Introduction

This material corresponds with Hecht, Chapter 14. In this lab you will explore several different engines and their cycles. You should read all the steps in each part before you start. Note that Experiment A is a demo that the TA will show to your group. Material in this lab has been adapted from Sokoloff, *Real Time Physics*.

Pre-Lab Homework

These **Pre-Lab Homework** problems must be done before you get to lab. They are predictions – your hypothesis – of what you think might happen. You will actually perform each of the experiments and discover if your predictions were correct. Write down what you honestly think will happen, so that at the end of the experiment you can compare your ideas with what you saw. Your TA's will be able to better help you in lab if they can see from your Pre-Lab what ideas you have about what is going on. You will not be graded down for wrong predictions, but you will lose points for missing predictions.

You will need to read Experiment B of the lab to answer these questions:

1. With the system closed to outside air and the flask in the cold reservoir, what should happen to the height of the platform during transition $A \to B$, as you add mass to the platform? Explain your reasoning.
2. What do you expect to happen to the height of the platform during transition $B \to C$, when you place the flask in the hot reservoir?
3. If you continue to hold the flask in the hot reservoir, what will happen to the height of the platform when the added mass is removed from the platform during transition $C \to D$? Explain your reasoning.
4. What do you predict will happen to the height of the platform during transition $D \to A$, when you now place the flask back in the cold reservoir? Explain your reasoning.
5. Draw a *PV*-diagram for this process.
6. Assume that your cold water bath is at a temperature of 0 °C, and the hot water bath is at a temperature of 70 °C. Calculate the Carnot efficiency of this engine. (This is not a prediction; a numerical answer can be obtained.)
7. Based on the Carnot efficiency you calculated above, predict the actual efficiency of this engine.

Experiment A: The Fire Syringe

This demonstration is depicted in Figure 14.13 in Hecht (pg. 581). Your TA's will show you this demonstration.
Examine the experimental set-up and give a brief description of the following:

- The materials used
- How the materials were put together (including a sketch)
- What you observe happening
- The physics that is occurring
- The forms of energy involved (Give at least three forms of energy.)

Experiment B: The Mass-Lifting Heat Engine

Materials:

- 10 cm^3 low-friction glass syringe with ring stand support
- Tygon tubing
- 25 mL flask with one-hole rubber stopper
- 2 Styrofoam cups to use as reservoirs
- Ruler
- 50 g mass
- Hot water (60-70 °C)
- Ice water
- Digital thermometer

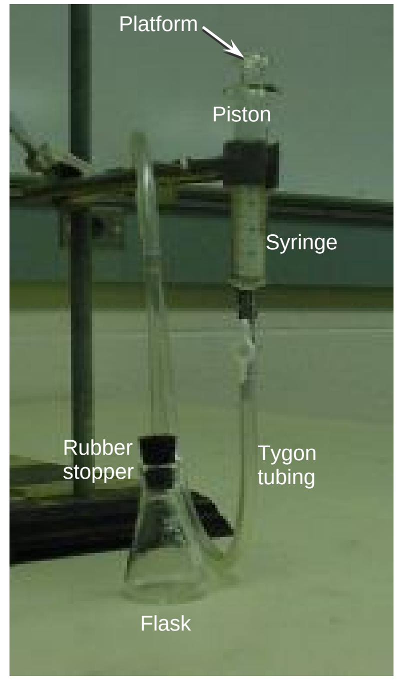

Fig. 1: Experimental setup.

Procedure:

The engine you will use can be taken through a four-stage expansion and compression cycle that uses heat energy from hot water and can do useful mechanical work by lifting small masses. Examine the equipment and set-up as shown in Fig. 1:

- The cylinder is a low-friction glass syringe.
- The flat top of the piston (plunger) is the platform where the 50 g mass will sit.
- The flask and syringe are connected with Tygon tubing.
- The two Styrofoam cups will be used as hot and cold reservoirs.

Fill one Styrofoam cup with ice water and one cup with hot water. While the flask is at room temperature, raise the piston so that there is 4-5 cc of air trapped inside the syringe, and then place the rubber stopper into the flask. If you notice that your piston is sticking in the syringe, wipe off any dust on the plunger with a paper towel. Now that you have the engine set up, we will take it through one cycle: *A-B-C-D-A.*

Point *A*: Place the flask in the cold reservoir. This is **point *A***.

Point *B*: Quickly place the 50 g mass on the platform. An adiabatic compression occurs. This is **point *B***.

Point *C*: Move the flask from the cold reservoir to the hot reservoir. An isobaric expansion occurs. This is **point *C***.

Point *D*: Now remove the mass from the platform. An adiabatic expansion occurs. This is **point *D***.

Point *A*: By placing the flask back into the cold reservoir, an isobaric compression occurs and the system is back at **point *A***.

Experiment B (continued):

Questions:

Going through the cycle again slowly, answer the following questions:

B1. When you add the mass going from $A \rightarrow B$, what do you observe? Is this what you predicted? Why is this adiabatic?

B2. When you move the flask into the hot reservoir going from $B \rightarrow C$, what do you observe? Is this what you predicted? Why is this isobaric?

B3. When you remove the mass going from $C \rightarrow D$, what do you observe? Is this what you predicted? Why is this adiabatic?

B4. When you place the flask back into the cold reservoir, what do you observe? Why should this be isobaric?

B5. How does the volume of air compare to the original volume of air at point *A* at the beginning of the cycle? Do you think the pressure of the gas is the same as it was originally? Explain your thinking.

B6. Take the engine through another cycle, this time carefully measuring the initial volume of air inside the syringe and measuring with a ruler the height the mass is raised when going from $B \rightarrow C$, and the temperatures of the hot and cold reservoir.

B7. Use the energy relation,

$$W = \text{PE} = mgh$$

to calculate the useful mechanical work done (in Joules) from raising the mass, *m*, from one level to another.

B8. Next you need to determine the number of moles of air in your system. This will take several steps, but it is not very difficult:

- First, bring your system to room temperature. If the 50 g mass is on the platform, remove it now. You may need to let the flask sit for a few minutes if it has recently been in one of the reservoirs.
- Now that the flask is at room temperature, you can assume the pressure is 1 atm. You should also measure the temperature of the air.
- Measure the length of the tubing and use the value of 0.5 cm for the inside diameter to calculate the volume of air in the tubing.
- Calculate the total volume of air in the system (assuming the tubing is cylindrical) using the equation,

$$V_{\text{total}} = V_{\text{syringe}} + V_{\text{tubing}} + V_{\text{flask}}$$

- Now use the ideal gas law,

$$PV = nRT$$

  to determine the number of moles of air in your system.

Experiment B (continued 2):

Questions (continued):

B9. Using the temperatures of the two reservoirs, calculate the heat transferred into the gas with the following relation:

$$Q = nC_p\Delta T$$

where C_p is 29.0 J/mol·K for air.

B10. Calculate the efficiency of this engine. Recall that percent efficiency is

$$e = 100\%\left(\frac{W_{out}}{Q_{in}}\right) = 100\%\left(\frac{W}{Q_H}\right)$$

B11. Is this engine very efficient? What percentage of the input heat is converted to useful work? What percentage is lost as heat and energy?

B12. The most efficient possible heat engine running between a hot reservoir T_H and a cold reservoir T_C is a Carnot engine. Calculate the Carnot percent efficiency given by

$$\eta = e_C = 100\%\left(1 - \frac{T_C}{T_H}\right)$$

where the temperatures, T_C and T_H are measured in Kelvin, *not* Celsius.

B13. How does the efficiency of the engine compare to the to the maximum possible (Carnot) efficiency? How does the actual efficiency compare with your prediction in Pre-Lab #7? Are you surprised?