Total Points: 100 (8 Problems) + 3 Bonus
This exam is out of 100 points with 3 bonus points avaliable. Show all your work and take particular care to explain your steps. Partial credit will be given. Use symbols defined in problems and define any new symbols you introduce. If a problem requires that you obtain a numerical result, first write a symbolic answer and then plug in numbers. Label any drawings you make. **Good luck!**

Problem 1 (10pts.)
The specific heat of liquid mercury is $c_{Hg} = 140$ J/kg· C°. When 1.0 kg of solid mercury at its melting point of ~ -40°C is placed in a 0.5 kg aluminum calorimeter filled with 1 kg of water at 20°C, the mercury melts and the final temperature of the combination is found to be 16°C. What is the heat of fusion of mercury? Take the specific heats of aluminum and water to be $c_{Al} = 900$ J/kg· C° and $c_W = 4200$ J/kg· C°, respectively. The calorimeter and water are intiallially in thermal equilibrium.

Problem 2 (15pts.)
The van der Waals equation of state is given by

$$\left(P + \frac{a}{(V/n)^2}\right)\left(\frac{V}{n} - b\right) = RT$$

where a and b are constants.

$P = \frac{RT}{\frac{V}{n} - b} - \frac{a}{(V/n)^2}$

(a) Explain the physical origins of the constants a and b.

(b) Given that the P versus V curve has an inflection point at the critical point, find the critical temperature and pressure, T_{cr} and P_{cr}, in terms of a, b, and R.

Problem 3 (10 pts. + 3 pts.)
Stars resist collapsing via the gravitational force by continually fusing nuclei together and thereby releasing energy. Nuclear fusion occurs when two nuclei get within a distance of $\sim 10^{-15}$ m of each other. At this distance, the repulsive Coulomb force gives way to the attractive strong nuclear force, which then causes the nuclei to fuse. Assume that we can model the protons in the stellar interior as a monatomic ideal gas of protons at temperature T. Protons have mass m_p and charge q.

(a) What is the root-mean-square velocity of the proton gas at temperature T?

(b) Assuming that we have two protons - one at a fixed position and the other approaching the first from infinity with the root-mean-square velocity - find an expression for the shortest distance between the protons.

(c) Using $T \sim 10^7$ K, $m_p \sim 10^{-27}$ kg and the approximate values of relevant physical constants on the equation sheet, estimate the shortest distance between the protons. How does this distance compare to the required 10^{-15} m?

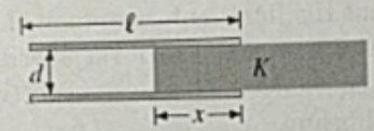
(d) **Bonus (3 pts.):** What does this imply for the fusion of stars?

Problem 4 (15 pts.)
Consider the parallel plate capacitor shown below, which consists of two plates of area A, side length l, and separated by a distance d. Between the plates, there is a layer of dieletric with cross section A, thickness d, and dielectric constant K. The dielectric has been pulled out of the capacitor so that only an amount of length x is still inside. The capacitor is kept at constant potential V_0.

(a) Find the capacitance of the setup below.

(b) Find the energy stored in the capacitor.

(c) Find the magnitude and direction of the force exerted on the slab.

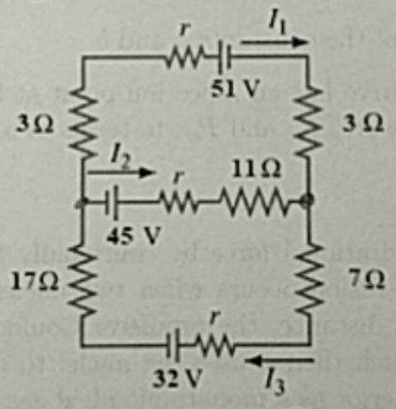


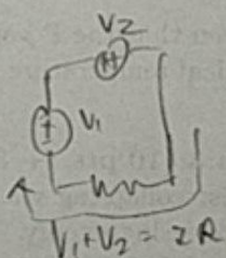
$V = \frac{U}{q}$

Problem 5 (10 pts.)

(a) Determine the currents I_1, I_2, and I_3 in the circuit below. The internal resistance of all three batteries is $r = 2\ \Omega$.

(b) What is the terminal voltage of the 32 V battery?





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Problem 6 (15 pts.)

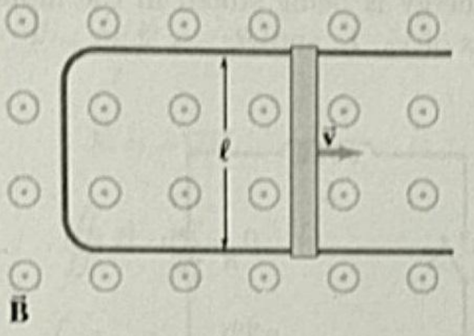
(a) The diagram below dipicts a conducting rod of length l and resistance R moving with a constant velocity v in a uniform magnetic field B as a force is applied to the rod by an observer. What is the induced emf in the rod?

(b) Find the magnitude and direction of the magnetic force the rod experiences as it moves.

(c) Find the magnitude and direction of the force applied on the rod by the person.

(d) Find the external power expended to move the rod.

(e) What is the power dissipated by the resistance of the rod? Explain how this result is consistent with the answer to part (d).

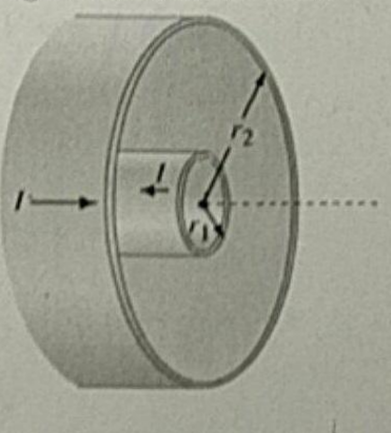


Problem 7 (10 pts.)

(a) Consider the coaxial cable below, which consists of two concentric cylindrical shells carrying a current I, with an inner radius r_1 and an outer radius r_2. Find the magnitude and direction (from the perspective of the diagram) of the magnetic field as a function of r for $0 < r < \infty$.

(b) Find the inductance per unit length of the coaxial cable.

(c) Find the energy per unit length stored in the cable.



Problem 8 (15 pts.)

Answer the following for the LR Circuit depicted below:

(a) At $t = 0$, the switch is closed. Derive the expression for I(t) in terms of V_0, L, and R.

(b) What is the current at $t = 0$?

(c) What is the time constant for the circuit?

(d) What is the maximum current I_M that can occur in the circuit?

(e) Find the value of $t_{1/2}$, which is the time after the switch is closed at which the current is at half its maximum value.

(f) What is the value of the power being delivered by the battery at $t_{1/2}$?

(g) What is the rate at which energy is being stored in the inductor's magnetic field at $t_{1/2}$? Give an answer in terms of V_0, L, and R.