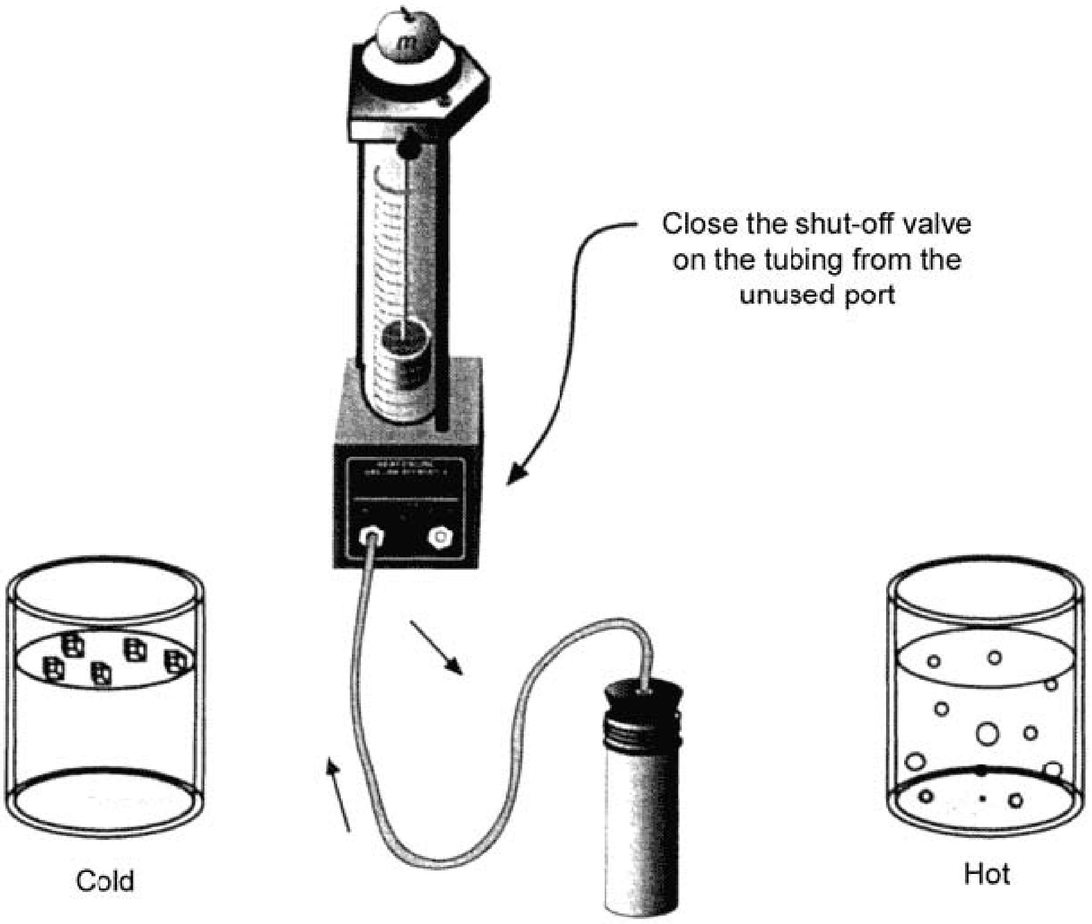
# AREN 2110: Heat Engine Experiment

## Problem

You will be using the piston/cylinder to investigate the work output of a heat engine. You will lift a mass by expanding a gas and will compute mechanical work, net thermodynamic work and net heat transfer.

## Equipment Required:

1. Heat Engine/Gas Law Apparatus (Piston/Cylinder) (See attached data sheet)
2. One 100-g mass (brass)
3. Hot Plate, 2 beakers, one capable of being heated to 100 C
4. Water, Ice
5. Barometer


Close the shut-off valve on the tubing from the unused port

## Background:

The heat engine consists of a hollow cylinder with a graphite piston that can move with very little friction. The cylinder attaches to an air chamber through a small flexible tube. As the air temperature inside the air chamber increases, its volume will increase forcing more air into the cylinder and raising the platform. If the air temperature in the air chamber decreases, its volume will decrease drawing air from the cylinder and tube and lowering the platform.

While the system does have a constant pressure throughout, the temperature in the cylinder and air chamber is not necessarily the same. Because of the narrow size and long length of the tube, it takes a great deal of time before the air chamber and cylinder temperatures can equilibriate. Thus, it is probably a good approximation to consider the air chamber and cylinder to be separate systems as far as temperature and heat transfer, but a single system when considering the expansion or contraction of the air inside.

In this experiment you will lift a mass using the expansion of a heated gas. In order to return the piston to the original position, your system must undergo an entire cycle. You can compute the mechanical work the system does by determining the distance through which the mass was lifted and the force required to do so. By carefully noting the pressure and volume at each point in the cycle, you can also compute the thermodynamic work required to complete the cycle

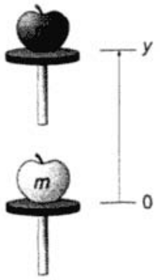


**Figure 5.1. Doing useful mechanical work by lifting a mass, *m*, through a height, *y*.**

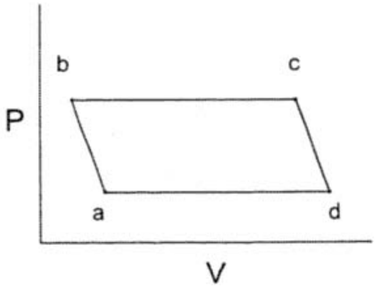


**Figure 5.2 Doing thermodynamic work in a heat engine cycle.**

# Introduction

The PASCO TD-8572 Heat Engine/Gas Law Apparatus is used for quantitative experiments involving the Ideal Gas Law (as described below) and for investigations of a working heat engine. The equipment allows the amount of work done by thermal energy to be measured.

The heart of this apparatus is a nearly friction-free piston/cylinder system. The graphite piston fits snugly into a precision-ground Pyrex cylinder so that the system produces almost friction-free motion and negligible leakage.

# Equipment

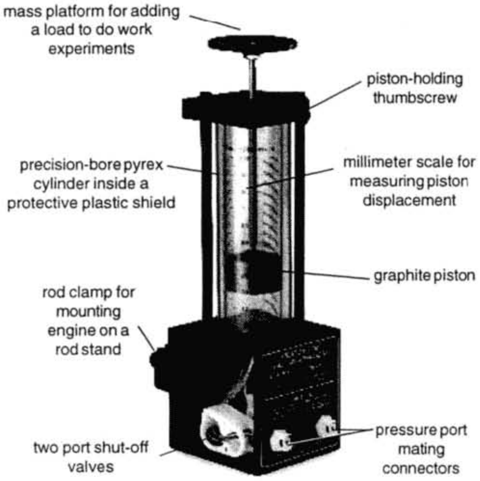


**Figure 1. Base apparatus**

The Heat Engine/Gas Law Apparatus is designed with two pressure ports with quick-connect fittings for connecting to the air chamber tubing.

The apparatus can be connected to a Low Pressure Sensor for use with PASCO computer interfaces.

Do not apply lubricant to the piston or cylinder.

Do not immerse the base apparatus in liquid.

Note: Use only non-caustic/non-toxic gases such as air or helium.

**The apparatus includes the following equipment**

- base apparatus (Figure 1)
  - piston diameter: 32.5 mm ± 0.1
  - mass of piston and platform: 35.0 g ± .06
- air chamber (Figure 2)
- 3 hose configurations: one with one-way check valves and one with a clamp (Figure 2), and one plain piece of tubing (not shown)
- 1 each, one-holed and two-holed rubber stopper

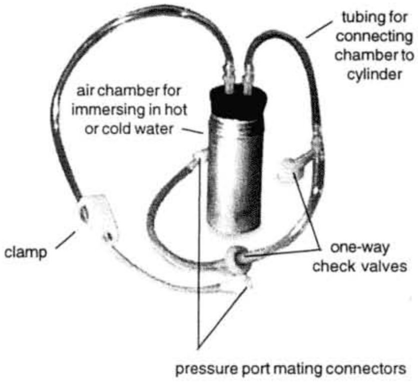


**Figure 2. Air chamber and tubing**

Always release the tubing clamps prior to storage to avoid permanently deforming the tubing.

Maximum Pressure: 345 kPa.

## Theory:

Mechanical Work:

Work=Force x distance or $W = F\,\Delta X$

Thermodynamic boundary work (at constant pressure):

Work = Pressure x volume change or $W = P\,\Delta V$

For a general thermodynamic process (pressure not necessarily constant)

Draw a graph of P vs V

Work = area under P-V curve. If volume is increasing work is positive or out of the system (work done by system) if V is decreasing, work is negative or into the system (work is done on system).

For a cycle, the net work is the area enclosed by the P-V curve. If curve goes clockwise, net work is positive. If P-V curve goes counter-clockwise, net work is negative.

For a piston in a cylinder, the pressure on the piston is the $P= F/A$ where $F$=force on the piston and A =area of the piston. When adding a mass to a vertical piston, the force is gravity, so $F=m\,g$ and the change in pressure is $\Delta P=m\,g/ A$.

## Procedure:

1. Record the barometric pressure and temperature in the room.
2. With the air chamber at room temperature, put piston about 1/3 of the way from the bottom to the top of the cylinder. (You can move the piston by opening the closed valve on the piston cylinder, moving the piston and closing that same valve.
3. Record the position of the cylinder.
4. Run the system through its the following cycle nine times, quickly recording the platform position at the end of each step:

Place Cylinder in Cold water

**A → B Add mass to platform**

**B → C Move cylinder to the hot water**

**C → D Remove the mass**

**D → A Return the cylinder to the cold water**

5. Replace the ice water bath with cool water at ~ room temperature and repeat step 4.

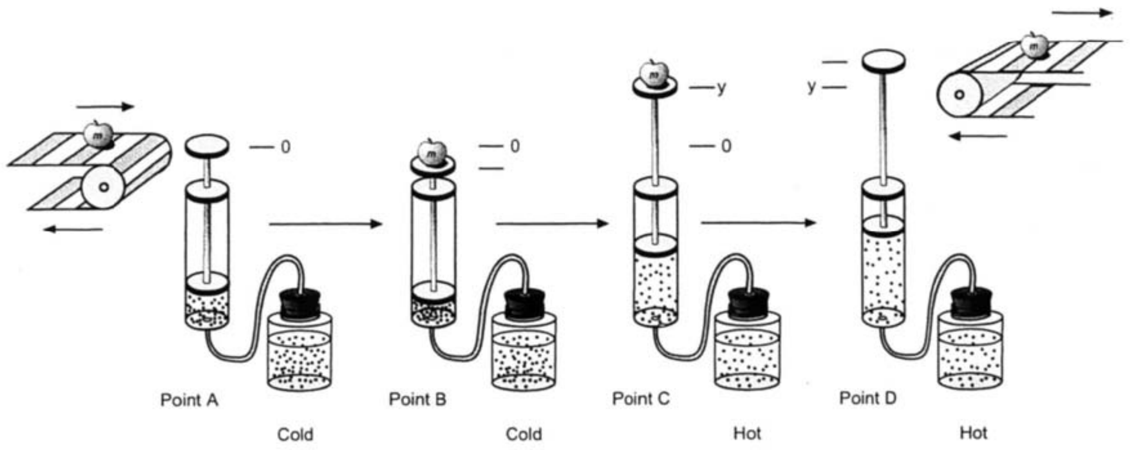


**Figure 5.3. A simplified diagram of the mass lifter heat engine at different stages of its cycle.**

Hints: When the mass is on the platform do NOT wait long for the piston position to equilibriate. The piston/cylinder leaks slightly and the position will be continually dropping with the mass attached. You should take the data within a second or of adding a mass or moving the air chamber between hot and cold water and the piston slowing its motion. Do NOT push down as you add the weight as it will add to the air leakage. Add the weight to the platform as carefully as possible while still doing it quickly. Do several trial runs to get the hang of it before you begin recording data.

## RESULTS AND DISCUSSION

1. Describe each thermodynamic process in the cycle: e.g., are processes adiabatic? Isobaric? Isothermal? Where is work done on/by the system? In which processes and in what direction does heat transfer occur?
2. For each of the nine experimental runs, compute the changes in pressure and volume for each process in the cycle and generate *P*-*V* curves.
3. From your *P*-*V* data/graph, compute the average net thermodynamic work for the cycle.
4. Compute the mechanical work done by the device. How does it compare to the thermodynamic work?
5. Quantify and discuss the effect of the temperature of the low-temperature reservoir on work produced by the heat engine.
6. How appropriate are the assumptions of a closed system? Could you consider these processes reversible? Why not?
7. What are the sources of error in this lab? How do they affect the measurements and computations?

**Mass Lifter Data Sheet** **Date:__________**

Barometric pressure: _____________

Low temperature reservoir temperature (**ice** water bath) _______________

Run 1

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 2

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 3

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 4

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 5

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 6

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 7

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 8

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 9

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

**Mass Lifter Data Sheet** **Date:**__________

Barometric pressure: _____________

Low temperature reservoir temperature (**cool** water bath) _______________

Run 1

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 2

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 3

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 4

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 5

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 6

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 7

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 8

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

Run 9

| State | Position |
|---|---|
| A | |
| B | |
| C | |
| D | |
| A | |

## Lab Report

Similar organization to previous report:

1. Abstract: < 200 words, summarize findings
2. Problem Statement: purpose and importance of experiments
3. Background/Approach/Hypothesis: theory, variables
4. Procedure: changes to procedure, observations about device
5. Results: graphs, tables, sample calculations
6. Discussion: should address points in handout above, including error analysis
7. Conclusion: summarize actual findings, suggest changes, etc., in bullets,