Physics III
Experiment X
The Heat Engine

Purpose

To study a simple thermodynamic engine that takes a fixed quantity of gas through a cyclic process converting heat energy into mechanical work.

Introduction

The heat engine you will use consists of two cylinders connected by a small tube. The main cylinder is fitted with a plunger that may be used to lift small weights. The graduations allow you to determine volume changes of the gas. The second cylinder is immersed into a hot or a cold heat-bath in order to change the temperature of the gas. Two kinds of process can be conveniently be performed by this heat engine. With the second cylinder at fixed temperature, placing (or removing) weights on the graduated cylinder produces approximately an isothermal compression (or expansion) of the gas. On the other hand, for a given weight on the plunger, an isobaric transfer of heat into (or out of) the system is accomplished by switching the second cylinder between the two heat baths. By combining these two processes it is possible to take the gas through a thermodynamic process that is a cycle.

Procedure

The cycle has four stages.

1) Initial state (no mass on the plunger), the second cylinder is in the cold heat-bath.
2) Place a weight on the plunger. This will produce a compression of the gas.
3) Swap the second cylinder from the cold to the hot heat-bath. This will produce an isobaric expansion of the gas as heat is added.
4) Remove the weight from the plunger and this will result in an additional expansion of the gas.

You should take the engine through this cycle a couple of times to see how it works. Perform the cycle in reverse once.

Each leg of the cycle must be defined in order to calculate the work, and heat transfer. The total pressure on the gas in the system is equal to the sum of the atmospheric pressure and the pressure produced by the weight of the plunger.

$$P = P_o + \frac{mg}{A} \tag{1.1}$$

Here A is the area of the plunger. Changes in volume can be noted by observing the motion of the plunger. The temperature control is probably the weakest point because only the air in the second cylinder is likely to be in equilibrium with the heat bath. However, since the connecting tube between the cylinders is small, the temperature of the gas is approximately given by the heat bath as long as the excursions of the plunger are not large. The plunger is fairly free of friction, but if you place weights much heavier than 200g then leaking of air around the plunger will be a source of error.

During the isothermal compressions there is both work being done and heat being transferred. If we assume that the air is an ideal gas then we can calculate the work performed and deduce the heat transferred. Starting from $PV=nRT$, we can see that at constant temperature:

$$W = \int PdV = nRT \int_{V_1}^{V_2} \frac{dV}{V} = nRT \log\left(\frac{V_2}{V_1}\right) \qquad (1.2)$$

Suggested Problems

1) Calculate the work, heat transfer and change in internal energy for each leg of the cycle based on measurements of the apparatus. Plot the cycle on a PV diagram indicating the four processes in the cycle.
2) Consider the role that friction, gas leakage, and temperature non uniformity might have on your results. Can you see any direct evidence that any of these effects (or others that you can identify) are playing a role in the experiment?