Physics 2010 (Schroeder) Name ______________________________
spring 2004

Problem Set 14

(due Thursday, April 22)

1. In this exercise you will work with the "Molecules" computer program that was demonstrated in class. The program should be installed on all of the Windows computers in SL228. You can also download it onto another computer (Macintosh or Windows) from the web page http://physics.weber.edu/schroeder/software. The program probably won't run on computers that are more than a few years old, and to decompress it you will need a suitable utility program. Because computer glitches can easily occur, please do not wait until the last minute to download and test the program. A computer-related problem is not a valid excuse to skip this exercise.

   The gist of this exercise is that you should play with the program long enough to observe some of the interesting behaviors of the molecules, and to develop some intuition for the molecular world. Although the program has many features that are beyond the scope of this exercise (two types of molecules with variable sizes, masses, and interaction strengths), feel free to play with all of the controls. I especially enjoy turning on the Gravity feature. The only "bad" thing that can occur is a numerical instability, when the molecules are moving too fast for the specified time step. If this happens, just select File-New to start over, and either reduce the time step or avoid adding so much energy to the system.

   After you've played with the program for a while, quit and relaunch the program to get back to the default settings. Then click on the Data tab and select the Average button. The bottom two numbers in the list display the temperature (computed from the average kinetic energy) and pressure (computed from the force exerted on the walls of the box). Your task is to determine how these two numbers are related. Vary the system's energy (using the top set of arrows or the H and C keyboard shortcuts) so that the temperature ranges from about 1.0 down to zero, in steps of about 0.1. At each temperature, wait several seconds for the numbers to stabilize, then record the temperature, pressure, and total energy (from the top of the control panel). Also write down a brief description of how the molecules are arranged. Then, for each temperature, calculate the pressure that would be predicted by the ideal gas law. (The "volume" of the box is its area, 40×40 in the units used. Boltzmann's constant is equal to 1 in these units.) Make a table showing all your measured data as well as the pressures that would be predicted by the ideal gas law. Comment briefly on the results, and on any other interesting observations that you made while using the program.

2. Estimate how long it *should* take to bring a cup of water up to boiling temperature in a typical 600-watt microwave oven. Assume that all of the energy from the microwaves ends up in the water. Explain why technically, there is no "heat" transferred to the water during this process.

3. In Problem Set 6, you estimated the number of jelly donuts that you should eat for breakfast before setting out to hike to the summit of Mt. Ogden. As you may recall, 1/4 of the calories consumed are converted into your final gravitational energy, while the other three-quarters are converted to thermal energy. If there were no way to dissipate this energy, by how many degrees would your body temperature increase?

4. In fact, the extra energy does not warm your body significantly; instead, it goes (mostly) into evaporating water from your skin. How many liters of water should you drink during the hike to replace the lost fluids? (At 25 °C, a reasonable temperature to assume, the heat of vaporization of water is 580 kcal/kg, slightly more than at 100°C.)

5. Give an example (other than the microwave oven in Problem 2) of a process in which no heat is added to a system, but its temperature increases. Then give an example of the opposite: a process in which heat is added to a system but its temperature doesn't change.

6. The specific heat capacity of Albertson's *Rotini Tricolore* (or any other dry pasta) is approximately 1.8 J/g·°C. Suppose you toss 340 g of this pasta (at 25°C) into 1.5 liters of boiling water. What effect does this have on the temperature of the water (before there is time for the stove to provide more heat)?

7. Your 200-gram cup of tea is boiling-hot. About how much ice should you add to bring it down to a comfortable sipping temperature of 65°C? (Assume that the ice is initially at -15°C, a typical freezer temperature.)

8. Calculate the rate at which heat is conducted through a single-pane window that measures 2 ft wide by 3 ft high by 1/8 inch thick. Take the inside temperature to be 20°C and the outside temperature to be 0°C. Ignore the layers of still air on either side of the window. Please express your answer in watts.

9. To get an idea of how important the air layers near a window are, calculate the rate at which heat is conducted through a layer of still air that measures 2 ft by 3 ft by 1 mm thick, for the same temperature difference as in the previous problem.

10. On average, the power radiated by the earth into space must be exactly equal to the power absorbed from sunlight. By equating these two quantities, make a *rough* estimate of the earth's average surface temperature. Hints: Draw a picture, and note that the sunlight arrives from only one direction, while the earth radiates in all directions. The intensity of sunlight arriving at earth's location is 1370 W/m^2. You may ignore the fact that the earth is somewhat reflective, and ignore the "greenhouse effect" caused by earth's atmosphere. The earth's size will cancel out if you don't plug in numbers too soon.

Study Guide

"Heat", in physics, is a spontaneous flow of energy from one object to another, caused by a difference in their temperatures. The symbol for the amount of heat energy that flows into an object (during some time period of interest) is Q.

The heat capacity, C, of an object is the amount of heat needed to raise its temperature, per degree: $C = Q/\Delta T$. (This definition is somewhat ambiguous, because other energy could be entering or leaving simultaneously.) The specific heat, c, of an object is its heat capacity per unit mass. Therefore

$$c = \frac{Q}{m\,\Delta T}.$$

The specific heat of water is 4.186 J/g·°C. This amount of energy is also called a calorie; the familiar food calorie is really a kilocalorie, or 4186 J.

During a phase change such as melting or boiling, the temperature does not change and so C is technically infinite. In this context we define the latent heat, L, to be the total heat to accomplish the change, per unit mass: $L = Q/m$. (For melting ice, the latent heat is 80 cal/g; for boiling water it is 540 cal/g.)

Specific mechanisms of heat transfer are grouped into three categories: conduction, convection, and radiation. You should understand these processes conceptually, and be able to use the formulas for the rates of conduction and radiation:

$$\frac{Q}{\Delta t} = \frac{k_t A(T_2 - T_1)}{\Delta x}; \qquad \frac{Q}{\Delta t} = e\sigma A T^4.$$

In both formulas, $Q/\Delta t$ is the rate of heat transfer (a form of power, measured in watts), while A is the object's surface area and T is temperature. In the first formula, δx is thickness and k_t is thermal conductivity, which depends on the material. In the second formula, σ is a universal constant equal to 5.67×10^{-8} in SI units, while e is a "fudge factor" between 0 and 1 called the *emissivity*, which is smaller for reflective surfaces.