Heat Engines and P-V Diagrams

Introduction:

In this lab you will investigate the properties of a heat engine. To accomplish this, you will set up a heat engine cycle to lift weights with a piston as shown below. When you are finished, you will construct and analyze a PV diagram to determine work and efficiency for your system. Finally, you will compare the thermodynamic work done by the engine to the mechanical work done in lifting mass. To this end, you will emulate the following cycle:

A: No weight on piston, cylinder in cold bath.

A → B: Placing weight onto piston gradually, cylinder in cold bath.

B: All weight on piston, cylinder in cold bath.

B → C: All weight on piston, cylinder heating up in hot bath.

C: All weight on piston, cylinder in hot bath.

C → D: Removing weight from piston gradually, cylinder in hot bath.

D: No weight on cylinder, cylinder in hot bath.

D → A: No weight on piston, cylinder cooling in cold bath.

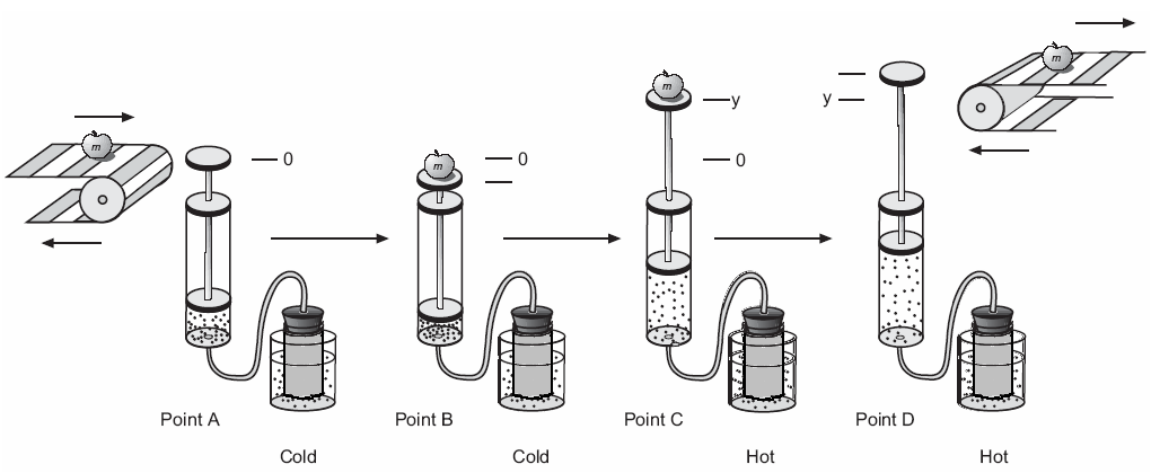
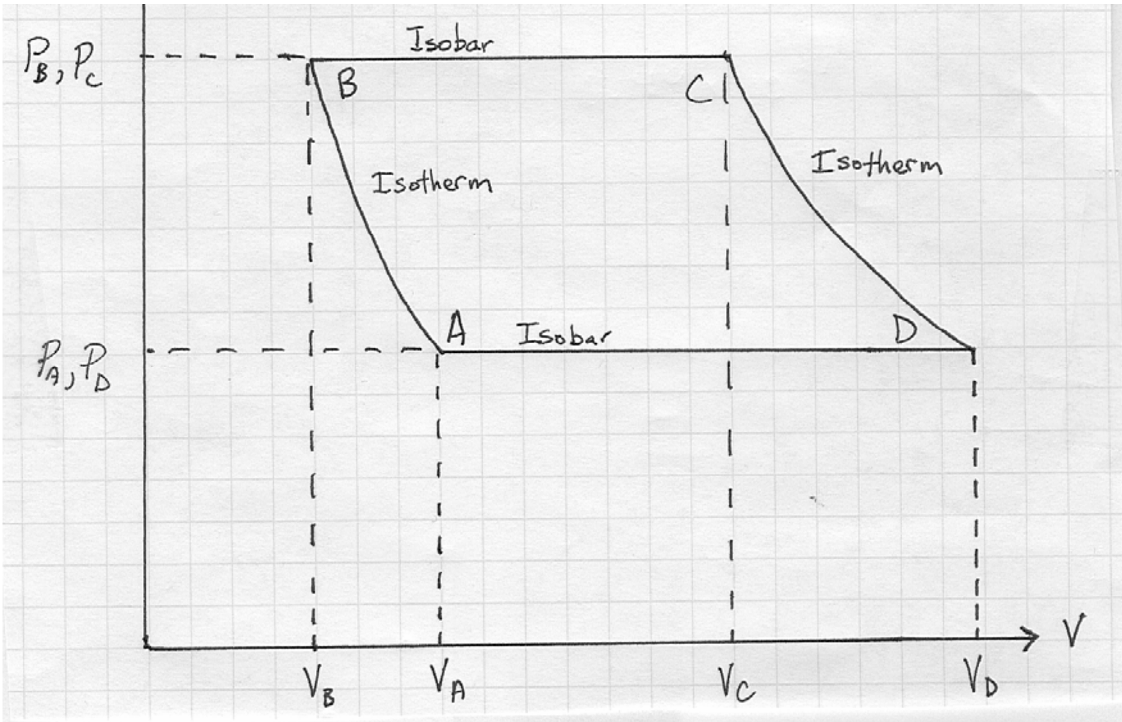


Figure adapted from PASCO Scientific instruction manual for Heat Engine / Gas Law Apparatus, document #012-06014C.

Two legs of the cycle are isotherms, and two are isobars. It is possible to calculate the work done by the system and the heat added to the system during each leg of the cycle as shown on the next page. The PV Diagram will look something like this:



We can calculate work and heat separately for each portion of the process:

Isotherm

Temperature is constant, so $P = nRT\frac{1}{V}$, where nRT is a constant.

$$W = \int PdV = nRT\int \frac{1}{V}dV = nRT\ln\left(\frac{V_f}{V_i}\right).$$

Since the added heat is not causing a change in temperature, all the heat must be contributing to the work done:

$$Q = W = nRT\ln\left(\frac{V_f}{V_i}\right).$$

Also, the ideal gas equation of state tells us that $PV = nRT$. Since nRT is a constant, $P_iV_i = P_fV_f = nRT$, so we can express the work and heat in any of the following ways:

$$Q = W = nRT\ln\left(\frac{V_f}{V_i}\right) = P_iV_i\ln\left(\frac{V_f}{V_i}\right) = P_fV_f\ln\left(\frac{V_f}{V_i}\right)$$

Isobar

Pressure is constant, so

$$W = \int PdV = P\int dV = P(V_f - V_i)$$

And

$Q = nc_p(T_f - T_i)$ where c_p is the specific heat at constant pressure.

Procedure:

1. Set up the heat engine/ gas law apparatus with the aluminum cylinder attached to one nozzle and the LabPro gas pressure sensor attached to the other.

2. Set up the lab pro and start up the Logger Pro software. You will be using the pressure sensor to measure pressure and the temperature sensor to measure the temperatures of the hot and cold baths.

3. Fill one beaker with ice water. Fill another beaker with water and set it on a hot plate to boil.

4. You should now be able to read the volume indirectly from the scale on the piston chamber, and the pressure and temperature off the computer screen in Logger Pro.

5. Execute a cycle of our heat engine, using a mass of no more than 250g. Measure pressure and piston height at each step of the way.

6. Repeat the A → B and C → D phases for three or four different masses. This way you will have P vs. V data for these legs of the cycle.

Analysis:

1. Determine the volume of gas present in the system as a function of the piston height. You'll need to take the volume of air in the aluminum cylinder (V_0) and in the piston ($A \cdot h$) chamber into account. Use your data from part 5 and the relation $P_1V_1 = P_2V_2$ where $V = Ah + V_0$ to determine V_0.

2. Create a PV diagram for the cycle.

3. Describe each leg of the cycle (isothermal, isobaric, etc.)

4. For each leg of the cycle, calculate the following:

    a. W (work done by the system) calculated by integrating PdV

b. Q (Heat added to the system)

5. Find the total work done by the system from your PV diagram.

6. Find the total mechanical work, $mg\Delta y$.

7. Compare the results of 5 and 6.

8. Calculate Q_{hot} for the entire cycle. Calculate the thermodynamic efficiency of your engine.

9. Calculate the Carnot Efficiency for your bath temperatures. How does your efficiency from part 8 compare?