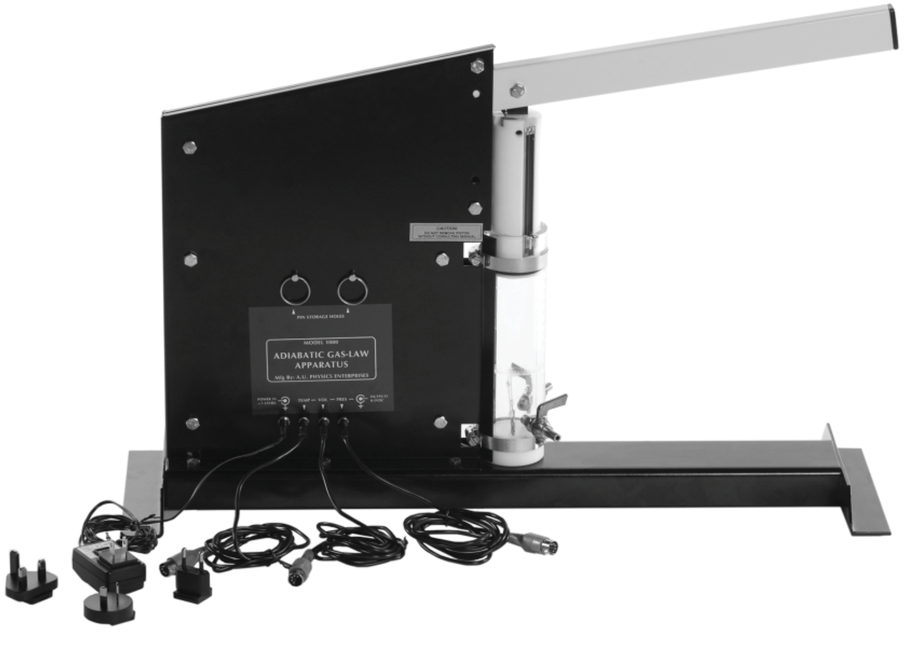
Andrews University
PHYSICS ENTERPRISES

Adiabatic Gas Law Apparatus

Instruction Manual for Model TD1000



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INTRODUCTION

Adiabatic and isothermal processes are difficult for beginning students to understand. The Adiabatic Gas Law Apparatus provides the ideal demonstration. It enables the user to investigate the compression and expansion of gases, either rapidly under near adiabatic conditions or slowly under isothermal conditions with direct measurement of pressure, volume, and temperature.

HOW IT WORKS

Sensitive transducers in the setup 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 a 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 interface connects to a computer workstation with the data acquisition program that can collect data and plot graphs of pressure, volume, and temperature.

PRODUCT INCLUDES

- Adiabatic Gas Law Apparatus
- 3 Signal Cables (3.5mm plug to 5-pin DIN)
- Power Adapter (9V DC @ 1A)
- Instruction Manual
- Experiment Guide

SPECIAL FEATURES

- Volume Transducer: A linear potential divider is mounted on the side of the piston. A 5-Volt source is applied across the potentiometer element. The voltage from the commutator brush on the cylinder is used to indicate the position of the piston and the volume of the confined gas.
- Pressure Sensor: A solid-state, piezoresistive device that forms part of a bridge circuit is mounted at the base of the cylinder.
- Temperature Sensor: Mounted in the cylinder on the top of the base. The active element is fine nickel wire with a high surface-to-mass ratio. The wire's temperature changes rapidly as the gas compresses or expands.

EXPERIMENTS

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

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

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

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

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

where R is the ideal gas constant.

The differential form of Eq. (2) may be written as

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

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

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

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

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

Thus, Eq. (4) becomes,

$$C_pPdV + C_vVdP = 0 \qquad (6)$$

or

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

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

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

which may be integrated to give

$$\gamma\ \ln V + \ln P = const. \qquad (9)$$

Exponentiation of both sides leads to

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

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.,

$$P_1V_1^{\gamma} = P_2V_2^{\gamma} \qquad (11)$$

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,

THEORY

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1} \tag{12}$$

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. O_2, N_2, 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 an ideal gas adiabatically. The work done **on** a gas is generally given by

$$W = -\int PdV. \tag{13}$$

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

$$W_{adiabatic} = -\int_{V1}^{V2} PdV = -k\int_{V1}^{V2}(dV/V^{\gamma}) = -(P_1V_1^{\gamma})[V^{1-\gamma}/1-\gamma]_{V1}^{V2} \tag{14}$$

resulting in

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

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 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. 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 as well as a high surface to mass ratio which allows its temperature to change rapidly as the gas compresses or expands.

A transparent millimeter scale, Fig 1, item **i**, 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 **h**, 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. Fig 1, item **j**, **k**, **l**, and **m**, are the 9V power input and the temperature, volume, and presure analog voltage outputs, respectably.

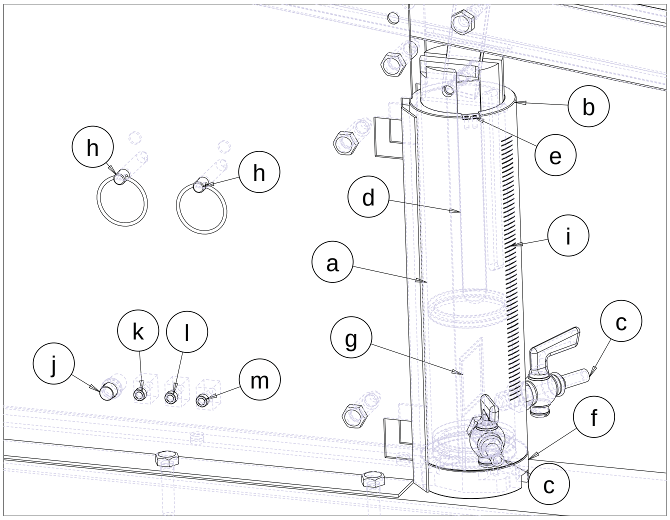


Fig 1: Apparatus details

The temperature sensor, Fig 1, item g, on the cylinder and the commutator brush, item e, associated with the volume transducer are 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.

INTERPRETATION OF TRANSDUCER OUTPUTS

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

- ***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.
- ***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 the user 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. 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.

MEASUREMENT OF WORK TO COMPRESS GASES ADIABATICALLY

EQUIPMENT NEEDED

- Adiabatic Gas Law Apparatus
- Multichannel A-to-D Interface
- Monatomic, Diatomic, and Polyatomic Gases (optional)

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.

⚠ ***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 30-50ms.***

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:
   - Connect the gas supply to one of the gas cocks.

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

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

3. 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.

MEASUREMENT OF WORK TO COMPRESS GASES ADIABATICALLY

SETUP

- Plug the DIN end of the signal cables into the computer interface.
- 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.
- 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.

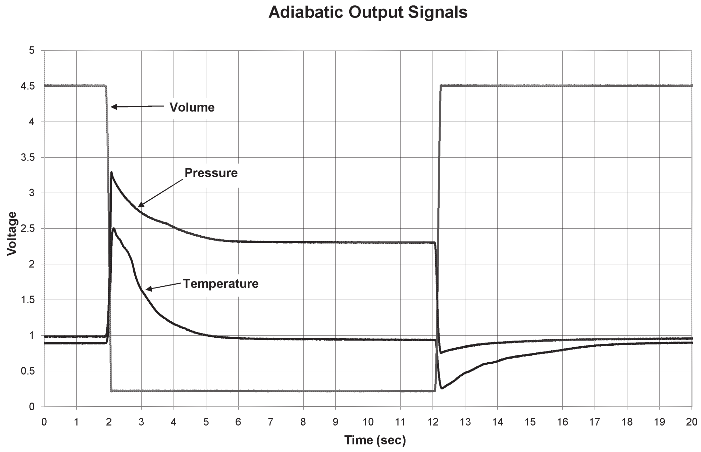


Fig 2: Typical graph of voltage from volume, pressure and temperature sensors vs. time for compression and expansion.

CALCULATIONS

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 11 and 12 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.

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 15, 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 may not give good quantitative results.

MEASUREMENT OF WORK TO COMPRESS GASES ADIABATICALLY

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 OF ANALOG OUTPUT CABLES

The pinout for the 3 signal cables is indicated in Fig 3 when facing the DIN connector pins.

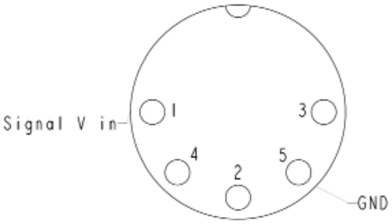


Fig 3: DIN connector pinout

CALIBRATION EQUATIONS

Serial Number # ___________

Absolute pressure
$P(V_P) = 100\,V_P$ (kPa)
Atmospheric Pressure at the time of Calibration = _________ kPa

Volume
$\mathrm{Vol}(V_V) =$ _________ $V_V +$ _________ (m^3)
Cylinder Internal Diameter = ___________cm

Absolute temperature
$T(V_T) =$ _________ $V_T +$ _________ (K)
Data Points Used in Temperature Calibration
(_______V, ________K) (_______V, ________K) (_______V, _______K)
Correlation of Linear Temperature Fit = ______________
Resistance of Temperature Filament = _______________ Ω

GENERAL INFORMATION

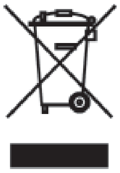
LIABILITY

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.

PRODUCT END OF LIFE DISPOSAL INSTRUCTIONS

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/disposal service or the product representative.

The European Union WEEE (Waste Electrical and Electronic Equipment) symbol on the product or on its packaging indicates that this product must not be disposed of in a standard waste container.



WARRANTY

The Adiabatic Gas Law Apparatus is warranted by A.U. 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.

If you purchased this product through our distributor please contact them for further information on warranty policy.

CONTACT