Instruction Manual and Experiment Guide for the PASCO scientific Model TD-8592

012-08375A

SMALL PISTON HEAT ENGINE APPARATUS

PASCO® scientific

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better ways to teach science

The exclamation point within an equilateral triangle is intended to alert the user of the presence of important operating and maintenance (servicing) instructions in the literature accompanying the appliance.

Table of Contents

Copyright, Warranty, and Equipment Return

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Credits

Editor: Sunny Bishop

Equipment Return

If the product requires return to PASCO scientific for any reason, notify PASCO scientific by letter, phone, or fax BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION FROM PASCO.

When returning equipment for repair, the units must be properly packed. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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Introduction

The PASCO TD-8592 Small Piston Heat Engine 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

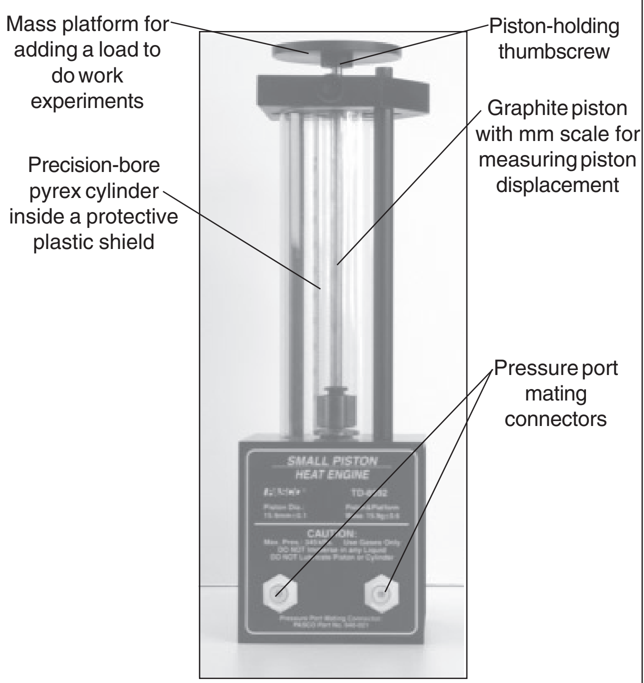


Figure 1. Base apparatus with piston

The Small Piston Heat Engine 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: 15.9 mm ± 0.1
  - mass of piston and platform: 15.9 g ± .06
- Air chamber (Figure 2)
- Three hose configurations: one with one-way check valves and one with a clamp (Figure 2), and one plain piece of tubing (not shown)
- One each, one-holed and two-holed rubber stopper

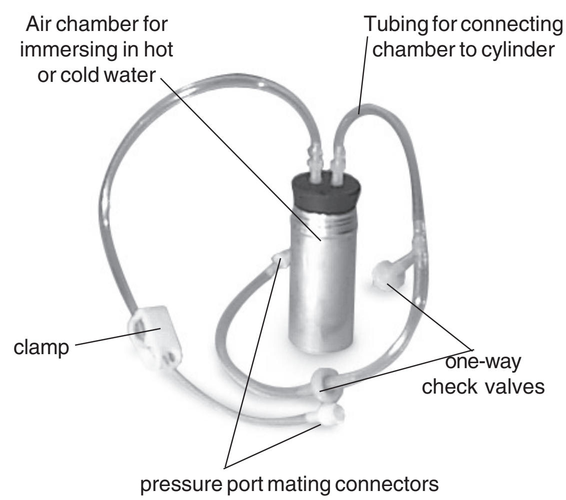


Figure 2. Air chamber and tubing

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

Maximum Pressure: 345 kPa.

Notes:

Experiment 1: Operation of a Heat Engine

Equipment Required:	
• Small Piston Heat Engine	• Container of hot water
• Mass, 50 – 100 g mass	• Container of ice water

Equipment Setup

① Using the one-holed stopper, connect the tubing with the one-way valves to the air chamber and to a connecting port on the base assembly.

② Close the shut-off valve on the tubing from the unused port.

③ Set a mass of 50 to 100 g on the mass platform.

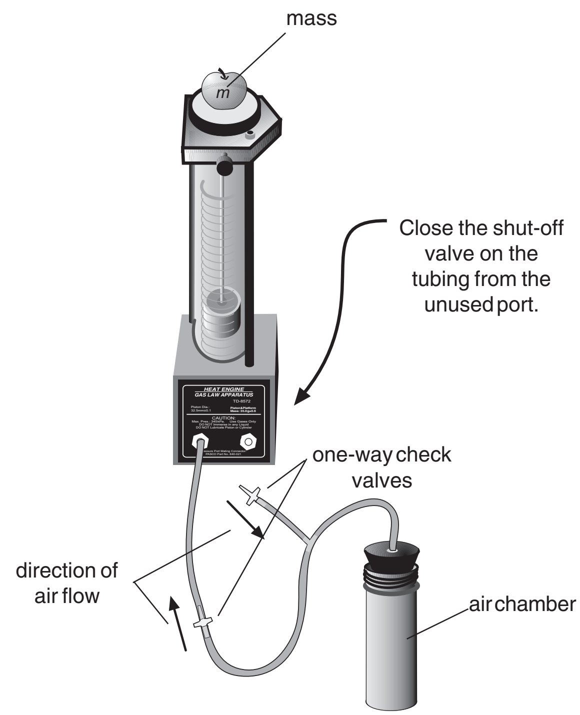


Figure 1.1. Setup for the Heat Engine

➤ **Note:** Use a maximum mass of 100 grams in the experiment. A larger mass will cause the valve seals to leak.

Procedure

① Move the air chamber from an ice water bath to a hot water bath. You will note that the air in the chamber quickly expands through the tubing and moves the piston up. Note also that the one-way check valve in the tubing connecting the base apparatus and the air chamber permits air to enter the cylinder, while the other one-way checkvalve prevents air from leaving through the branched tube.

② Move the air chamber back to the cold bath and note that external air is sucked into the air chamber through the one-way valve located at the end of the branched tube. Note also that the one-way valve in the connecting tube prevents the air from escaping from the piston, so the height of the piston remains the same.

③ Repeat steps 1 and 2 until the mass has been completely lifted. The greater the temperature differential between the hot and cold water baths, the greater the lift achieved through each cycle through them.

Note: For a more detailed, quantitative investiagtion of the heat engine operation, see Experiment 5 (page 11).

Notes:

Experiment 2: Charles' Law

Equipment Required:	
• Small Piston Heat Engine	• Container of hot water
• Thermometer	• Ice

Theory

Charles' law states that at a constant pressure, the volume of a fixed mass or quantity of gas varies directly with the absolute temperature:

$V = cT$ (at constant *pressure, P,* where *temperature, T,* is expressed in degrees Kelvin)

Setup

① Using the one-holed stopper and plain tubing, connect the base apparatus and the air chamber.

② Close the shut-off valve on the tubing from the unused port.

③ Turn the base apparatus on its side. (In this position, the force acting on the apparatus is the atmospheric pressure and is equal throughout the range of operation of the piston.)

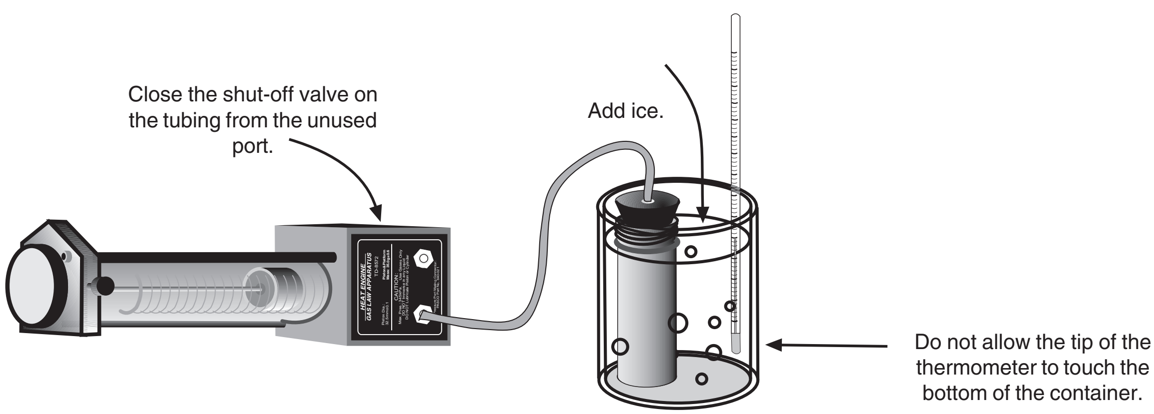


Figure 2.1: Experiment setup

Procedure

① Place the air chamber in a container of hot water. After the chamber equilibrates to the temperature, record the temperature and the height of the piston.

② Add ice to the container and record the temperature and pressure at regular time intervals.

③ Calculate the gas volumes at the various piston positions you measured and make a graph of plots of temperature versus volume. (Hint: The diameter of the piston is 15.9± 0.1 mm.)

Notes:

Experiment 3: Boyle's Law

Equipment Required:	
• Small Piston Heat Engine	• *ScienceWorkshop* computer interface*
• Pressure Sensor (CI-6532A)	• DataStudio software

*For details on setting up and operating the Pressure Sensor with *DataStudio software*, please consult the instruction sheet for the Pressure Sensor and the *DataStudio online help.*

Theory

Boyle's law states that the product of the volume of a gas times its pressure is a constant at a fixed temperature:

$$PV = a$$

Therefore, at a fixed temperature, the pressure will be inversely related to the volume, and the relationship will be linear:

$$P = \frac{a}{V}$$

Setup

① With the platform raised to its uppermost position, connect the Pressure Sensor to a port on the base apparatus with a short piece of tubing (Figure 3.1).

② Close the shut-off valve on the tubing from the unused port.

③ Connect the Pressure Sensor to the computer interface and set up DataStudio to record pressure. Be sure that you set up the keyboard sampling option so you can enter height data by hand. (See "Manual Sampling" or "Keyboard Sampling" in the DataStudio online help.)

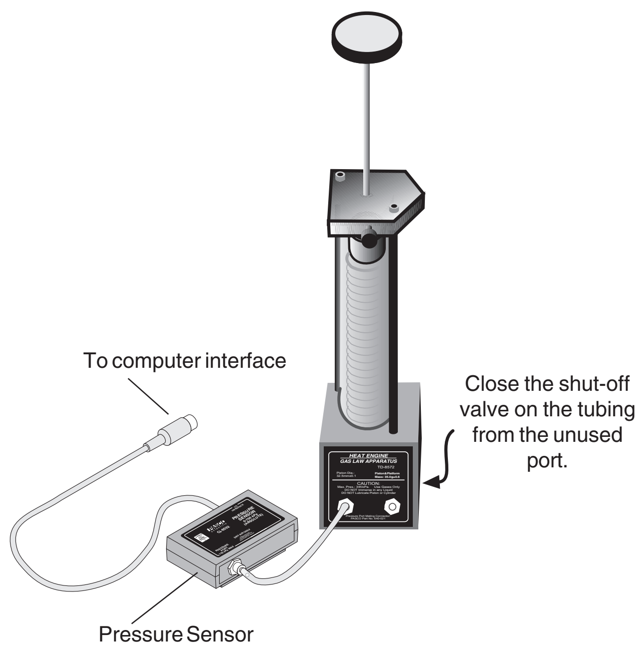


Figure 3.1. Experiment setup

Procedure

① Record the height of the piston and the pressure when the platform is raised to its highest position.

② Press the platform down to a series of levels and record the height and pressure at each level.

③ Convert the height measurements to gas volume measurements. (Hint: The diameter of the piston is 32.5 mm.)

④ Prepare a graph of pressure versus volume.

➤ Note: At pressures greater than 120 kPa, the relationship between pressure and volume may not be linear because of air leakage from the valves and ports at higher pressures.

Notes:

Experiment 4: Combined Gas Law (Gay-Lussac's)

Equipment Required:	
• Small Piston Heat Engine	• Hot plate
• Pressure Sensor (CI-6532)	• Beaker with water
• *Science Workshop*® computer interface*	• Ice
• Temperature Sensor (CI-6505)	• DataStudio software

*For details on setting up and operating the Pressure Sensor and Temperature Sensor with DataStudio software, please see the instruction sheets for the Pressure and Temperature Sensors and the DataStudio online help.

Theory

Charles' law states that the volume,*V,* is proportional to the temperature, *T*. Boyle's law states that the volume, *V,* is proportional to the pressure, P, where pressure=1/P. Combining these, we have:

$$V = \frac{aT}{P}$$

The combined gas law predicts that for a given mass of gas, if *V* is held constant, *P* is proportional to *T*.

Setup

① Secure the piston just above its lowest position by tightening the thumb screw.

② Connect the Pressure Sensor to a port on the base apparatus with a short piece of tubing.

③ Connect the air chamber fitted with the two-holed stopper to the other port of the base apparatus with a piece of tubing.

④ Insert the Temperature Sensor into the other hole of the rubber stopper.

> ⚠ Use a silicon lubricant on the end of the Temperature Probe to aid insertion and to prevent damage to the probe.

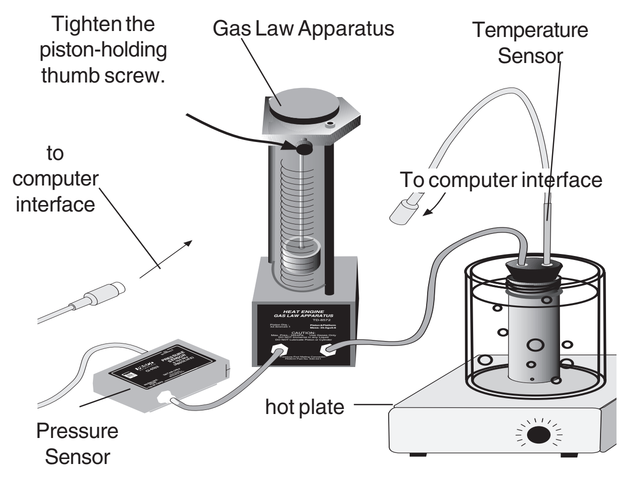


Figure 4.1. Experiment Setup

⑤ Connect the Pressure Sensor and Temperature Sensor to the computer interface, and set up the DataStudio software program to graph temperature versus pressure.

> ➤ Note: You can substitute a thermometer in the water container for the Temperature Sensor. Be sure to keep the tip of the thermometer from touching the bottom of the container.

⑥ Place the air chamber in the Pyrex container and turn on the hot plate.

Procedure

① Record the temperature and pressure as the water heats.

② Display a graph of temperature versus pressure in DataStudio software.

Notes:

Experiment 5: The Mass Lifter Heat Engine[1]

The Small Piston Heat Engine is ideal for use in the calculus-based experiment 18.10 of the *Workshop Physics Activity Guide*. Following is a slightly modified reprint of the experiment:

Equipment Required:	
• Small Piston Heat Engine (1)	• Calipers (1 set)
• Beakers (2), 1000 ml (to use as reservoirs)	• Mass set, 20 g, 50 g, 100 g, 200 g
• Ruler (1)	• Hot plate(1)
• Barometer pressure gauge (1)	• Vat to catch water spills (1)

Optional:

- A computer-based laboratory system with barometer sensor

Your working group has been approached by the Newton Apple Company about testing a heat engine that lifts apples that vary in mass from 50 g to 100 g from a processing conveyer belt to the packing conveyer belt that is 10 cm higher. The engine you are to experiment with is a "real" thermal engine that can be taken through a four-stage expansion and compression cycle and that can do useful mechanical work by lifting small masses from one height to another. In this experiment, we would like you to verify experimentally that the useful mechanical work done in lifting a mass, *m,* through a vertical distance, *y*, is equal to the net thermodynamic work done during a cycle as determined by finding the enclosed area on a *P-V* diagram. Essentially you are comparing useful mechanical "$ma_g y$" work (which we hope you believe in and understand from earlier studies) with the accounting of work in an engine cycle as a function of pressure and volume changes given by the expression:

$$W_{net} = \oint PdV$$

Although you can prove mathematically that this relationship holds, the experimental verification will allow you to become familiar with the operation of a real heat engine.

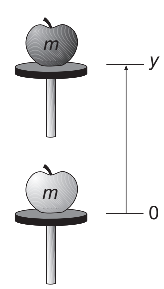


Figure 5.1. Doing useful mechanical work by lifting a mass, *m*, through a height, *y*.

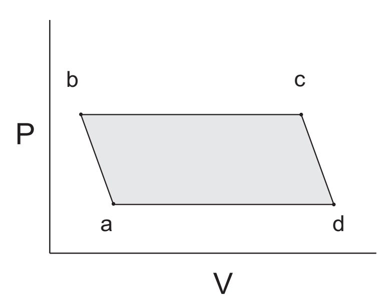


Figure 5.2 Doing thermodynamic work in a heat engine cycle.

[1]Priscilla W. Laws, et al. *Workshop Physics Activity Guide*, 1996 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.

The Incredible Mass Lifter Engine

The heat engine consists of a hollow cylinder with a graphite piston that can move along the axis of the cylinder with very little friction. The piston has a platform attached to it for lifting masses. A short length of flexible tubing attaches the cylinder to an air chamber (consisting of a small can sealed with a rubber stopper that can be placed alternately in the cold reservoir and the hot reservoir. A diagram of this mass lifter is shown in Figure 5.2.

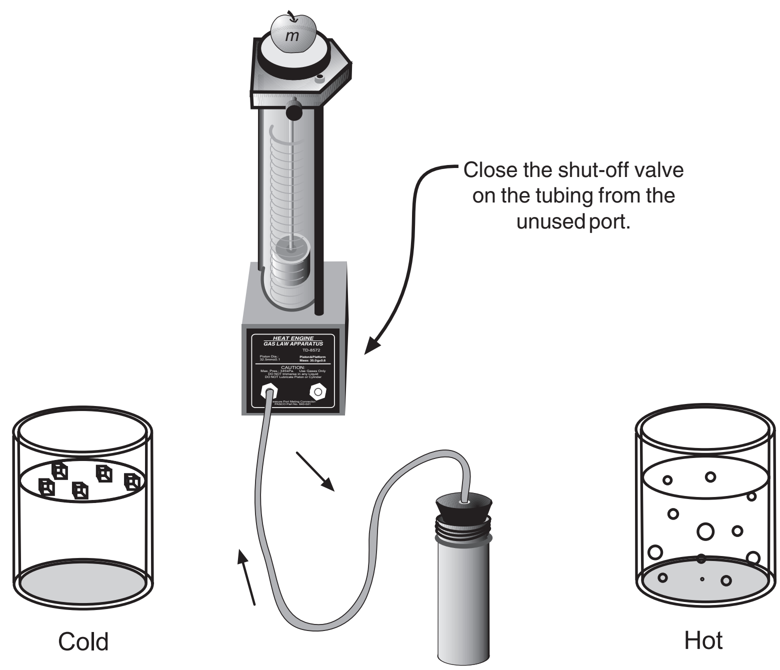


Figure 5.3. A schematic diagram of the incredible mass lifter heat engine

If the temperature of the air trapped inside the cylinder, hose, and can is increased, then its volume will increase, causing the platform to rise. Thus, you can increase the volume of the trapped air by moving the can from the cold to the hot reservoir. Then, when the apple has been raised through a distance *y*, it can be removed from the platform. The platform should then rise a bit more as the pressure on the cylinder of gas decreases a bit. Finally, the volume of the gas will decrease when the air chamber is returned to the cold reservoir. This causes the piston to descend to its original position once again. The various stages of the mass lifter cycle are shown in Figure 5.3.

Before taking data on the pressure, air volume, and height of lift with the heat engine, you should set it up and run it through a few cycles to get used to its operation. A good way to start is to fill one container with room temperature water and another with hot tap water or preheated water at about 60–70°C. The engine cycle is much easier to describe if you begin with the piston resting above the bottom of the cylinder. Thus, we suggest you raise the piston a few centimeters before inserting the rubber stopper firmly in the can. Also, air does leak out of the cylinder slowly. If a large mass is being lifted, the leakage rate increases, so we suggest that you limit the added mass to something between 50 g and 100 g. After observing a few engine cycles, you should be able to describe each of the points *a, b*, *c*, and *d*

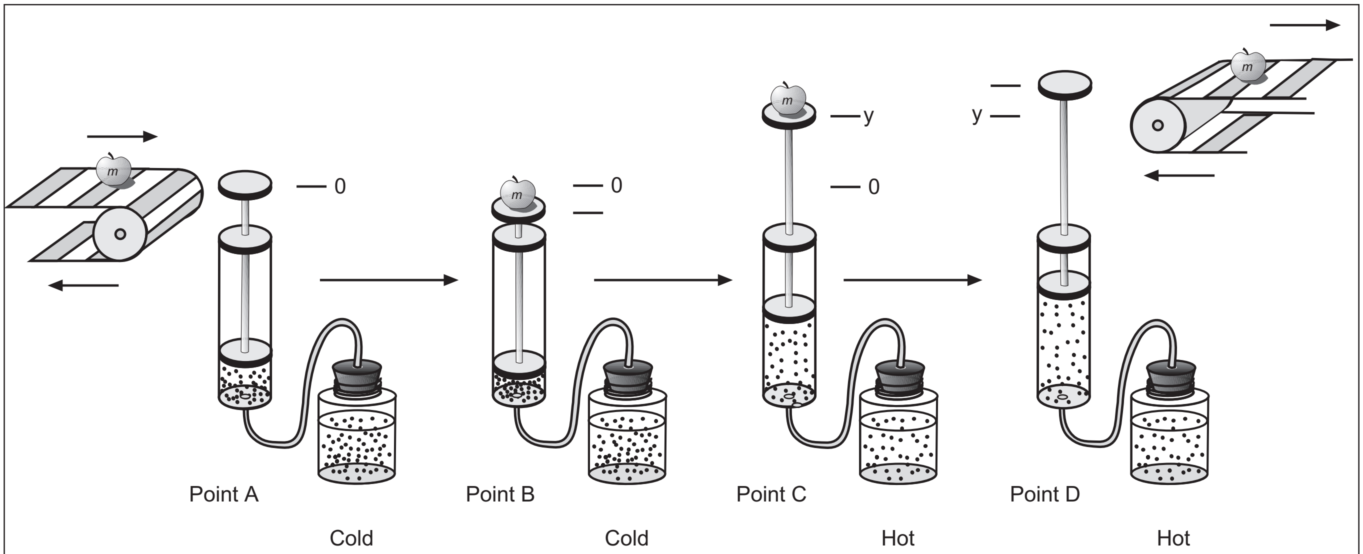


Figure 5.4. A simplified diagram of the mass lifter heat engine at different stages of its cycle

of a cycle carefully, indicating which of the transitions between points are approximately adiabatic and which are isobaric. You can observe changes in the volume of the gas directly and you can predict how the pressure exerted on the gas by its surroundings ought to change from point to point by using the definition of pressure as force per unit area.

5.1 Activity: Description of the Engine Cycle

a. Predicted transition *a*➔*b*: Close the system to outside air but leave the can in the cold reservoir. Make sure the rubber stopper is firmly in place in the can. What should happen to the height of the platform when you add a mass? Explain the basis of your prediction.

b. Observed transition *a*➔*b*: What happens when you add the mass to the platform? Is this what you predicted?

c. Predicted transition *b*➔*c*: What do you expect to happen when you place the can in the hot reservoir ?

d. Observed transition *b*➔*c*: Place the can in the hot reservoir and describe what happens to the platform with the added mass on it. Is this what you predicted? (This is the engine power stroke!)

e. Predicted transition *c*➔*d*: Continue to hold the can in the hot reservoir and predict what will happen if the added mass that is now lifted is removed from the platform and moved onto an upper conveyor belt. Explain the reasons for your prediction.

f. Observed transition *c*➔*d*: Remove the added mass and describe what actually happens. Is this what you predicted?

g. Predicted transition *d*➔*a*: What do you predict will happen if you now place the can back in the cold reservoir? Explain the reasons for your prediction.

h. Observed transition *d*➔*a*: Now it's time to complete the cycle by cooling the system down to its original temperature for a minute or two before placing a new mass to be lifted on it. Place the can in the cold reservoir and describe what actually happens to the volume of the trapped air. In particular, how does the volume of the gas actually compare to the original volume of the trapped air at point a at the beginning of the cycle? Is it the same or has some of the air leaked out?

i. Theoretically, the pressure of the gas should be the same once you cool the system back to its original temperature. Why?

Determining Pressures and Volumes for a Cycle

To calculate the thermodynamic work done during a cycle of this engine, you will need to be able to plot a *P-V* diagram for the engine based on determinations of the volumes and pressures of the trapped air in the cylinder, tubing, and can at the points *a, b, c*, and *d* in the cycle.

5.2 Activity: Volume and Pressure Equations

a. What is the equation for the volume of a cylinder that has an inner diameter of *d* and a length *L*?

b. Use the definition of pressure to derive the equation for the pressure on a gas being contained by a vertical piston of diameter *d* if the total mass on the piston including its own mass and any added mass is denoted as *M*. **Hints:** (1) What is the definition of pressure? (2) What is the equation needed to calculate the gravitational force on a mass, *M*, close to the surface of the Earth? (3) Don't forget to add in the atmospheric pressure, P_{atm}, acting on the piston and hence the gas at sea level.

Now that you have derived the basic equations you need, you should be able to take your engine through another cycle and make the measurements necessary for calculating both the volume and the pressure of the air and determining a *P-V* diagram for your heat engine. Instead of calculating the pressures, if you have the optional equipment available, you might want to measure the pressures with a barometer or a barometer sensor attached to a computer-based laboratory system.

5.3 Activity: Determining Volume and Pressure

a. Take any measurements needed to determine the volume and pressure of air in the system at all four points in the engine cycle. You should do this rapidly to avoid air leakages around the piston and summarize the measurements with units in the space below.

b. Next you can use your measurements to calculate the pressure and volume of the system at point *a*. Show your equations and calculations in the space below and summarize your results with units. Don't forget to take the volume of the air in the tubing and can into account!

$P_a =$

$V_a =$

c. Use the measurements at point *b* to calculate the total volume and pressure of the air in the system at that point in the cycle. Show your equations and calculations in the space below and summarize your results with units.

$P_b =$

$V_b =$

d. What is the height, *y*, through which the added mass is lifted in the transition from *b* to *c*?

e. Use the measurements at point *c* to calculate the total volume and pressure of the air in the system at that point in the cycle. Show your equations and calculations in the following space and summarize your results with units.

$P_c =$

$V_c =$

f. Remove the added mass and make any measurements needed to calculate the volume and pressure of air in the system at point *d* in the cycle. Show your equations and calculations in the space below and summarize your results with units.

P_d=

V_d=

g. We suspect that transitions from $a \rightarrow b$ and from $c \rightarrow d$ are approximately adiabatic. Explain why.

h. You should have found that the transitions from $b \rightarrow c$ and from $d \rightarrow a$ are isobaric. Explain why this is the case.

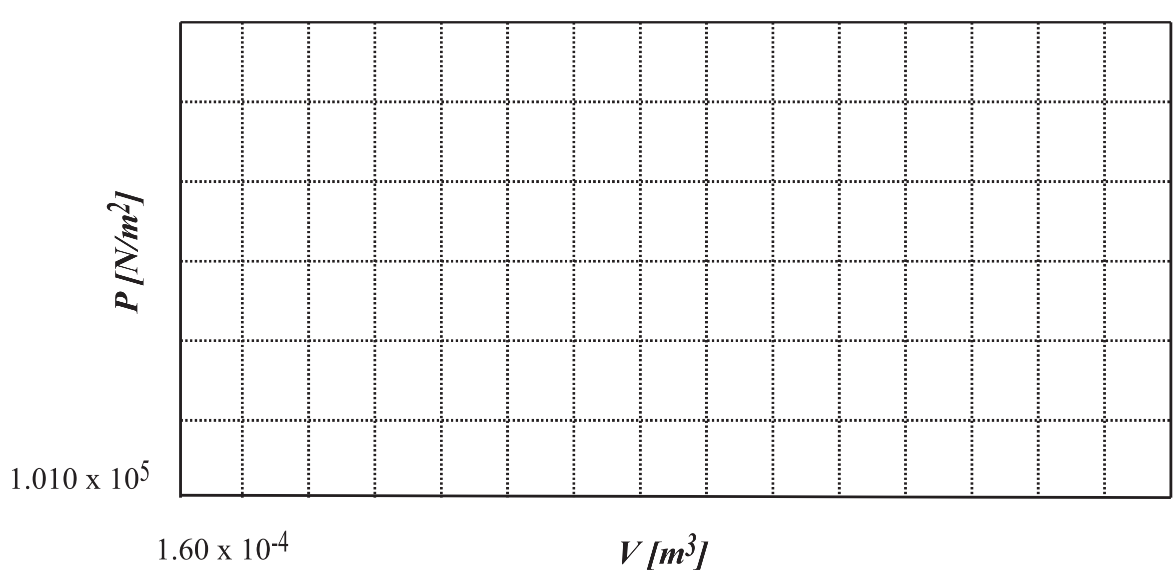
Finding Thermodynamic Work from the Diagram

In the next activity, you should draw a *P- V* diagram for your cycle and determine the thermodynamic work for your engine.

5.4 Activity: Plotting and Interpreting a *P-V* Diagram

a. Fill in the appropriate numbers on the scale on the graph frame that follows and plot the *P-V* diagram for your engine cycle. Alternatively, generate your own graph using a computer graphing routine and affix the result in the space below.

b. On the graph in part a, label each of the points on the cycle (*a*, *b*, *c*, and *d*). Indicate on the graph which of the transitions ($a \rightarrow b$, $b \rightarrow c$, etc.) are adiabatic and which are isobaric.



Next you need to find a way to determine the area enclosed by the *P-V* diagram. The enclosed area doesn't change very much if you assume that *P* is approximately a linear function of *V* for the adiabatic transitions. By making this approximation, the figure is almost a parallelogram so you can obtain the enclosed area using one of several methods. Three of the many possibilities are listed below. *Creative students have come up with even better methods than these, so you should carefully think about your method of analysis carefully*.

Method I

Since the pressure doesn't change from point *b* to point *c,* you can take the pressure of those two points as a constant pressure between points. The same holds for the transition from *d* to *a.* This gives you a figure that is approximately a parallelogram with two sets of parallel sides. You can look up and properly apply the appropriate equation to determine the net thermodynamic work performed.

Method II

Display your graph with a grid and count the boxes in the area enclosed by the lines connecting points *a*, *b*, *c*, and *d*. Then multiply by the number of joules each box represents. You will need to make careful estimates of fractions of a box when a "leg" of a cycle cuts through a box.

Method III

Fit a straight line to each of the starting and ending points for the four transitions in the cycle. Each equation will give you a function relating *P* and *V*. Perform an integral for each of these equations, since

$$\oint PdV = \int_a^b PdV + \int_b^c PdV + \int_c^d PdV + \int_d^a PdV$$

5.5 Activity: Comparing Thermodynamic and Useful Mechanical Work

a. Choose a method for computing the thermodynamic work in joules, describe it in the space below, and show the necessary calculations. Report the result in joules.

b. What is the equation you need to use to calculate the useful mechanical work done in lifting the mass from one level to another?

c. Use the result for the height that the mass is lifted in the power stroke of the engine to calculate the useful mechanical work performed by the heat engine.

d. How does the thermodynamic work compare to the useful mechanical work? Please use the correct number of significant figures in your comparison (as you have been doing all along, right?)

The Incredible Mass Lifter Engine Is Not So Simple

Understanding the stages of the engine cycle on a *P-V* diagram is reasonably straightforward. However, it is difficult to use equations for adiabatic expansion and compression and the ideal gas law to determine the temperature (and hence the internal energy of the air throughout the cycle. There are several reasons for this. First, air is not an ideal gas. Second, the mass lifter engine is not well insulated and so the air that is warmed in the hot reservoir transfers heat energy through the cylinder walls. Thus, the air in the can and in the cylinder are probably not at the same temperature. Third, air does leak out around the piston, especially when larger masses are added to the platform. This means that the number of moles of air decreases over time. You can observe this by noting that in the transition from point *d* to point *a,* the piston can actually end up in a lower position than it had at the beginning of the previous cycle. However, the Incredible Mass Lifter Engine does help us understand typical stages of operation of a real heat engine.

➤ Note: The previous experiment was intended to help students consolidate the concepts of pressure and volume by taking their own data for height and mass in each part of the cycle and then calculating the pressures using the basic definition of pressure vs. force per unit area. An alternate method for doing this experiment is to use the *Science Workshop* computer interface with the Pressure Sensor (CI-6532) in conjunction with either a Motion Sensor (CI-6529) or Rotary Motion Sensor (CI-6538) to detect pressure, volume, and height automatically with a computer.

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Fax: (916) 786-3292

E-mail: techsupp@pasco.com

Web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is with the PASCO apparatus, note:

- Title and model number (usually listed on the label);
- Approximate age of apparatus;
- A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.);
- If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:

- Part number and revision (listed by month and year on the front cover);
- Have the manual at hand to discuss your questions.