# Dual Program Level 1 Physics Course

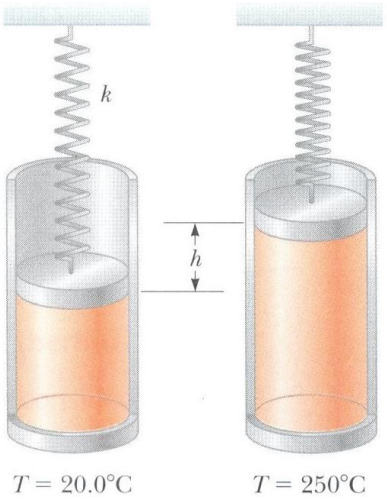
## Assignment 15

**Due: 11/Feb/2012 14:00**

Assume that water has a constant specific heat capacity of 4190 J/kg K at all temperatures between its melting point and boiling point.
Take 1 atm = 101.3 kPa.
Assume that all gases can be considered as simple ideal gas, unless otherwise specified.

1. (a) At what temperature is the Fahrenheit scale reading the same as the Celsius.
   (b) Consider two gas containers of the same fixed volume. One of them has hydrogen inside and the other has nitrogen. If they both have the same pressure of 80 kPa (kilopascals, 1 Pa = 1 $N/m^2$) and the same temperature obtained in (a), what is the difference in pressure when they are in thermal equilibrium with boiling water? Which one has a higher pressure?

2. A cylinder is closed by a piston connected to a spring of with spring constant $k = 2000$ N/m, as shown in the figure below. With the spring relaxed, the cylinder is filled with 5 L of gas at a pressure of 1 atm and a temperature of 20℃.
   (a) If the piston has a cross-sectional area 0.01 $m^2$ and negligible mass and thickness, how high will it rise when the temperature is raised to 250℃?
   (b) What is the pressure of the gas at 250℃?



3. The mass of a hot-air balloon and its cargo (not including the air inside) is 200 kg. The air outside is 10℃. The volume of the balloon is 400 $m^3$. To what temperature must the air in the balloon be warmed before the balloon will lift off? (Air density at 10℃ is 1.244 $kg/m^3$.)

4. A certain diet doctor encourages people to diet by drinking ice water. His theory is that the body must burn off enough fat to raise the temperature of water from 0℃ to 37℃. How many liters of ice water would have to be consumed to burn off 454 g (about 1 lb) of fat, assuming that this much fat burning requires 3500 Cal be transferred to the ice water? Why is it not advisable to follow this diet? (One liter = $10^3$ $cm^3$. The density of water is 1 $g/cm^3$. The calorie here is the "big" calorie (Cal) used for food.)

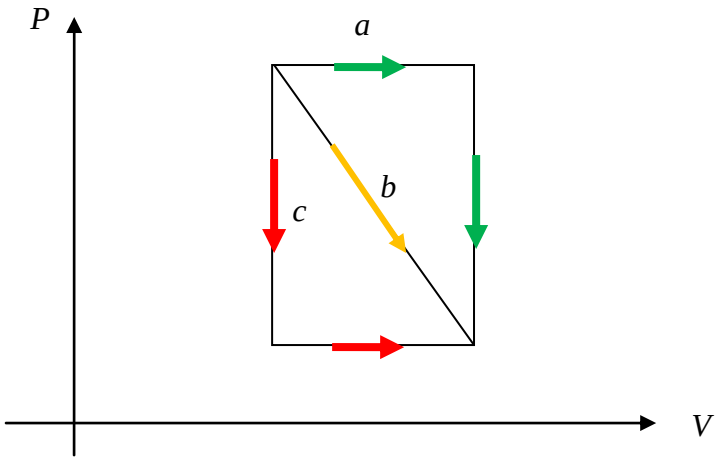
5. A certain substance has a mass per mole of 60 g/mol. When 314 J is added as heat to a 20 g sample, the sample's temperature rises from 20℃ to 30℃.
   (a) What is the heat capacity of the sample?
   (b) What is the specific heat capacity of the substance?
   (c) What is the molar heat capacity (heat capacity per mole) of the substance?

6. How much water remains unfrozen after 50.2 kJ is transferred as heat from 260 g of liquid water initially at its freezing point?

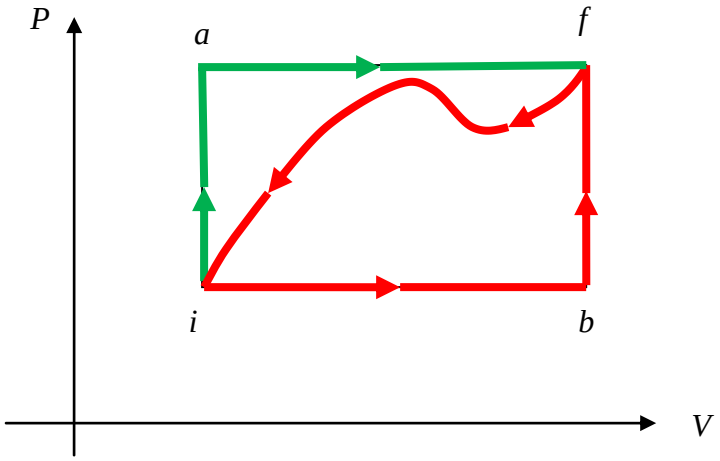
7. A 150 g copper bowl contains 220 g of water, both at 20℃. A very hot 300 g copper cylinder is dropped into the water, causing the water to boil, with 5 g being converted to steam. The final temperature of the system is 100℃. Neglect energy transfers with the environment.
   (a) How much energy is transferred to the water as heat?
   (b) How much to the bowl?
   (c) What is the original temperature of the cylinder?

8. Consider that 300 J of work is done on a system and 60 cal is extracted from the system as heat. In the sense of the first law of thermodynamics, what are the values (including algebraic signs) of (a) $W$, (b) $Q$, and (c) $\Delta U$?

9. A sample of gas expands from 2 $m^3$ to 4 $m^3$ while its pressure decreases from 50 Pa to 10 Pa. How much work is done **by** the gas if its pressure changes with volume via each of the three paths shown in the *PV* diagram below.




10. When a system is taken from state *i* to state *f* along path *iaf* in the figure below, $Q = 60$ cal and $W = -30$ cal. Along path *ibf*, $Q = 36$ cal.
    (a) What is $W$ along path *ibf*?
    (b) If $W = 15$ cal for the return path *fi*, what is $Q$ for this path?
    (c) Take $U_i = 20$ cal. What is $U_f$?
    (d) If $U_b = 30$ cal, what are the values of $Q$ for path *ib* and path *bf*?



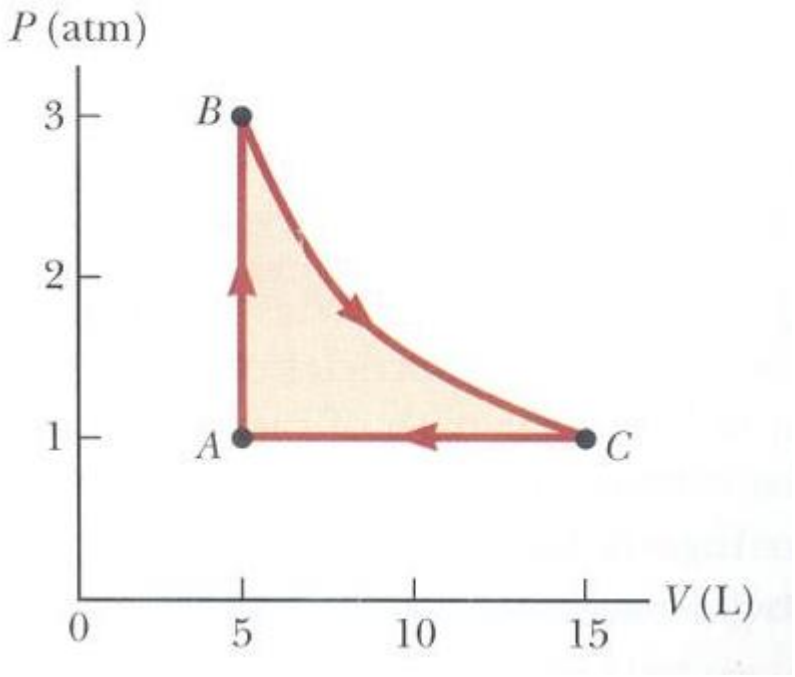

11. A sample of an ideal gas occupies 5 L at atmospheric pressure and 300 K (point *A* in the figure below). It is warmed at constant volume to 3 atm (point *B*). Then it is allowed to expand isothermally to 1 atm (point *C*) and at last compressed isobarically to its original state.
    (a) Find the number of moles in the sample.
    (b) Find the ideal gas temperature at point *B*.
    (c) Find the ideal gas temperature at point *C*.

(d) Find the volume at point *C*.

(e) Now consider the processes *A* → *B*, *B* → *C*, and *C* → *A*. Describe how to carry out each process experimentally.

(f) Find *Q*, *W*, and $\Delta U$ for each of the processes.

(g) For the whole cycle *A* → *B* → *C* → *A*, find *Q*, *W*, and $\Delta U$.




12. (a) Suppose the internal energy of a gas is given by $U = \frac{f}{2}PV$, where *f* is a certain constant. (When *f* = 3, it reduces to the simple ideal gas model we considered in class.) Find the equation of the adiabats.

(b) Model air as a diatomic ideal gas with *M* = 28.9 g/mol. For diatomic gas, the approximation of the molecules as point particle, which yields *f* = 3, is not valid. A cylinder with a piston contains 1.2 kg of air at 25℃ and $2\times10^5$ Pa. It can be shown that for diatomic gas at this temperature range, *f* = 5. Energy is transferred by heat into the system as it is permitted to expand, with the pressure rising to $4\times10^5$ Pa. Throughout the expansion, the relationship between pressure and volume is given by

$$P = CV^{1/2}$$

where *C* is a constant.

(i) Find the initial volume.

(ii) Find the final volume.

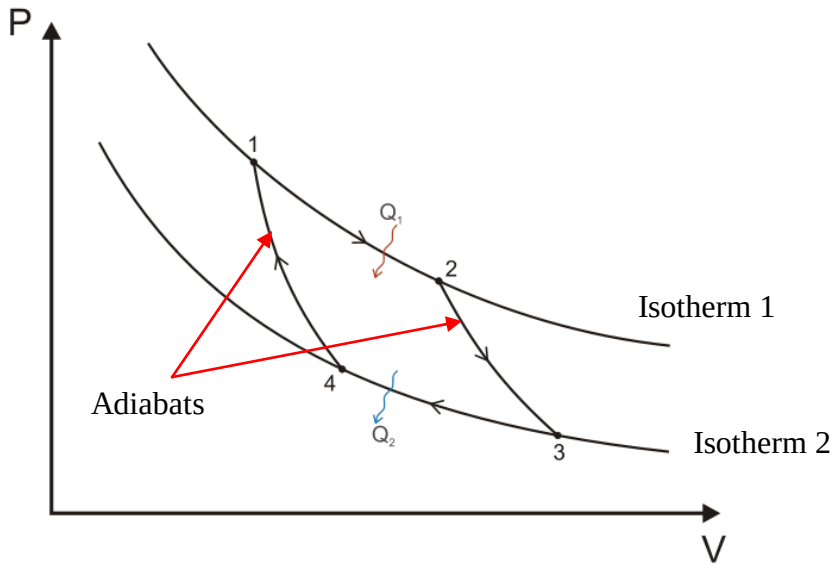
(iii) Find the final temperature.

(iv) Find the work done on the air.

(v) Find the energy transferred by heat.

13. **Carnot Cycle**

A Carnot cycle consists of two isothermal processes and two adiabatic processes. Consider the Carnot cycle of a simple ideal gas shown in the figure below.




For ideal gas, the isotherms are determined by $PV$ = Constant.

Let $PV = C_1$ for isotherm 1 and $PV = C_2$ for isotherm 2.

Let the heat added **<u>to</u>** the system when it moves along isotherm 1 and isotherm 2 be $Q_1$ and $-Q_2$, respectively.

(a) Show that $\dfrac{Q_1}{Q_2} = \dfrac{C_1}{C_2}$.

(b) Consider different Carnot cycles with the same two isotherms (the two adiabats can change). What can you say about $Q_1$, $Q_2$, and $Q_1/Q_2$ of the different cycles?