

Introduction

The Model 1000 Adiabatic Gas Law Apparatus enables 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 are monitored by any good two or three channel analog-to-digital data acquisition system that is capable of collecting at least 500 data points per second in each channel simultaneously. The data collection system functions as a multichannel storage oscilloscope. In addition, most data acquisition programs can plot graphs of pressure, temperature, and volume. Using this data, the graph of pressure verses volume can be integrated to determine the work done on the gas.

Equipment Included:

The Model 1000 consists of the Adiabatic Gas Law Apparatus and this instruction manual. All signals output through 3.5mm mini-phone jacks. Power is supplied by an AC/DC power adaptor. Three signal cables with 3.5mm mini-phone plugs on one end and a 5 pin BNC on the other end are provided. Some interfaces may require adapter cables.

Features:

- Measure γ , the ratio of specific heats for the gas (C_p/C_v).
- Measure the work done on the gas and compare it with the change in internal energy ($C_v\Delta T$), and also with the theoretical work performed.
- Compare the final pressure and temperature with values predicted by the Adiabatic Gas Law.
- Use monatomic, diatomic, and polyatomic gases to determine the effects of molecular structure on γ .
- Investigate isothermal compression and expansion by performing the experiment slowly, in incremental steps.

Theory

A thermodynamic process performed without heat entering or leaving the system ($dQ=0$) is defined as an *adiabatic* process. A process is considered adiabatic if either the system is perfectly thermally insulated or the process occurs so rapidly that there is no time for the system to exchange heat with the environment. The following is a derivation of the adiabatic ideal gas law relating the absolute pressure, P , absolute temperature, T , and volume, V , when an ideal gas is compressed or expanded adiabatically.

For an adiabatic process, no heat is exchanged and the first law of thermodynamics becomes

$$dQ = nC_v dT + PdV = 0 \quad (1)$$

where n is the number of moles and C_v is the molar specific heat at constant volume. For an ideal gas in general

$$PV = nRT \quad (2)$$

where R is the ideal gas constant.
The differential form of Eq. (2) may be written as

$$dT = PdV/nR + VdP/nR \quad (3)$$

Substituting Eq. (3) into Eq. (1) yields,

$$dQ = nC_v(PdV/nR + VdP/nR) + PdV = (C_v/R + 1) PdV + C_v/R(VdP) = 0 \quad (4)$$

The specific heat at constant pressure, C_p , is related to the specific heat at constant volume through the relation

$$C_p = C_v + R \quad (5)$$

Thus, Eq. (4) becomes,

$$C_p PdV + C_v VdP = 0 \quad (6)$$

or

$$(C_p/C_v)(dV/V) + (dP/P) = 0 \quad (7)$$

With the introduction of $\gamma \equiv (C_p/C_v)$, the ratio of specific heats, Eq. (7) becomes

$$\gamma (dV/V) + (dP/P) = 0 \quad (8)$$

which may be integrated to give

$$\gamma \ln V + \ln P = \text{const.} \quad (9)$$

Exponentiation of both sides leads to

$$PV^\gamma = k \quad [\text{adiabatic process, ideal gas}] \quad (10)$$

where k is a constant. Equation (10) is the adiabatic ideal gas law. It is useful for relating the pressure and volume at one point in the adiabatic process to these quantities at a second point, i.e.,

$$P_1V_1^\gamma = P_2V_2^\gamma \quad (11)$$

The ideal gas law, Eq. (2) may be used to eliminate the pressures, P, from Eq.(11) resulting in an alternative form of the adiabatic gas law relating temperatures and volumes,

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1} \quad (12)$$

The Value of γ , the ratio of specific heats depends on the type of gas that is being expanded or compressed. According to the equipartition theorem of statistical mechanics, each degree of freedom contributes R/2 to the molar specific heat at constant volume, C_v . Thus, an ideal monatomic gas, such as helium (free to translate in three directions), has three degrees of freedom, with $C_v = 3R/2$. By Eq. (5), $C_p = 5R/2$ and $\gamma_{monatomic} = 5/3$. Diatomic molecules (e.g. O₂, N₂, or air) at room temperature can store thermal energy in the three translational modes as well as in rotations about two axes, resulting in a total of five degrees of freedom with $\gamma_{diatomic} = 7/5$. The carbon-dioxide molecule has more internal degrees of freedom and thus a smaller ratio of specific heats than a diatomic molecule.

Another aspect of this experiment is the measurement of the work required to compress and ideal gas adiabatically. The work done **on** a gas is generally given by

$$W = -\int PdV. \quad (13)$$

When the process is performed adiabatically from an initial pressure and volume, P_1 and V_1 , to a final volume, V_2 , we obtain

$$W_{adiabatic} = -\int_{V_1}^{V_2} PdV = -k \int_{V_1}^{V_2} (dV/V^\gamma) = -(P_1V_1^\gamma)[V^{1-\gamma}/1-\gamma]_{V_1}^{V_2} \quad (14)$$

resulting in

$$W_{adiabatic} = (P_2V_2 - P_1V_1)/\gamma - 1 \quad (15)$$

Description of Apparatus

A piston, Fig 1, item **a**, made of acetal plastic is manually driven down or up in an acrylic cylinder, Fig 1, item **b**, which is filled with any of several gases, including monatomic argon, diatomic air or nitrogen, triatomic carbon-dioxide, and other polyatomic gases, which are injected and exhausted through the two brass gas cocks, Fig 1, item **c**. Mounted on the side of the piston is a linear potential divider, Fig1, item **d**, is used to monitor the position of the piston. The 5 volt source from the computer, or other low voltage source available, is applied across the potentiometer element. The voltage

from the commutator brush, Fig 1, item **e**, is then used to indicate the position of the piston and thus the volume of the confined gas.

The acetal base, Fig 1, item **f**, which seals the bottom of the cylinder has two transducers mounted on it. Sealed against the lower surface of the base is a solid state pressure transducer. The active element of the transducer is a piezo-resistive device which forms part of a bridge circuit. Mounted in the cylinder on the top of the base is the temperature sensor, Fig 1, item **g**. The active element 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. (However, there is still a small delay or time lag.) This wire is also one arm of a bridge circuit. 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.

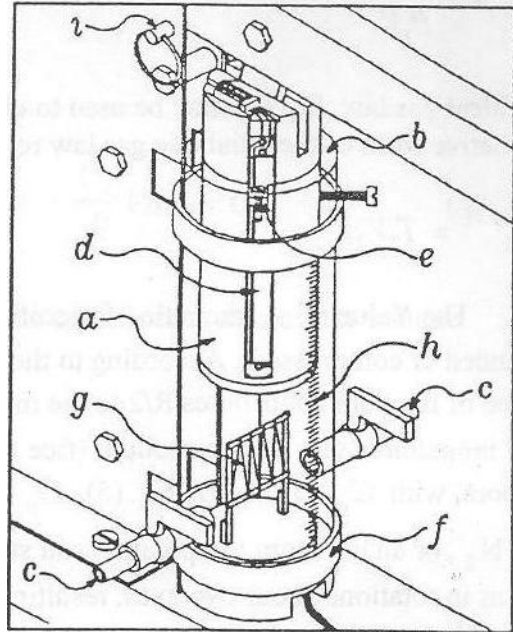


Figure 1

- **IMPORTANT:** The temperature sensor, Fig 1, item **e**, associated with the volume transducer is extremely fragile. There should be no need to disassemble the cylinder. If it is ever necessary, remove the commutator brush, Fig 1, item **e**, at the top of the cylinder before removing the piston. Next remove the base, carefully avoiding any contact with the temperature sensor. Damage to the temperature sensor will necessitate returning the equipment to the manufacturer for repair and re-calibration.

A transparent millimeter scale, Fig 1, item **h**, on the front of the cylinder facilitates direct measurement of the initial and final piston position to use in the computations and to calibrate the volume data acquisition. Two removable pins, Fig 1, item **i**, are provided to vary the excursion of the piston by limiting the motion of the piston lever. Holes to store the pins when not used are provided directly above the central label.

Interpretation of Transducer Outputs:

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

1. *Pressure*: The pressure transducer and accompanying electronics has been calibrated by the manufacturer. The output voltage is 1.00 V per 100 kPascals absolute pressure.
2. *Temperature*: The temperature transducer system has also been calibrated by the manufacturer and a calibration equation 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.
3. *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. This indicates the displacement of the piston which, when multiplied by the cross section area, is the volume. The diameter of the piston is approximately 4.45 cm. For best results use the actual measured diameter stated on the information card. Since for some calculations the ratios of volumes are used, the displacements can be used in the calculations instead of the actual volumes.

➤ **NOTE:** A minor error in the volume measurement is caused by the port or opening in the gas cocks. Add one cubic centimeter to all volume measurement or 0.06 cm to the piston displacements.

Experiment: Measurement of Work to Compress Gases Adiabatically

EQUIPMENT NEEDED:

- Adiabatic Gas Law Apparatus
- Multichannel A-to-D Interface

Optional:

- Monatomic, Diatomic, and Polyatomic Gases.

Purpose:

The purpose of this experiment is to show $P_1V_1^\gamma = P_2V_2^\gamma$ and $T_1V_1^{(\gamma-1)} = T_2V_2^{(\gamma-1)}$, to determine the value of Gamma, and to measure the amount of work done to compress a gas adiabatically.

Description:

In this experiment a gas confined in the cylinder is compressed so rapidly that there is only sufficient time for a small quantity of thermal energy to escape the gas. For this reason the process is almost adiabatic. The more rapidly the volume is changed the closer the process approaches 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 by 30-50 ms.

A complete experiment would include the study of gases having different structures including monatomic argon, diatomic air or nitrogen, and triatomic carbon dioxide.

Procedure for Evacuating a Gas from the Cylinder:

1. Select a gas to compress, (air is a good gas to start with).
2. If you are using a gas other than air, purge the cylinder in the following manner:
 - a. Connect the gas supply to one of the gas cocks.

➤ **NOTE:** The pressure should be less than 35 kPa or 5 PSI. This prevents damage from the external gas cylinder or supply to the temperature sensor. The flow of gas must be kept at a low level to avoid breaking the wire or the sensor.

- b. Remove the piston excursion limit pins so the range of volumes is at the maximum (approximately 16 to 6).
 - c. With the piston down and the second gas cock closed, fill the cylinder to maximum volume with the gas.
 - d. Now shut the incoming gas cock off and exhaust through the second gas cock.
 - e. Close the exhaust cock and re-fill with gas.

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

Setup:

1. Plug the DIN end of the signal cables into the computer interface.
2. Plug 3.5 inch mini-phone end of the cables into the output jacks on the side of the Gas Apparatus. There are four jacks on the side of the Adiabatic Gas Apparatus. These are, in order from the front of the machine to the back, pressure, volume, temperature and power.
3. Plug the AC/DC adapter into the final jack.

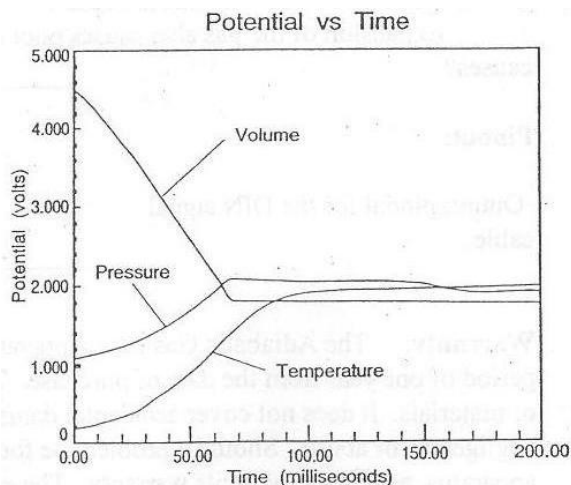
Graphs and Data Tables

Now compress the gas while taking data as described in the Setup portion of your manual. Obtain graphs and a data table for analysis.

-A Typical Graph of Voltage from Volume, Pressure and Temperature sensors vs. Time.

Calculations

1. From your graphs or data table determine the final pressure and temperature at the time the compression was completed. By extrapolating the temperature graph, the best value of temperature can be determined. Using equations 3 and 4 from the Theory section, calculate the theoretical temperature and pressure predicted by the adiabatic gas law. Note that pressure and temperature must be expressed in absolute units.
2. Plot Pressure vs. Volume using a consistent set of units such as Pascals and m^3 . Perform a numerical integration to determine the work done on the gas during the adiabatic process. Next, by integration of the adiabatic gas law, equation 5, determine the theoretical value of work done and compare with your measured value.



Optional

Plot Log Pressure vs. Log Volume and determine Gamma which equals the negative of the slope.

Expansion of a Gas

To perform a qualitative demonstration of the adiabatic expansion of a gas, do the following:

Clamp the cylinder to maximum displacement at atmospheric pressure. Close the gas cock and compress the gas. Set the trigger level to a value slightly higher than the steady value and set the slope to positive or “going up”. When ready to take data,

compress the gas to this initial volume, hold it there until equilibrium is achieved (about 30 seconds), and then very rapidly expand the gas fully.

When compressing the gas, some work is done against friction in the cylinder, 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. For this reason, the expansion data does not give good quantitative results.

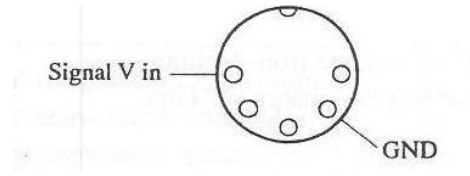
Questions:

Low mass monatomic gasses give rather poor quantitative results in this experiment. Give an explanation of why this occurs.

Expansion of the gas also causes poor quantitative results. What are some possible causes?

Pinout:

Output pinout for the DIN signal cables when looking at the connector pins.



Warranty: The Adiabatic Gas Law Apparatus is warranted by AU Physics Enterprises for a period of one year from the date of purchase. This warranty covers any defects in workmanship or materials. It does not cover accidental damage, damage as a result of operator error, negligence, or abuse. Should a problem be found, DO NOT attempt to disassemble the apparatus, as this will void its warranty. The entire unit should be returned for repair.

Liability: This product has been designed for educational demonstration purposes only! Use in research, medical, commercial, or industrial applications is prohibited. Any use of this product outside of its intended purpose is done so at the risk of the end user, who shall assume full liability, and fully indemnify A.U. Physics Enterprises and its agents, for any and all damages resulting from such prohibited use.

Calibration Equations:

Serial Number # _____

Absolute pressure

$$P(V_P) = 100 V_P \text{ (kPa)}$$

Atmospheric Pressure at the time of Calibration = _____ kPa

Volume

$$\text{Vol}(V_V) = \text{_____} V_V + \text{_____} \text{ (m}^3\text{)}$$

Cylinder Internal Diameter = _____ cm

Absolute temperature

$$T(V_T) = \text{_____} V_T + \text{_____} \text{ (K)}$$

Data Points Used in Temperature Calibration

(_____ V, _____ K) (_____ V, _____ K) (_____ V, _____ K)

Correlation of Linear Temperature Fit = _____

Resistance of Temperature Filament = _____ Ω