

Experiment 4: Heat Engine Cycle

Equipment Needed	
Heat Engine/Gas Law Apparatus	Mass and Hanger Set
PASCO Interface and Data Collection Software	90 cm Steel Rod
PASCO Dual Pressure Sensor	Large Rod Stand
PASCO Rotary Motion Sensor OR	Thread
PASCO Motion Sensor	Plastic Containers (set of 2)

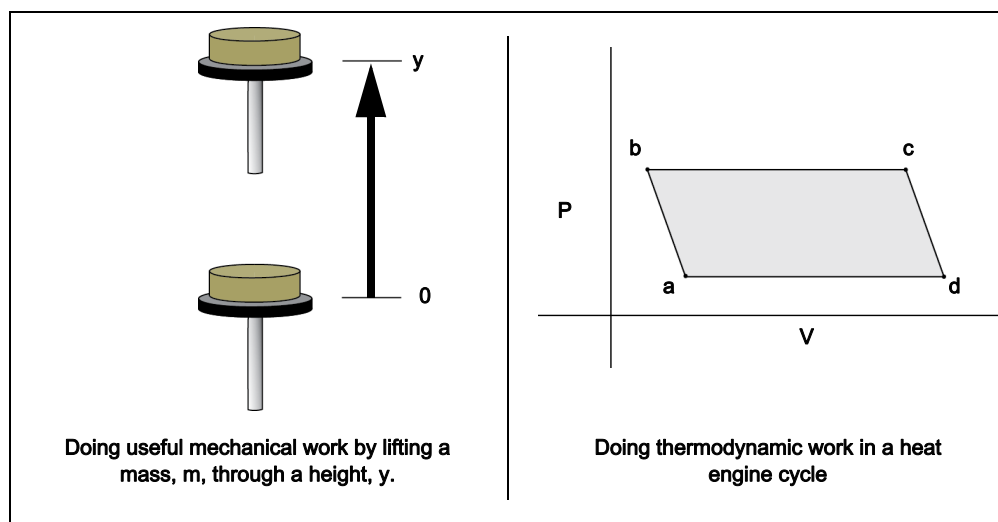
Introduction

A heat engine is a device that does work by extracting thermal energy from a hot reservoir and exhausting thermal energy to a cold reservoir. In this case, the heat engine consists of the air inside a metal cylinder. The air expands when the cylinder is put into hot water. The expanding air pushes on a piston and does work by lifting a mass. The heat engine cycle is then completed when the cylinder is put into cold water, and the air pressure and volume return to the starting values.

The heat engine in this experiment will go through a four-stage expansion and compression cycle and do mechanical work by lifting a 200 gram mass from one height to another. Verify that the mechanical work done in lifting a mass, m , through a vertical distance, y , is equal to the net thermodynamic work done during the cycle as determined by finding the enclosed area on a pressure versus volume (P-V) diagram. Compare the mechanical work, ma_y , with the work from a heat engine as a function of pressure and volume changes give by the following expression.

$$W_{\text{net}} = \oint P dV$$

You can prove mathematically that this relationship holds, and the experimental verification allows you to become familiar with the operation of a real heat engine.

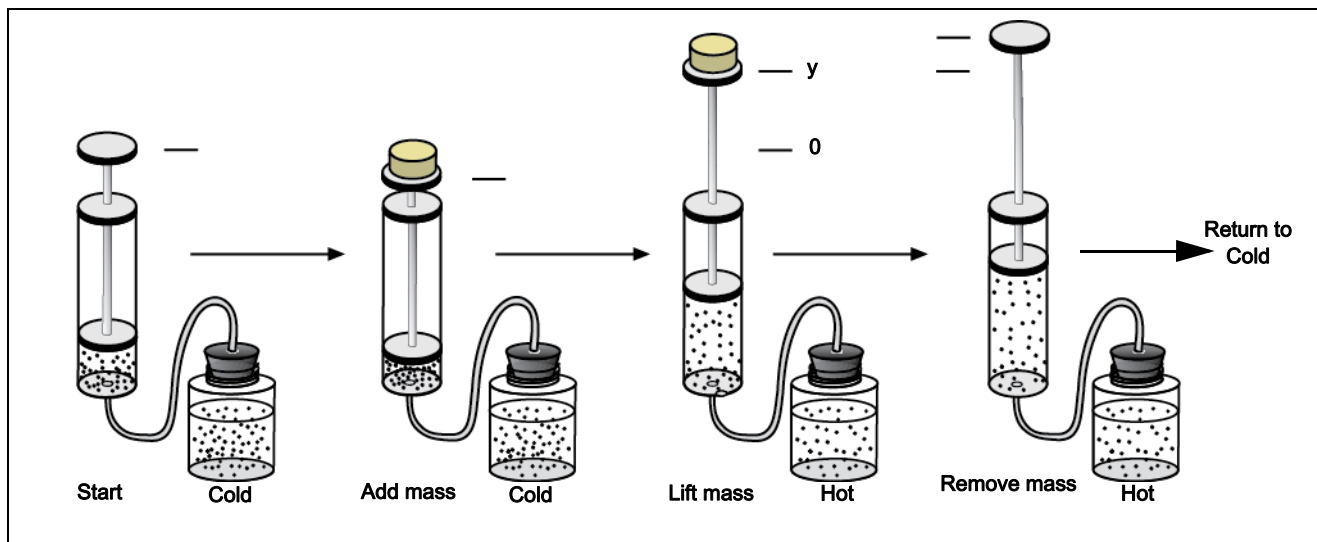


The PASCO Heat Engine/Gas Law Apparatus consists of a hollow cylinder with a low friction graphite piston that can move along the axis of the cylinder. The piston has a platform attached to it for lifting a mass. A metal can

sealed with a rubber stopper connects through flexible tubing to the Heat Engine/Gas Law Apparatus. A PASCO Pressure Sensor also connects to the flexible tubing. A PASCO Rotary Motion Sensor or PASCO Motion Sensor measures the position of the platform as it moves up or down.

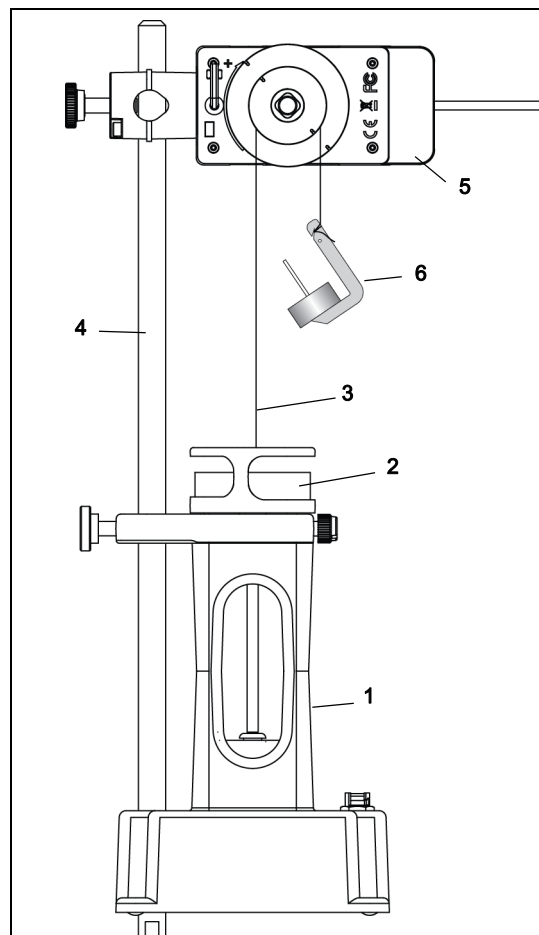
Theory of Operation

If the temperature of the air trapped inside the piston, metal can, and tubing increases, the volume will increase, causing the piston to lift the platform. You can increase the volume of the trapped air by immersing the metal can in hot water. When the platform has been lifted a distance, y , the mass is removed from the platform. The platform should then rise a bit more because the pressure on the cylinder of gas is decreased. Finally, the volume of the air will decrease when the metal can is immersed in cold water. This causes the platform to drop to its original position.

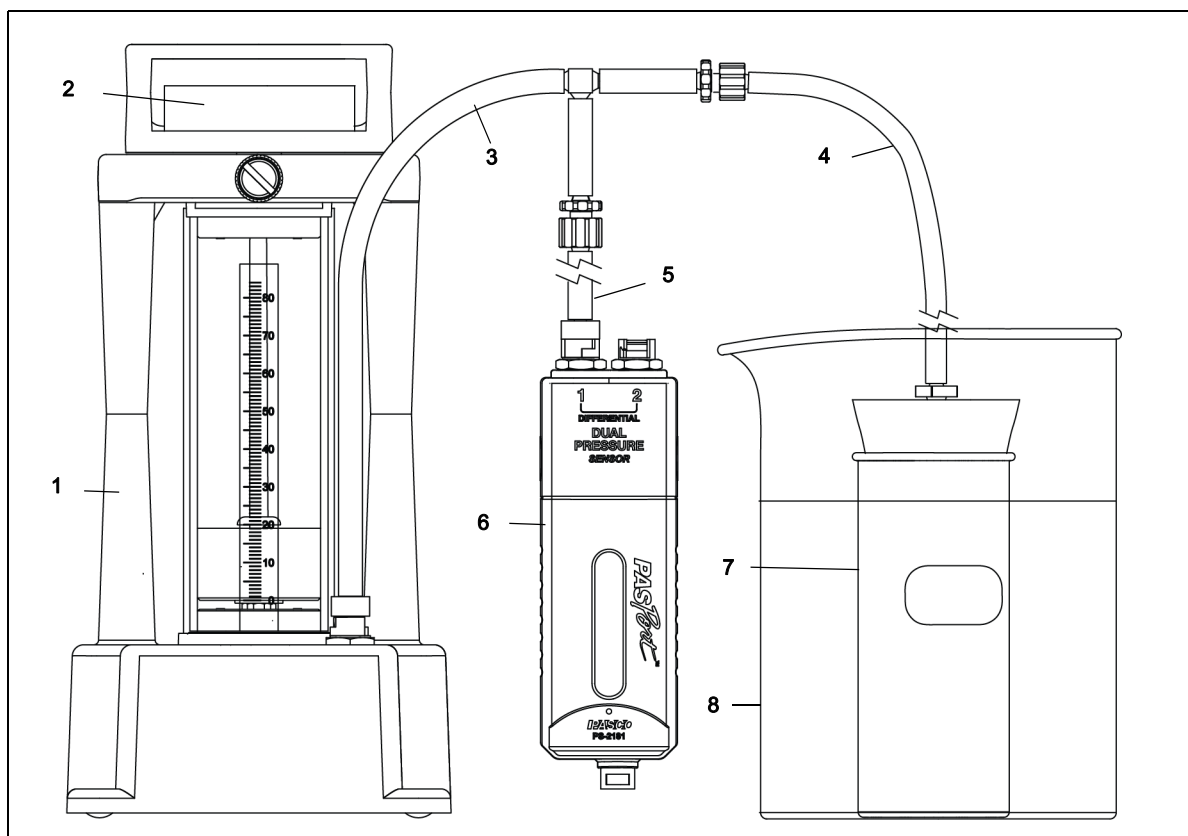


Equipment Setup

1. Assemble a base and support rod. Place the Heat Engine rod clamp mount onto the support rod. Position the Heat Engine close to the bottom of the support rod and tighten the thumbscrew of the rod clamp mount.
2. Attach a PASCO Rotary Motion Sensor at the top of the support rod. Align the medium groove of the pulley on the sensor so a string coming from the center of the Heat Engine mass platform can pass over the groove of the pulley.
3. Select a mass hanger and add masses to it so the total mass is 48.5 grams. (The mass hanger and masses serves as a counterweight for the mass platform.)
4. Attach a thread to the hole in the top of the mass platform. Pass the thread over the medium groove of the Rotary Motion Sensor pulley and attach the mass hanger and masses to the thread.
5. Connect the PASCO Rotary Motion Sensor to a computing device.



Setup Items	Setup Items
1. Heat Engine	2. 200 gram Mass
3. Thread	4. Support Rod
5. PASCO Rotary Motion Sensor	6. Mass Hanger and Masses



Setup Items	Setup Items
1. Heat Engine	2. 200 gram Mass
3. Main Connector Tubing	4. Rubber Stopper Tubing
5. Pressure Sensor Adapter Tubing	6. PASCO Dual Pressure Sensor
7. Thermal Can	8. Container* (one of two)

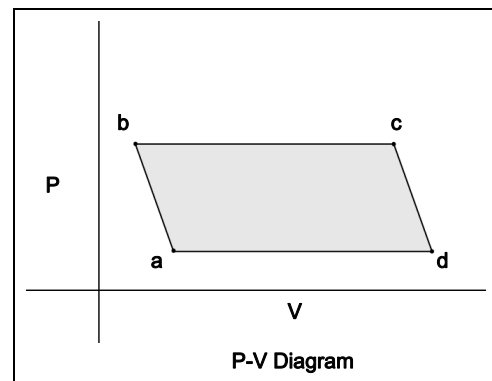
*You also need hot water (about 80°C) for one container and cool water for the second container.

6. Connect the main connector tubing to the quick-release connector port on the base of the Heat Engine.
7. Connect the rubber stopper tubing to the end female Luer barb on the main connector tubing.
8. Connect the pressure sensor adapter tubing to the side female Luer barb on the main connector tubing.
9. Attach the PASCO Pressure Sensor to the quick-release connector on the end of the adapter tubing.
10. Connect the PASCO Pressure Sensor to a computing device.

Before taking measurements of the pressure and volume and height of lift with the heat engine, set it up and run through the cycle a few times to get used to its operation. A good way to start is to fill one container with room temperature water and the second container with hot water (about 80°C). The engine cycle is much easier to describe if the piston begins a little above the bottom of the cylinder. Therefore, raise the piston platform about 2 centimeters (cm). After the piston platform is raised, firmly insert the rubber stopper into the thermal can.

- Start with the can immersed in the cool water.
- Add the mass to the piston platform (a → b).
- Move the can to the hot water (b → c).
- After the mass is lifted, remove it from the platform (c → d).
- Return the can to the cool water (d → a).

After observing a few heat engine cycles, you should be able to describe each of the points, a, b, c, and d of a cycle.



Software Setup

For information about collecting, recording, displaying and analyzing data, refer to the User's Guide or Online Help System for the data collection software.

1. Start the PASCO data collection software.
2. Create a calculation of the volume of gas in the cylinder based on the radius of the cylinder, r , (1.625 cm) and the height of the piston, y , as measured by the PASCO sensor that records the position of the piston platform.
3. Set up a display to watch the pressure versus the calculated value of the volume of gas in the cylinder.

Predictions

1. Transition (a → b): With the can in the cool water, what should happen to the height of the piston platform when you add the 200 gram mass?
2. Transition (b → c): What should happen when you place the thermal can into the container of hot water?
3. Transition (c → d): With the can still in the hot water, what should happen to the height of the piston platform when you remove the 200 gram mass?
4. Transition (d → a): What should happen when you place the thermal can back into the container of cool water?

Data Collection and Observations

1. Record the starting position of the bottom of the piston in the cylinder.
2. Start recording pressure and position data with the data collection software.
3. With the thermal can in the cool water, add the 200 gram mass to the platform. Describe what happens. Is this what you predicted?
4. Move the thermal can to the hot water. Describe what happens. Is this what you predicted?
5. With the thermal can still in the hot water, remove the 200 gram mass from the platform. Describe what happens. Is this what you predicted?
6. Move the thermal can to the cool water. Describe what happens. Is this what you predicted? In particular, how does the volume of the air at the end of the cycle compare to the volume of air at the beginning? Are they the same, or did some air leak out?

7. End data recording.

Analysis

Calculate the mechanical work done in lifting the mass, m , a vertical distance, y .

Convert the graph of pressure versus position to a graph of pressure versus volume. Use the graph of pressure versus volume to calculate the thermodynamic work done.

Questions

How does the thermodynamic work compare to the mechanical work?

Notes

Understanding the stages of the heat 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 internal energy of the air throughout the cycle. There are several reasons for this. First, air is not an ideal gas. Second, the Heat Engine is not well insulated and heat travels through the cylinder wall. Therefore, the air in the thermal can and the air in the cylinder are probably not at the same temperature. Third, air does leak out around the piston. This means that the number of moles of air decreases over time. You can observe this by looking closely at the transition from d to a. The piston can actually end up in a lower position than it had at the beginning of the cycle. The Heat Engine does help the understanding of the actual stages in the operation of a real heat engine.

Specifications

Piston Diameter	33.5 mm \pm 0.1
Mass of Piston and Platform	48.5 g \pm 0.6
Maximum Pressure	340 kPa

More Information

See the PASCO catalog or web site for more information.

www.pasco.com

Technical Support

For assistance with any PASCO product, contact PASCO at:

Address:	PASCO scientific 10101 Foothills Blvd. Roseville, CA 95747-7100
Phone:	916-786-3800 (worldwide) 800-772-8700 (U.S.)
Web:	www.pasco.com
Email:	support@pasco.com

Limited Warranty

For a description of the product warranty, see the PASCO catalog or www.pasco.com/legal.

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