Assignment 3
Physics/ECE 176

Made available:	Sunday, January 30, 2011
Due:	Thursday, February 3, 2011, by the beginning of class.

Problem 1: Effect of Plate Temperature on Pressure Balance

A long thermally isolated plastic cylinder is divided into two equal halves by a thin circular metallic impermeable partition that has an extremely small mass and that can easily slide back and forth along the axis of the cylinder with negligible friction. One half of the cylinder is filled with He gas and the other half with gaseous sulfur hexafluoride SF_6 so that thermodynamic equilibrium is attained with constant pressures, temperatures, and volumes on both sides of the partition. An electrical current is then passed through the partition so that its temperature instantly increases by a large amount. Immediately after this temperature increase and before the temperatures of the two gases can change, determine whether the metal partition will move and, if so, in what direction.

Hints: choose some small area A on the metal partition, apply to both sides of the wall the simplest kinetic theory that relates particle properties to pressure on the area A, and make the not-quite-so-physical assumption that, when a molecule hits the wall, it instantaneously reaches equilibrium with the temperature of the wall.

Problem 2: Temperature Rise of a Falling Penny

Estimate without use of a calculator and to one significant digit the height h in meters from which a penny at room temperature would have to fall so that the potential energy released, if delivered entirely to the penny, would raise the penny's temperature by one degree Kelvin.

Note: A penny has a mass of 2.5×10^{-3} kg and can be assumed to be pure zinc (it is actually 97.6% zinc coated with 2.4% copper). To get full credit, you need to give details such as how you estimated the heat capacity (do not look this number up on the Internet, calculate it from first principles) and how you rounded various numbers and simplified combinations of numbers.

Problem 3: Degrees of Freedom in a Chemical Reaction

Explain which has more degrees of freedom f:

1. two molecules of ethane C_2H_6 and seven molecules of O_2,
2. or the combustion products of ethane with oxygen, consisting of four CO_2 molecules and six H_2O molecules.

The total number of atoms is the same in both cases. Give your answers for two cases: no degrees of freedom are frozen out, and only the vibrational degrees of freedom are frozen out.

Problem 4: Schroeder Problems

1. Problem 1.22 on page 14, parts (e) and (f) only. Make sure you explain clearly any assumptions you made.

Begin by showing that the equation given by Schroeder in part (c) of this problem (middle of page 14) is equivalent to Eq. (4) that you derived in the previous homework assignment up to a small difference in the numerical factor. Hint: Explain why dividing dE/dt in Eq. (4) of the previous homework by the kinetic energy $(1/2)mv^2$ gives the expression dN/dt, the number of particles per unit time that strike a given area A.

2. Problem 1.34 on page 23.

   Some partial answers to help keep you on track: you should find that the change in energy ΔU for step A is $(5/2)V_1(P_2 - P_1)$, that the heat absorbed by the gas during step B is $(7/2)P_2(V_2 - V_1)$, and that the total heat absorbed by the gas after one cycle (all four steps) is $(P_2 - P_1)(V_2 - V_1)$.

3. Continue Problem 1.34 by solving Problem 4.1 on page 124. You will need to read just enough of Section 4.1 to understand and use Eqs. (4.3) and (4.5) but do not worry about how they are derived. (The discussion uses the concept of entropy, which we are only now beginning to discuss.)

   A partial answer: you should find that the ratio of the efficiency of the rectangular cycle (Fig. 1.10b on page 23) to the efficiency of an ideal engine operating between the same temperature range is about 14%.

4. Problem 1.36 on page 26. The answers to one significant digit are respectively 0.3 liters for (a), 200 J for (b),and 500 K for (c) but you should give your answers to *two* significant digits so that I know you know how to get the answer.

5. Problem 1.41 on page 31. To one significant digit, you should get the answer $60\,\mathrm{J}/^\circ\,\mathrm{C}$ for (c) but you need to give all answers to two significant digits.

   This is a simple but important problem: please make sure you understand the details of how one measures the heat capacity of an object.

6. Problem 1.44 on page 31. This problem is a great opportunity for you to explore how much you can understand about the rotational and vibrational properties of substances based on their experimentally measured molar specific heats at constant pressure, C_P. For this problem, summarize your insights about these particular categories:

   (a) gases of single atoms such as Ar, H, He, and Ne;

   (b) gases of diatomic molecules such as CO, Cl_2, H_2, N_2, and O_2;

   (c) gases of polyatomic molecules such as CH_4 (methane), CO_2 (carbon dioxide, presumably linear because of the two double bonds), H_2O (water vapor), NH_3 (ammonia), and C_2H_6 (ethane);

   (d) solids of atoms such as Al, C (graphite), C (diamond), Cu, Fe, and Pb;

   (e) compound solids (multiple atoms per unit cell) such as Al_2SiO_5, $CaCl_2$, NaCl, and PbO_2;

   (f) and finally, see if the values of C_P make any sense for liquids like Hg (mercury), C_2H_5OH (ethanol), and H_2O.

7. Problem 1.54 on page 36 of Schroeder. The solution is useful for those of you who like to hike, say Grandfather Mountain (elevation $\approx 6000\,\mathrm{ft}$) in the western part of North Carolina.

8. Problem 1.55 on pages 36-37.

   For part (a), use at some point Newton's second law for circular motion, $Gm^2/(2r)^2 = m(v^2/r)$.

   For part (d), a "dimensional analysis" means to determine whether the physical units of some quantity of interest, here potential energy, can be obtained by multiplying together powers of units of other quantities that one thinks are important for the problem, here the gravitational constant G, the mass M, and the radius R. Dimensional analysis can sometimes provide a quick way to determine how various physical quantities combine algebraically to give some answer of interest, without knowing much physics and without having to worry about possibly complicated details.

A bracket notation $[E]$ is often used to denote the physical units of some quantity like energy. From the fact that energy is force times distance and force is mass times acceleration, you should be able to verify that

$$[E] = \frac{\mathrm{kg\,m^2}}{\mathrm{s^2}}, \tag{1}$$

in terms of the SI units of mass (kg), length (m), and time (s). From Newton's inverse square law for the gravitational force, $F = Gm_1m_2/r_{12}^2$, you should be able to verify that

$$[G] = \frac{\mathrm{m^3}}{\mathrm{kg\,s^2}}. \tag{2}$$

Dimensional analysis for this problem then involves asking whether there are three exponents α, β, and γ (not necessarily positive or integers) such that

$$[E] = [G]^\alpha \times [M]^\beta \times [R]^\gamma. \tag{3}$$

Substituting the units for E, G, M, and R, and equating powers of the same units on both sides will give you three linear equations in three unknowns which you can solve to determine α, β, and γ.

For part (d), also show me that you remember your freshman physics by deriving analytically (via a radial integral) the exact expression $(3/5)GM^2/R$ for the total potential energy of a star of mass M, radius R, with a uniform mass density.

For part (e), compare your answer with the Sun's surface temperature of 6,000 K and with the Sun's estimated central core temperature of about 15,000,000 K.

9. Problem 2.3 on page 52 of Schroeder. A hint for part (g):

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probs = Table[ Binomial[ 50., n ] / 2.^50 , { n, 0, 50 } ]
ListLinePlot[ probs ]
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Problem 5: Time to Finish This Homework Assignment

Please tell me the approximate time in hours that it took you to complete this homework assignment.