

## Problem Set 12

(due Friday, April 1)

1. In 1964, the temperature in the Siberian village of Oymyakon reached a value of  $-71^{\circ}\text{C}$ . Convert this temperature to the Fahrenheit scale. The highest officially recorded temperature in the continental U.S. was  $134^{\circ}\text{F}$ , in Death Valley, CA. Convert this temperature to the Celsius scale. Also convert both of these temperatures to the kelvin scale.
2. Run the Molecular Dynamics Applet (<http://physics.weber.edu/schroeder/software/MDApplet.html>), and spend at least 20 minutes playing with it. Explore the transformations between the solid, liquid, and gas phases. Turn in descriptions of at least three interesting phenomena that you observe in the simulation.
3. Use the phase diagram of  $\text{H}_2\text{O}$  to explain why it takes longer to cook noodles at high altitude.
4. Gold has a molar mass of 197 g/mol. (a) How many moles of gold are in a sample with a mass of 2.5 g? (b) How many atoms are in the sample?
5. The best vacuum (lowest gas pressure) that can be attained in the laboratory using current technology is about  $10^{-18}$  atm. How many gas molecules are there per cubic centimeter in such a vacuum at room temperature?
6. Estimate the number of air molecules in your living room (within a factor of 2 or so).
7. Rooms A and B are the same size, and are connected by an open door. Room A, however, is warmer (since its windows face the sun). Which room contains the greater mass of air? (Hint: use the ideal gas law.)
8. A weather balloon is loosely inflated with helium at a pressure of 1 atm (or 760 torr) and a temperature of  $20^{\circ}\text{C}$ . The gas volume under these conditions is  $2.2\text{ m}^3$ . At an elevation of 22,000 ft, the atmospheric pressure is only 380 torr and the helium has expanded (since there's plenty of room in the loose balloon envelope). At this elevation the temperature is  $-48^{\circ}\text{C}$ . What is the gas volume now?
9. A cylinder with a movable piston contains a gas at atmospheric pressure, at an initial volume of 1.5 liters. (a) The piston is pulled out, increasing the volume to 2.5 liters, while the pressure is held constant. How much work is done by the gas? (b) Now the piston is pushed in until the volume is only 1.0 liters (still at constant pressure). How much work is done by the gas? (c) How is it even possible to maintain constant pressure while the volume is changing? Explain carefully.
10. A sample of gas expands from  $1.0\text{ m}^3$  to  $4.0\text{ m}^3$  while its pressure decreases from 40 Pa to 10 Pa. How much work is done by the gas if its pressure changes with volume as follows: (a) The pressure is maintained at 40 Pa during the entire expansion, then the pressure is lowered at fixed volume; (b) the pressure decreases linearly as a function of

- volume during the expansion; (c) the pressure is first decreased to 10 Pa at constant volume, then this pressure is maintained during the expansion. (Hint: Draw a  $PV$  diagram for each case.)
11. By applying a pressure of 200 atm, you can compress water to 99% of its usual volume. Sketch this process (not necessarily to scale) on a  $PV$  diagram, and estimate the work required to compress a liter of water by this amount. Does the result surprise you?

## Study Guide

Temperature is a measure of the willingness of an object to spontaneously give up energy to its surroundings. You can measure the temperature of something by putting a thermometer in contact with it and waiting a little while. (Most thermometers work on the principle of thermal expansion.) You should understand the various temperature scales and be able to convert between them. The Kelvin scale is best, and some equations work *only* when temperatures are expressed in Kelvin.

You should have a good understanding of the differences (at the molecular level) between solids, liquids, and gases.

The behavior of an “ideal” (i.e., not too dense) gas is described by the ideal gas law,

$$PV = nRT \quad \text{or} \quad PV = Nk_B T,$$

where  $P$  is pressure,  $V$  is volume,  $T$  is temperature *in Kelvin units*,  $n$  is the number of moles of gas, and  $N$  is the number of *molecules* of gas. Since the number of molecules in a mole is Avogadro’s number ( $N_A = 6.02 \times 10^{23}$ ), the constants of proportionality are related by

$$k_B = \frac{R}{N_A}.$$

Numerically,  $R = 8.31$  J/mol-K and  $k_B = 1.38 \times 10^{-23}$  J/K. Please memorize the exponents of  $N_A$  and  $k_B$ .

The work performed in compressing an object (often a gas) can be expressed as minus the pressure times the change in volume:

$$W_{\text{compression}} = -P \Delta V.$$

If the pressure changes significantly during the compression, then you have to break up the process into little steps and compute  $-P \Delta V$  for each step, then add them all up to get the total work. If you draw a graph of  $P$  vs.  $V$ , then the work done is minus the area under the graph. If the volume increases, then the work done on the system is negative.