

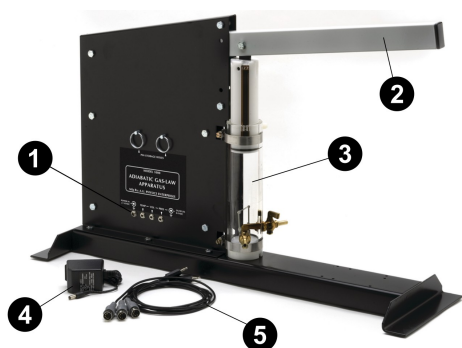
# Adiabatic Gas Law Apparatus (TD-8565)

## Introduction

The Adiabatic Gas Law Apparatus allows the user to investigate the compression and expansion of gases. Sensitive transducers in the apparatus measure the pressure, temperature, and volume of the gas almost simultaneously as the gas is compressed or expanded rapidly under nearly adiabatic conditions, or slowly under isothermal conditions. Analog signals from the sensors can be monitored by PASCO Capstone data collection software using the 850 Universal Interface (UI-5000). The interface acts as a three channel storage oscilloscope while Capstone plots graphs of pressure, temperature, and volume. The program can also be used to plot a graph of pressure versus volume and integrate under the curve to find the work done on the gas.

## Equipment

### Included equipment:



#### 1 Power and signal output jacks

Connect the power adapter and signal cables to these jacks during the experiment.

#### 2 Lever arm

Can be moved up and down to compress or expand the gas in the cylinder.

#### 3 Cylinder

Contains a piston which moves up and down in response to the lever arm, compressing or expanding the trapped gas.

#### 4 Power adapter (9 V DC @ 1 A)

Can be plugged into any standard power outlet.

#### 5 3x signal cables

3.5 mm phone plug-to-5-pin DIN plug.

### Required equipment:

- PASCO Capstone data collection software
- 850 Universal Interface (UI-5000)

## Get the software

Collecting data from the apparatus requires PASCO Capstone software. We offer a free trial of Capstone for Windows and Mac. To get the software, go to [pasco.com/downloads](https://www.pasco.com/downloads).

If you have installed the software previously, check that you have the latest update by opening the **Help** menu and clicking **Check for Updates**.

## Theory

### Relevant equations

A process is considered *adiabatic* if no thermal energy enters or leaves the system during the process. This would occur if the system were perfectly thermally insulated, or if the process occurred so rapidly that there could not be any heat transfer. The following is a derivation of the relationship of the pressure  $P$ , temperature  $T$ , and volume  $V$  when  $n$  moles of a confined ideal gas are adiabatically compressed or expanded.

For an adiabatic process, the first law of thermodynamics can be stated as:

$$dQ = nC_V dT + PdV = 0$$

where  $C_V$  is the molar specific heat at constant volume and  $R$  is the universal gas constant (approximately  $8.314 \text{ J/mol}^\circ\text{K}$ ). For any ideal gas,  $PV = nRT$ . Thus, taking the derivative of both sides, we get  $PdV + VdP = nRdT$ . Solving this equation for  $dT$ , we get:

$$dT = \frac{PdV}{nR} + \frac{VdP}{nR}$$

Substituting this equation into our original one, we get:

$$\begin{aligned} dQ &= nC_V \left( \frac{PdV}{nR} + \frac{VdP}{nR} \right) + PdV = 0 \\ &= \left( \frac{C_V}{R} + 1 \right) PdV + \frac{C_V}{R} VdP \\ &= (C_V + R)PdV + C_V VdP \\ &= C_P PdV + C_V VdP \end{aligned}$$

where  $C_P$  is the molar specific heat at constant pressure, which is equal to  $C_V + R$ . The ratio of  $C_P/C_V$  is denoted as  $\gamma$  (gamma). Using these results, we obtain:

$$\begin{aligned} \frac{C_P PdV}{C_V PV} + \frac{dP}{P} &= 0 \\ \gamma \frac{dV}{V} + \frac{dP}{P} &= 0 \\ \gamma \ln V + \ln P &= \text{constant} \end{aligned}$$

From this, we can derive that:

$$\begin{aligned} PV^\gamma &= \text{constant} \\ P_1 V_1^\gamma &= P_2 V_2^\gamma \end{aligned}$$

This result is considered the standard Adiabatic Gas Law. From this equation and the ideal gas law  $PV = nRT$ , we can find a second form of this relationship:

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

Another relationship that can be examined with this apparatus is the energy expended or work done on the gas in the process of compressing it adiabatically. From the Adiabatic Gas Law, we know that:

$$PV^\gamma = k = P_1V_1^\gamma$$

We can solve this equation for P to obtain:

$$P = \frac{k}{V^\gamma}$$

Therefore, we find that the work done to compress the gas from a volume  $V_1$  to a smaller volume  $V_2$  is given by:

$$\int_{V_1}^{V_2} PdV = k \int_{V_1}^{V_2} \frac{dV}{V^\gamma} = k \left[ \frac{V^{1-\gamma}}{1-\gamma} \right]_{V_1}^{V_2} = (P_1V_1^\gamma) \left[ \frac{V^{1-\gamma}}{1-\gamma} \right]_{V_1}^{V_2}$$

Simplifying this, we get our work equation:

$$W = \frac{P_1V_1^\gamma}{1-\gamma} (V_2^{1-\gamma} - V_1^{1-\gamma})$$

Because work is being done *on* the gas to compress the gas from a large volume to a smaller volume, the value of work given by this equation will always be negative.

## Function of the tube

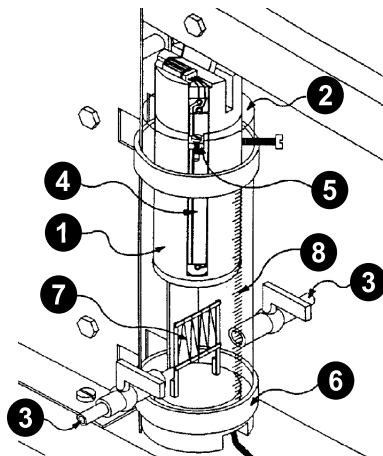


Figure 1. Cylinder

The diagram in Figure 1 demonstrates the key components of the apparatus. A **piston** (item ①) made of acetal plastic is manually driven up or down in an **acrylic cylinder** (②), which is filled with any of several gases, including monatomic argon, diatomic air or nitrogen, triatomic carbon dioxide, and other polyatomic gases. These gases can be injected and exhausted through the two brass **gas cocks** (③).

Mounted on the side of the piston is a **linear potential divider** (④), which is used to monitor the position of the piston. The 5 volt source from the 850 Universal Interface is applied across the potentiometer element. The voltage from the **commutator brush** (⑤) is then used to indicate the position of the piston, and thus the volume of the confined gas.

Two transducers are mounted on the **acetal base** (⑥) which seals the bottom of the cylinder. A solid state pressure transducer is sealed against the lower surface of the base. The active element of this transducer is a piezo-resistive device which forms part of a bridge circuit. The **temperature sensor** (⑦) is mounted in the cylinder on the top of the base. The active element of the sensor is an extremely fine nickel wire, which has a very high temperature coefficient of resistance. The fine wire also has a high surface to mass ratio, which allows its temperature to change rapidly as the gas compresses or expands, with only a small delay. This wire is also one arm of a bridge circuit.



**IMPORTANT:** The temperature sensor and commutator brush are *extremely* fragile. There should be no need to disassemble the cylinder at any point. If doing so becomes necessary, start by removing the commutator brush at the top of the cylinder, then remove the piston, and finally remove the base. Make sure to avoid *any* contact with the brush or temperature sensor! Any damage to the temperature sensor will require the apparatus to be replaced.

The electronic circuitry of the apparatus consists of two excitation voltage supplies and appropriate amplifiers for the two bridge circuits. The outputs of the amplifiers are analog voltages proportional to the pressure and temperature respectively. The electronics are powered by the 9 V DC power adapter.



The negative input is NOT chassis ground. The sleeves of the output jacks are connected to chassis ground, which is maintained at +4 V relative to the negative external input.

A transparent **millimeter scale** (⑧) on the front of the cylinder allows direct measurement of the initial and final piston position of "volume" to use in computations, or to calibrate the volume data acquisition. Two removable pins (not pictured) are provided to vary the excursion of the piston by limiting how much the piston lever can move. Holes to store these pins when not in use are provided above the central label.

## Interpretation of transducer outputs

The apparatus comes with a small card that gives information on how to interpret the output voltage of the pressure, temperature, and volume transducers.

- **Pressure:** The pressure transducer and accompanying electronics have been calibrated by the manufacturer. The output voltage is 1.00 V per 100 kilopascals of absolute pressure.
- **Temperature:** The temperature transducer system has also been calibrated by the manufacturer, and a calibration equation is provided. The equation assumes a linear relationship, which is approximately correct. Three calibration points are provided so you can improve the measurements slightly by fitting a curve to the points.
- **Volume:** For some of the calculations, only the initial and final volumes are needed. These can be determined by reading the transparent scale located on the front of the cylinder, which indicates the displacement of the piston. Multiplying this displacement by the cross-section area yields the current volume. The diameter of the piston is approximately 4.45 cm. For best results, perform your own diameter measurement.



**NOTE:** The port or opening in the gas cocks creates a small error in the volume measurement. Always add one cubic centimeter to all volume measurements, or 0.06 cm to all piston displacements, to account for this.

## Setup

### Hardware setup



1. Connect the power adapter to the **Power In** jack on the apparatus. Plug the adapter into an electrical outlet.
2. Connect one signal cable each to the output jacks for temperature, volume, and pressure on the apparatus.



**IMPORTANT:** Do NOT connect the power adapter or another voltage source to the output jacks. Doing so may cause damage to the amplifiers.

3. Plug the signal cable from the **Pressure** output into Analog Input **A** of the 850 Universal Interface.
4. Plug the signal cable from the **Temperature** output into Analog Input **B** of the 850 Universal Interface.
5. Plug the signal cable from the **Volume** output into Analog Input **C** of the 850 Universal Interface.

### Software setup

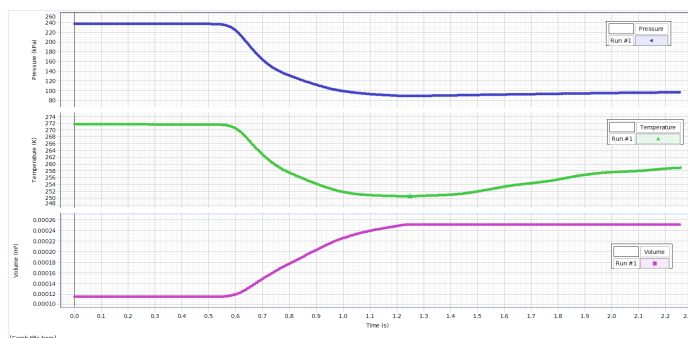
1. Start PASCO Capstone, then select **Hardware Setup** from the **Tools** palette.
2. Turn on the 850 Universal Interface and connect it to your computer via USB cable. A diagram of the interface will appear in the Hardware Setup tool.
3. Click the yellow circle over Analog Input **A** in the diagram, then select **Voltage Sensor** from the list of sensors. Repeat this step for Analog Input **B** and **C**.
4. Double-click the **Graph** icon in the **Displays** palette to create a Graph display.
5. In the toolbar at the top of the display, click the **Add Plot Area**  tool twice to create two additional plot areas on the graph. The display should now feature three vertically separated y-axes sharing an x-axis.
6. In the **Sample Rate** box at the bottom of the display, select **Common Rate** and enter a rate of **1000 Hz**.
7. Select **Calculator** from the **Tools** palette.
8. In the Calculator tool, create a calculation called **Pressure** by entering the text  $Pressure = 100 * [Voltage, Ch A (V)]$  into the text box. Enter units of **kPa** for this calculation.
9. Create a calculation called **Temperature** by entering the text  $Temperature = 40.8 * [Voltage, Ch B (V)] + 252.4$  on the second row. Enter units of **K** for this calculation.
10. Create a calculation called **Volume** by entering the text  $Volume = 3.32E-5 * [Voltage, Ch C (V)] + 9.66E-5$  on the third row. Enter units of **m<sup>3</sup>** for this calculation.
11. In the Graph display, click the **<Select Measurement>** box for each of the y-axes to choose a measurement to plot on that axis. Select **Pressure** for the topmost axis, **Temperature** for the middle axis, and **Volume** for the third axis. The x-axis will automatically update to measure time.
12. When you are ready, click the **Record**  button to begin recording data.

## Studying the expansion of a gas

To perform a qualitative demonstration of the adiabatic expansion of a gas, follow these steps:

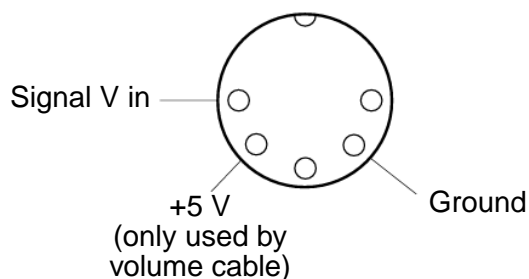
1. Clamp the front foot of the apparatus base to the table.
2. Fill the cylinder to maximum displacement at atmospheric pressure, then close the gas cock.
3. Compress the gas to its initial volume and hold it there until equilibrium is achieved. This should take about 30 seconds.
4. When you are ready, begin recording data and then very quickly expand the gas fully.

An example of the data obtained from this experiment is shown below. Note that some work is done against friction in the cylinder when compressing the gas, but the part of the cylinder that becomes warm is not in contact with the gas. However, when *expanding* the gas, the part of the cylinder that is warmed is in contact with the gas. Therefore, the expansion data should not be considered to be a fully accurate quantitative result.



## DIN connector pin configuration

The image below shows the configuration of the signal cables' DIN connector pins when the pins are pointed towards the viewer.



## Software help

The PASCO Capstone Help provides additional information on how to use this product with the software. You can access the help within the software or online.

**Software:** Help > PASCO Capstone Help

**Online:** [help.pasco.com/capstone](http://help.pasco.com/capstone)

# Experiment: Measurement of work required to compress gases adiabatically

## Equipment needed

### Required equipment:

- Adiabatic Gas Law Apparatus
- 850 Universal Interface (UI-5000)
- PASCO Capstone data collection software

### Optional equipment:

- Monatomic, diatomic, and polyatomic gases

## Purpose

The purpose of this experiment is to show that  $P_1 V_1^\gamma = P_2 V_2^\gamma$ , to determine the value of gamma, and to measure the amount of work done to compress a gas adiabatically.

## Theory

In this experiment, a gas confined in the cylinder is compressed extremely rapidly. In this scenario there is only enough time for a small amount of thermal energy to escape the gas, and so the process is considered nearly adiabatic. The more rapidly the volume is changed, the closer the process gets to being adiabatic.



**NOTE:** The response times of the pressure and volume transducers are negligibly short. However, the unavoidable thermal inertia of the temperature sensor causes the temperature measurement to lag about 30-50 ms behind the other two measurements.

To make the experiment more complete, try studying multiple gases with different structures, including monatomic argon, diatomic air or nitrogen, and triatomic carbon dioxide.

## Procedure

Start by selecting a gas to be studied. Air works well as a gas to start with, but others can be used if desired.

If you are using a gas other than air, purge the cylinder of air through these steps:

1. Connect the gas supply to one of the gas cocks.



**IMPORTANT:** The pressure of the gas supply should be less than 35 kPa (or 5 PSI) to prevent damage to the temperature sensor. Keep the flow of gas at a low level to avoid breaking the sensor or the wire.


2. Remove the piston excursion limit pins so the range of volumes is at its maximum (approximately 16 to 6).
3. With the piston down and the second gas cock closed, fill the cylinder to its maximum volume with the selected gas.
4. Shut the incoming gas cock off and exhaust the cylinder through the second gas cock.
5. Close the exhaust cock and refill the cylinder with gas.

Repeat this process at least nine more times, ending with a full cylinder of your chosen gas. Shut *both* gas cocks before performing the experiments. If some gas escapes during the experiment, simply add more as necessary.

Once the cylinder is prepared with your chosen gas:

1. Follow the steps in the **Setup** section of the manual to connect the apparatus to Capstone and create a Graph display of each of the three measurements.
2. When you are ready, begin recording and quickly compress the gas in the cylinder.
3. Once you have obtained graphs for analysis, stop recording.

## Calculations

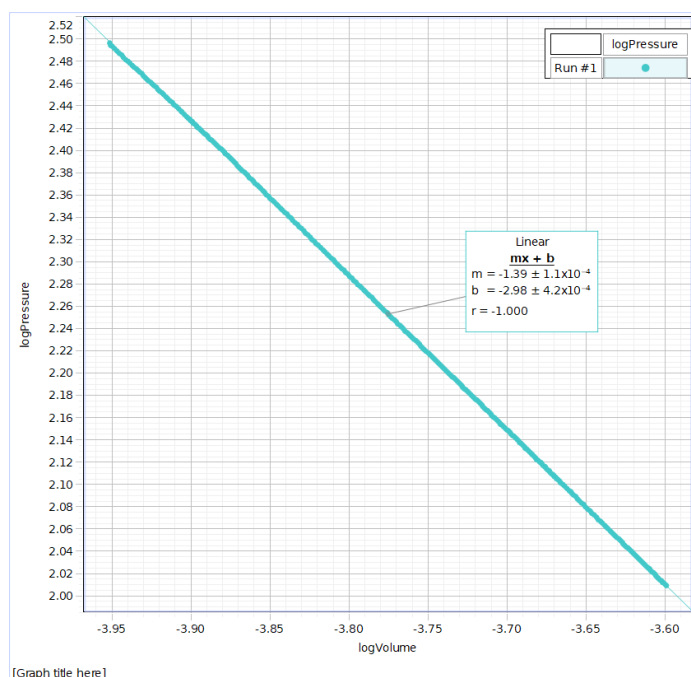
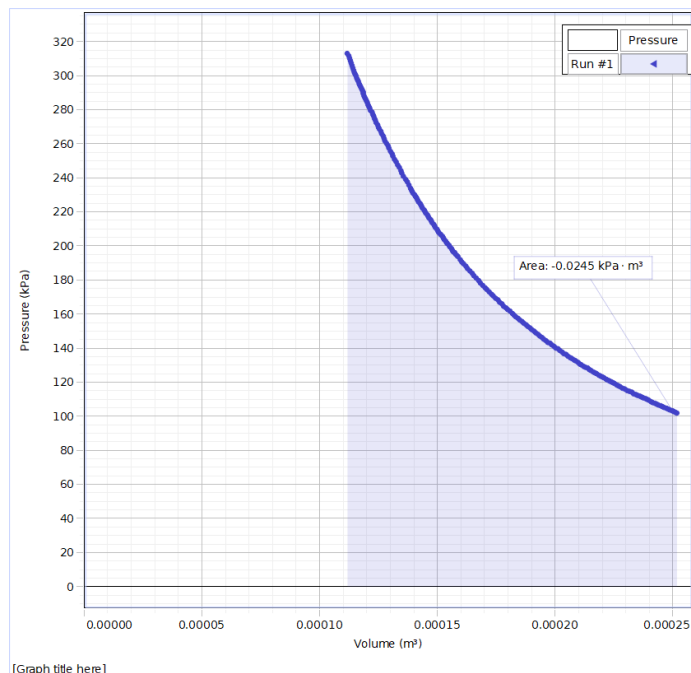
1. From your graphs and Capstone's built-in analysis tools, determine the final pressure and temperature at the time the compression was completed. For temperature, extrapolate the best value possible from the graph, as you may not have a single clear value.
2. Using the equations from the **Theory** section of the manual, calculate the *theoretical* final temperature and pressure predicted by the adiabatic gas law. Note that pressure and temperature must be expressed in absolute units.
3. In Capstone, create a plot of Pressure versus Volume.
4. Using the **Area Tool** , find the area under the curve of the Pressure versus Volume graph. The value of this integration is equal to the *work* done on the gas during the adiabatic process.
5. Using the final equation of the **Relevant equations** section, calculate the *theoretical* value of the work done. Compare this value to the experimental value found in Step 4.

## Optional

Create a plot of  $\log(\text{Pressure})$  versus  $\log(\text{Volume})$ . The value of  $\gamma$  should equal the negative of the slope of this graph.

## Sample data

The graphs below contain sample Pressure versus Volume and log(Pressure) versus log(Volume) plots created using the instructions from the experiment. Data you collect using Capstone should generally resemble what is shown here.



In the sample data above, note that  $\gamma$ , the negative of the slope, is equal to 1.39. This is consistent with the expected value for a diatomic gas (1.40).

## Technical support

Need more help? Our knowledgeable and friendly Technical Support staff is ready to answer your questions or walk you through any issues.

- ☐ Chat [pasco.com](https://www.pasco.com)
- ☐ Phone 1-800-772-8700 x1004 (USA)  
+1 916 462 8384 (outside USA)
- ☐ Email [support@pasco.com](mailto:support@pasco.com)

## Regulatory information

### Limited warranty

For a description of the product warranty, see the Warranty and Returns page at [www.pasco.com/legal](https://www.pasco.com/legal).

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### Product end-of-life disposal



This electronic product is subject to disposal and recycling regulations that vary by country and region. It is your responsibility to recycle your electronic equipment per your local environmental laws and regulations to ensure that it will be recycled in a manner that protects human health and the environment. To find out where you can drop off your waste equipment for recycling, please contact your local waste recycle or disposal service, or the place where you purchased the product. The European Union WEEE (Waste Electronic and Electrical Equipment) symbol on the product or its packaging indicates that this product must not be disposed of in a standard waste container.

### CE statement

This device has been tested and found to comply with the essential requirements and other relevant provisions of the applicable EU Directives.