Physics 263

Experiment 5b
The Heat Engine

1 Purpose

A simple heat engine is used to raise a weight. The pressure and volume of the engine's gas is measured during the entire cycle, and the work done by the engine is computed. This is compared with the potential energy change of the weight.

2 Introduction

A heat engine is a device which converts heat into mechanical energy, when run in the "forward" direction. The thermodynamic cycle of a heat engine is a closed loop in the Pressure- Volume (P-V) plane. We consider here cycles created by compression and expansion of a gas.

We know that for any gas, the work done by the gas pressure in an expansion is

$$W_{12} = \int_{V_1}^{V_2} P dV$$

in which P is some function of V. The work is just the **area** under the curve $P(V)$. For a complete cycle, the system is returned to its starting point, generally following a different path. So the work done returning is

$$W_{21} = \int_{V_2}^{V_1} P dV$$

If $V_1 > V_2$ then $W_{12} > 0$, and $W_{21} < 0$. So the **total** work done over the cycle is just the sum of these two terms, which corresponds to the area enclosed by the loop. This is illustrated in Figure 1.

Sometimes, actual physical systems correspond closely to loops which can be calculated. Some examples are the Otto cycle, the Diesel cycle and the Carnot cycle. We will consider a simpler cycle, illustrated in Figure 2. Let's call it the "Pasco" cycle.

To achieve this cycle, a cylinder and piston are used. A heating chamber, which may be put in different thermal baths, is connected to the cylinder.

The experimental arrangement is shown in Figure 3. Initially the system starts at point 1 in Figure 2, with the chamber in cold water. Then an additional "load" mass is gradually [1] placed on top of the piston. This causes a decrease in the volume, V, and

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[1]The term "gradually" means to slowly release the weight of the load mass. If this is not done, the piston will "bounce" and additional energy losses due to friction will occur.
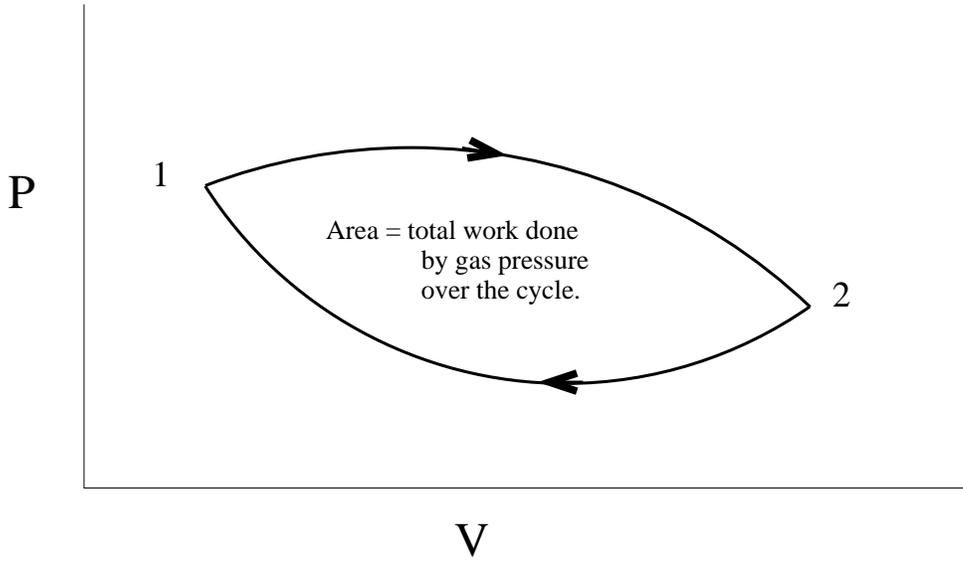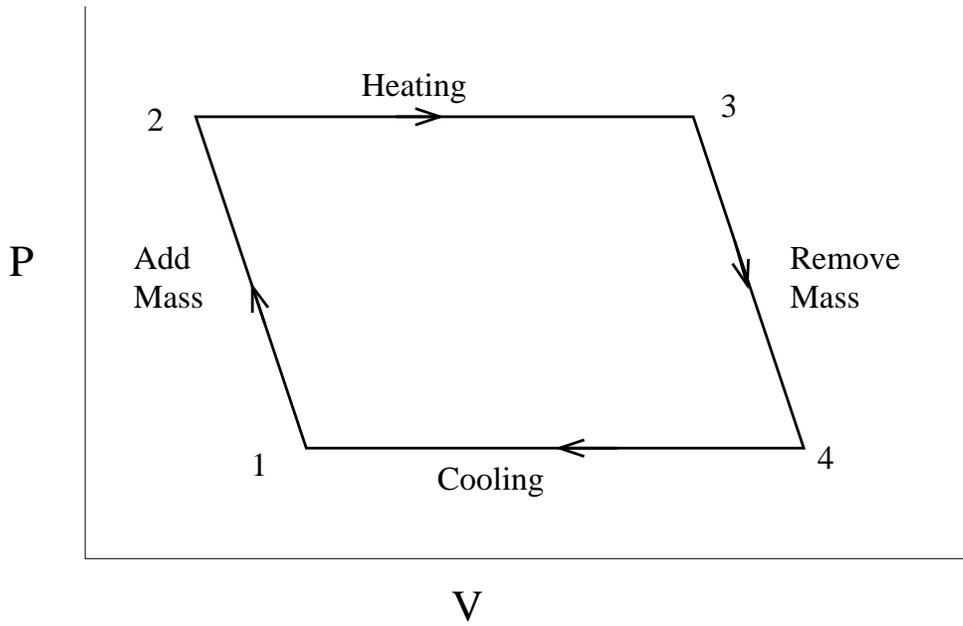
Figure 1: A complete cycle on the $P - V$ plane.

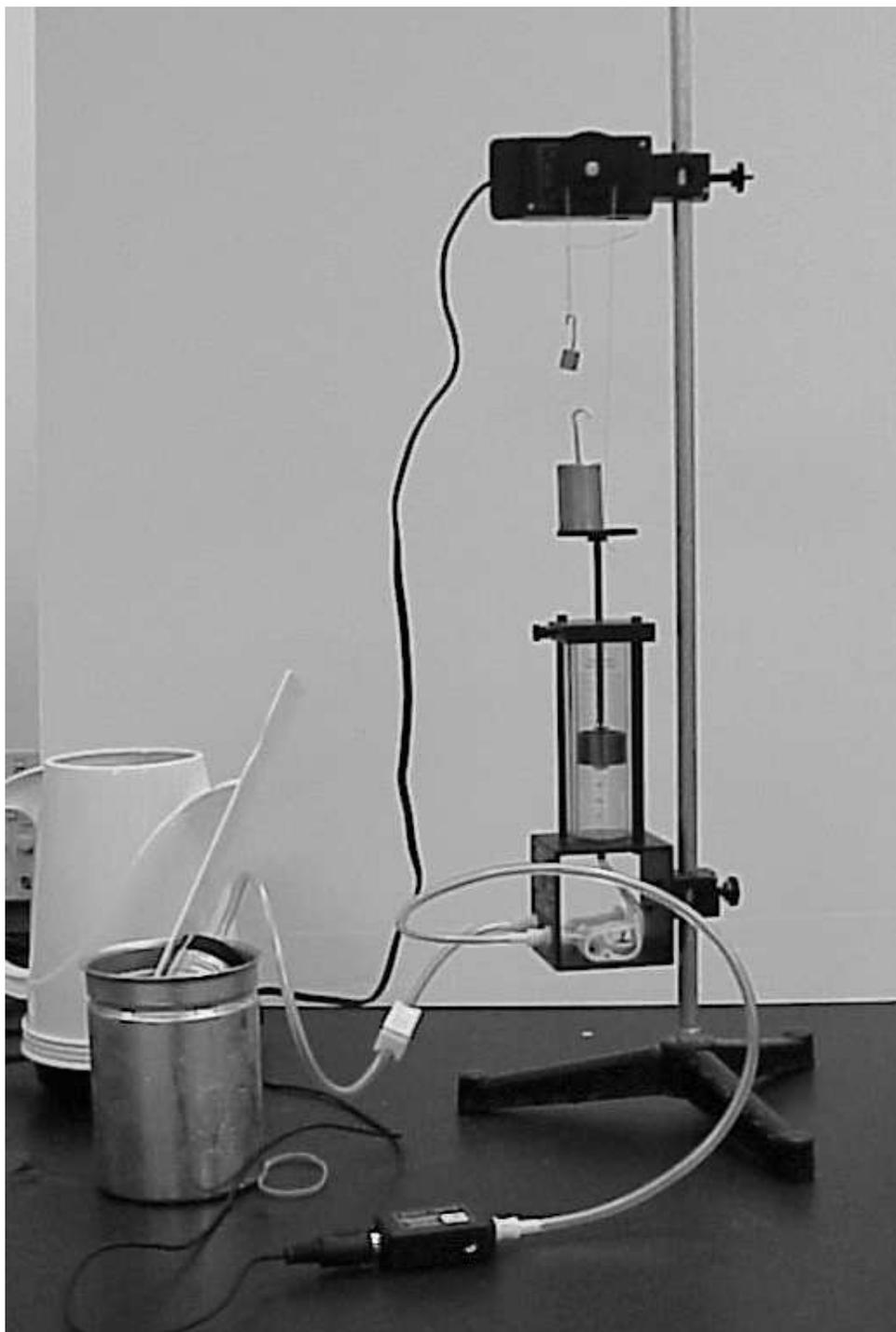Figure 2: The "Pasco" cycle on the $P - V$ plane.

Figure 3: Heat engine apparatus.

an increase in pressure, P. [2] Then the chamber is placed in hot water, producing an expansion at constant P. This raises the load mass, increasing its potential energy. Then the load mass is gradually removed, increasing V and decreasing P. Finally, the chamber is placed back in cold water, restoring the system to its initial state.

3 Procedure

1. Set up the rotary motion sensor as shown in Figure 3. Make sure the pulley moves clockwise when the piston goes up.

2. Using the Calculator, compute the volume $V = Ax$ where x is position and A is the cross sectional area of the cylinder. The diameter of the cylinder is marked on its side.

3. Connect the Pressure and Rotary Motion Sensor to the Pasco Interface. Double click on the rotary motion sensor icon and under Measurements, select Position (m).

4. Set up a graph of Volume and Pressure. To do this, open the graph display from the list of displays. Now drag Volume from the data list to the x-axis of the graph. Do the same thing for Pressure and drag it to the y-axis.

5. Use ice water for the cold bath, and hot (not boiling) water for the hot bath. First put the chamber in the cold bath and wait for the piston to sink.

6. Press the start button in Data Studio to begin taking data.

    (a) Slowly place a $200g$ mass on top of the heat engine to increase the pressure.

    (b) Leaving the mass on top of the heat engine, move the chamber to the hot bath. item Next, slowly remove the mass from the heat engine.

    (c) Lastly, complete the cycle by placing the chamber into the cold bath again.

7. Now Press the Stop button and view the graph. If it looks OK, print it out. Estimate the area of the graph by assuming the cycle is a parallelogram. Compute the work done by the engine on the $200g$ mass. Is it equal to the area of the graph? What effect(s) could make them different?

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[2]The left and right sides of the cycle are most likely somewhere between isothermal ($P \propto 1/V$) and adiabatic ($P \propto 1/V^{1.4}$) changes. Because the fractional changes in P and V in this experiment are so small, the curves are very close to straight lines.