Instruction Manual and
Experiment Guide for
the PASCO scientific
Model TD-8565

012-05110C
5/94

Adiabatic Gas Law Apparatus
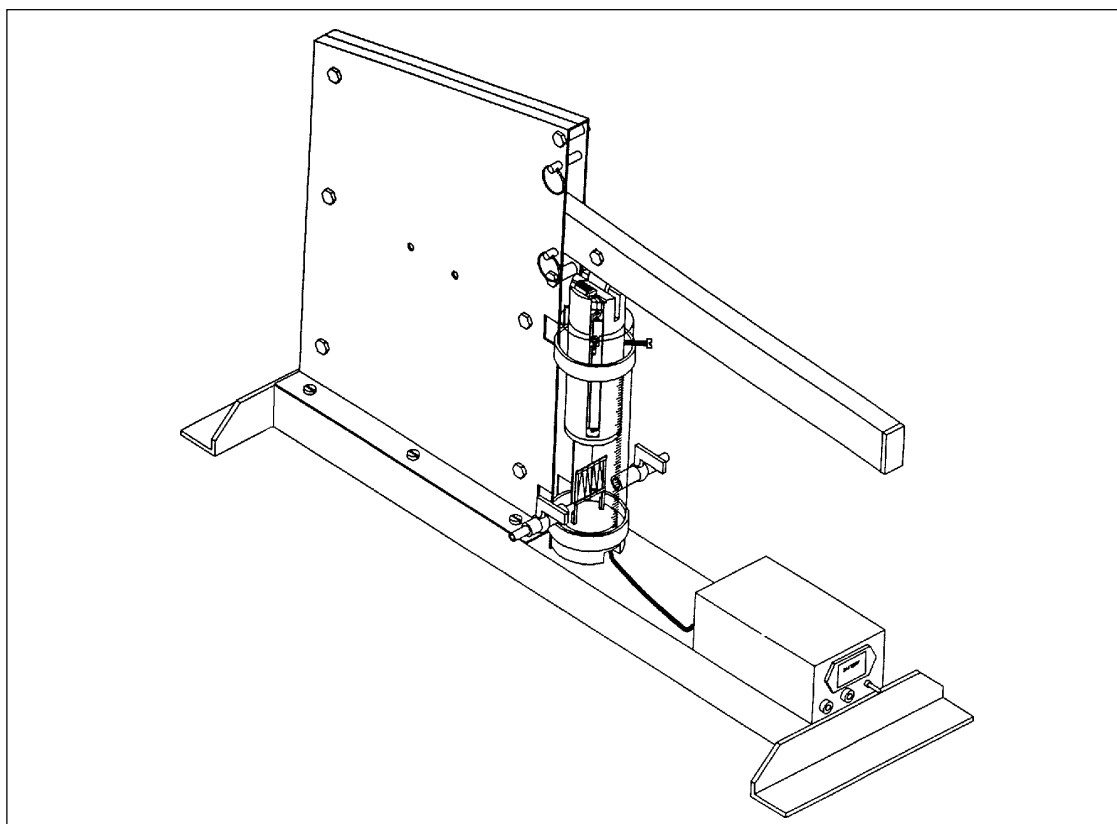
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Introduction

The PASCO Model TD-8565 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 near adiabatic conditions, or slowly under isothermal conditions. Analog signals from the sensors are monitored by the Series 6500 Computer Interface, a three channel analog-to-digital data acquisition system. The computer functions as a three channel storage oscilloscope. In addition, the data acquisiton program, Data Monitor, can plot graphs of pressure, temperautre, and volume. It can plot a graph of pressure versus volume and integrate under the curve to determine the work done on the gas.

Equipment Included:

The TD-8565 consists of the Adiabatic Gas Law Apparatus and this instruction manual (part number 012-05110). The apparatus comes with a permanently attached cable with a five pin DIN plug that carries the signal from the volume transducer, and two DIN-plug-to-mini-phone-plug cables (part number 520-063) that carry the signals from the pressure and temperature sensors.

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.

Other:

- The Adiabatic Gas Law Apparatus can also be used with the MultiPurpose Lab Interface (MPLI) from Vernier Software.

- The Apparatus can use a nine volt battery to supply the excitation voltage for the bridge circuits of the temperature and pressure sensors. You can also use an external 12 V, 10 mA power supply, but it must be a "floating ground" supply.

How to Use this Manual

The first section of this manual describes the theory of the adiabatic process and the operation of the apparatus. The next section describes the setup, calibration, and data collection procedure. The final section contains the experimental write-up, apparatus schematic and specifications.

Theory

When a process takes place without thermal energy entering or leaving the system it is an *adiabatic process*. This would occur if the system were perfectly thermally insulated or if the process occurred so rapidly that there could be no 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 compressed or expanded adiabatically.

The first law of thermodynamics can be stated as:

① $$dQ = nC_v dT + pdV = 0$$

for an adiabatic process where C_v is the molar specific heat at constant volume, **T** is the absolute temperature, **n** is the number of mole, and **V** is the volume. For any ideal gas **PV = nRT**. Thus **PdV + Vdp = nRdT**. Solving for **dT** gives:

② $$dT = \frac{PdV}{nR} + \frac{VdP}{nR}$$

Substituting equation 2 into equation 1 gives:

$$dQ = nC_v\left(\frac{PdV}{nR} + \frac{VdP}{nR}\right) + PdV = 0$$
$$= \left(\frac{C_v}{R} + 1\right)PdV + \frac{C_v}{R}VdP$$
$$= (C_v + R)PdV + C_v VdP$$
$$= C_P PdV + C_v VdP$$

where C_P is the molar specific heat at constant pressure. C_P is related to C_V by C_P-C_V = R. The ratio of C_P to C_V is denoted as γ, (gamma). Using these results we obtain:

$$\frac{C_P PdV}{C_v PV} + \frac{dP}{P} = 0$$
$$\gamma \frac{dV}{V} + \frac{dP}{P} = 0$$
$$\gamma \ln V + \ln P = constant$$

③ $$PV^\gamma = constant$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

This result is the standard adiabatic gas law. From equation 3 and the ideal gas law **PV = nRT** a second form of the adiabatic gas law is:

④ $$T_1 V_1^{(\gamma-1)} = T_2 V_2^{(\gamma-1)}$$

Another relationship to be examined in this experiment is the energy expended or work done on the gas while compressing it adiabatically. Equation 3, the Adiabatic Gas Law, states that:

$$PV^\gamma = k = P_1 V_1^\gamma \quad \text{or} \quad P = \frac{k}{V^\gamma}$$

work done to compress the gas is:

⑤ $$W = \int_{V_1}^{V_2} PdV = k\int_{V_1}^{V_2} \frac{dV}{V^\gamma} = k\left[\frac{V^{(1-\gamma)}}{1-\gamma}\right]_{V_1}^{V_2} = (P_1 V_1^\gamma)\left[\frac{V^{(1-\gamma)}}{1-\gamma}\right]_{V_1}^{V_2}$$

$$W = \frac{P_1 V_1^\gamma}{1-\gamma}\left(V_2^{(1-\gamma)} - V_1^{(1-\gamma)}\right)$$

R = universal gas constant (approximately 8.314 J/mole˚K.

Description of Apparatus

A piston, Fig 2, item a, made of acetal plastic is manually driven down or up in an acrylic cylinder, Fig 2, 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 2, item c. Mounted on the side of the piston is a linear potential divider, Fig 2, item d, 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 2, item e, is then used to indicate the position of the piston and thus the volume of the confined gas.

The acetal base, Fig 2, 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 2, 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.

➤ **IMPORTANT**: The temperature sensor, Fig 2, item g, on the cylinder and the commutator brush, Fig 2, 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 2, 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.

As mentioned above, the electronic circuit consists of the two amplifiers with bridge excitation sources. The electronics may be powered with an external "floating ground" 10 V DC supply (current about 10 ma), or a 9 volt battery.
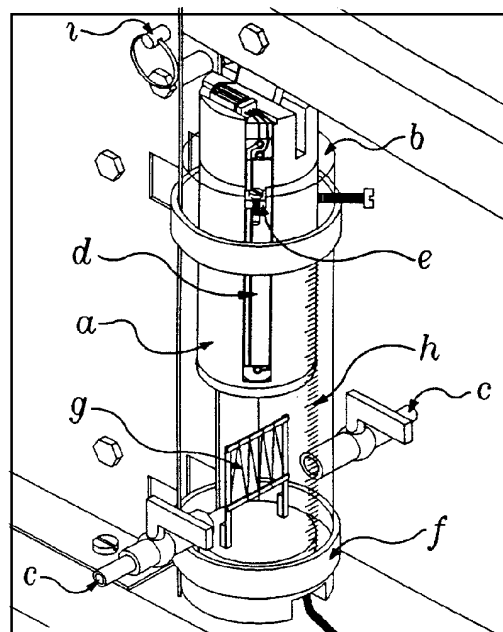

Figure 2, Cylinder

➤ **IMPORTANT:** The negative input is not chassis ground. The sleeves of the output jacks are connected to chassis ground which is maintained at +4 volts relative to the negative external input. For this reason the supply voltage from your computer should not be used to power the equipment if the computer voltage source and inputs have a common ground.

A transparent millimeter scale, Fig 2, item h, on the front of the cylinder facilitates direct measurement of the initial and final piston position of "volume" to use in the computations or to calibrate the volume data acquisition. Two removable pins, Fig 2, 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, measure the actual diameter. 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 measurements or 0.06 cm to the piston displacements.
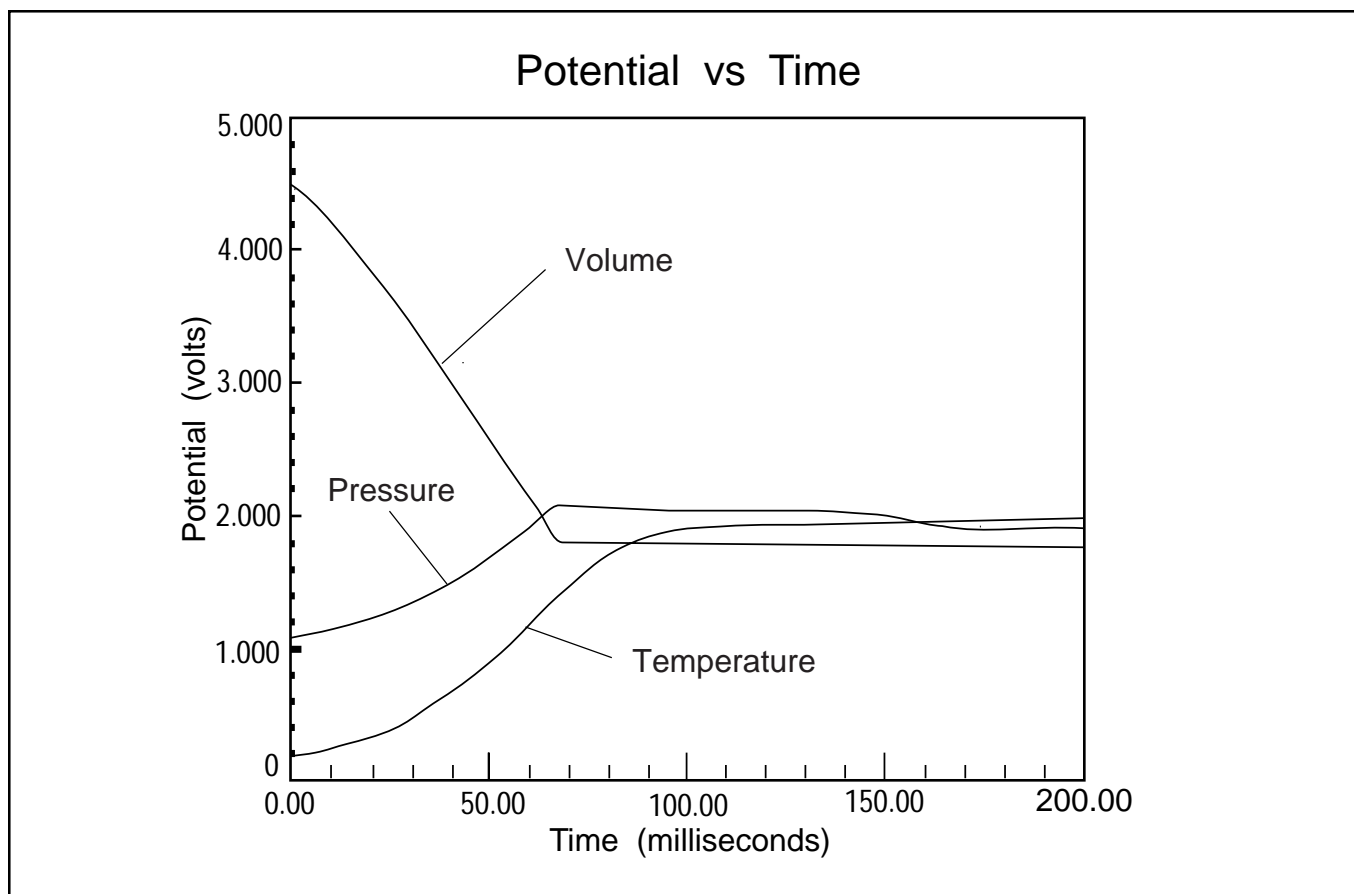
Potential vs Time

Figure: Graph of Voltage from Volume, Pressure and Temperature Sensors vs time

Setup

Connecting the Voltage Supply

Install a nine volt battery (not included) in the battery compartment located on the front of the electronics box, OR, connect a "floating ground" external voltage source to the jacks on the front of the electronics box. The external power supply must provide a stable DC voltage source of no more than 15 volts. Set the indicator switch on the front of the electronics box to "ON" for battery, or "ON" for an external power supply, depending on which voltage supply you are using. If you are using a battery, be sure to switch it off when you are not using the apparatus.

Connecting the Signal Cables

Connect one of the DIN-plug-to-mini-phone-plug cables to the output jack for the temperature sensor (located on the back of the electronics box). Connect the other cable to the pressure sensor output jack. The signal cable for the volume sensor (the linear potential divider) is permanently attached to the base of the cylinder.

> ➤ **CAUTION**: DIN connectors on the cables provided are wired for use with the PASCO Series 6500 Computer Interface, the Mac65 interface or the MPLI from Vernier Software. (The pin configuration is shown elsewhere in this manual.) If you are using a different interface, check the pin configuration on the inputs and make any needed changes before connecting. CONNECTING A VOLTAGE SOURCE TO THE OUTPUT JACKS MAY DAMAGE THE AMPLIFIERS.

Other Setup

Place the piston excursion limit pins in the position selected to provide the compression ratio desired. Maximum compression ratio may not give best results.

Using the TD-8565 with the PASCO Series 6500 Computer Interface

IBM compatible computers

① Connect the plug of the volume cable into Analog Channel A of the Series 6500. Use the adapter cables supplied with the apparatus to connect the temperature and pressure sensors to Channels B and C respectively.

② Start the Data Monitor program. An ideal operating mode for learning about the apparatus is the three channel "L–Oscilloscope" mode. Set the sweep speed to 20 milliseconds per division and the sensitivity of each channel to 1.00 volts per division. Move the piston up and down to determine that the system is operating properly. Make any necessary adjustments to the sweep speed and sensitivity.

③ To facilitate setting the triggering level, return to the Main Menu and select "M–Monitor Input". This will allow you to observe the three input voltages. For compressions, the temperature signal should range from 0.1 volts to +3 volts and for expansion from 0 volts to about -2 volts. The pressure signal should range from 0 volts to +3 volts for compression and expansion. The volume signal should range from +5 volts at highest value to 0 volts.

④ Return to the Main Menu and choose option "Z–Calibration". In the calibration menu, choose "Z" again to calibrate each input, then select the input you wish to calibrate. Follow the directions given on the screen.

    A: Volume: Hold the piston at the highest position ($\approx$15.5 cm) and press enter when the reading has stabilized. Enter the actual volume corresponding to that reading. (Calculate it based on the position and the radius of the cylinder.) Now put the piston on the lowest position and enter another calibration point.

    B: Temperature: Use the calibration equation provided with your unit to calculate the temperature corresponding to the voltage for the first calibration point. Pressurize the system and quickly press <Enter> to get a higher reading, then use the calibration equation again to get the second point.

C: Pressure: Hold the piston at a high position, and press <Enter> when the reading has stabilized. The pressure in Pascals is 100,000 times the voltage from the apparatus; enter this value. Make sure the gas cocks are closed and move the piston to a low position. When the reading has stabilized, press <Enter> and enter the new pressure.

Now the three inputs are calibrated in SI units.

* The calibration information is on a card on the side of the unit and also on the underside of the lid of the battery compartment.

⑤ Return to the Main Menu and choose "L–Oscilloscope" mode. Set the sweep speed to 20 ms/div with the right and left arrow keys. Use the up and down arrow keys and the space bar to set the sensitivity 1 V/div

⑥ Go to the triggering menu and set triggering to "Automatic on channel A". Voltage should be set to about 4.75 V, and the direction should be "Down". (Set the voltage threshold level to a voltage just below the maximum you will be using.)

⑦ Return to the 'scope and press "S"for single-sweep mode. Move the piston down sharply to see if all three traces are showing correctly. You may wish to change the sweep speed or the volts/div on the three inputs to get better traces.

⑧ Once you have a good trace, exit the oscilloscope mode making sure that you save the data. Now you may choose several options, including plotting the graphs again (together or separately) or plotting pressure vs. volume as suggested in the lab.

➤ **NOTE**: If you wish to numerically integrate the pressure vs. volume graph, you must first sort the data. Choose "O–Other Options"—from the main menu, then "S" to sort the data. Sort on the Y axis, with respect to input A. This may take a few seconds.
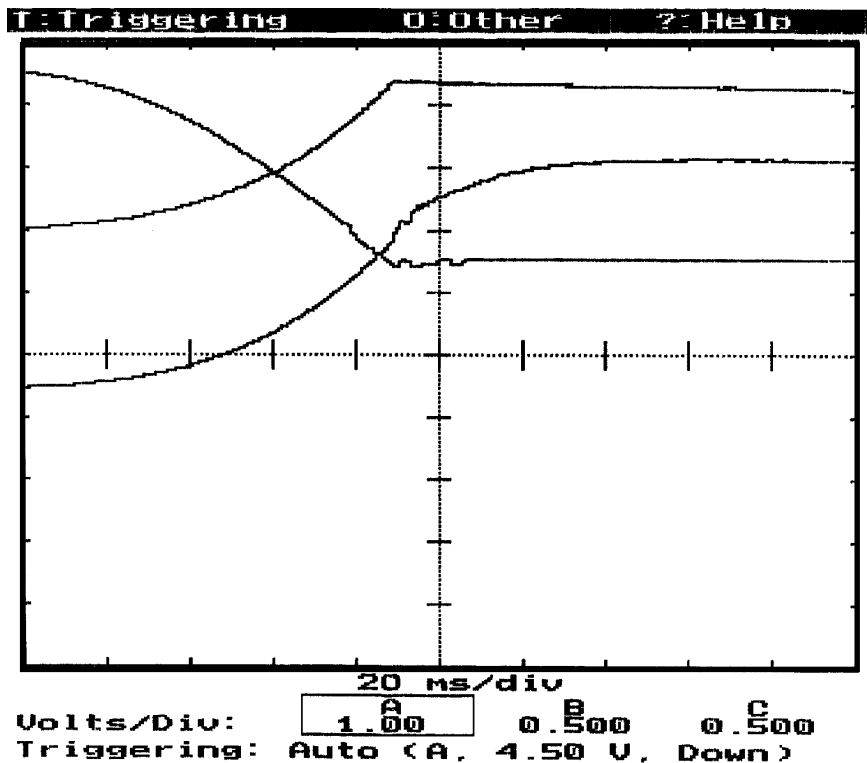

Figure: Oscilloscope Mode (MS-DOS version)

Apple II compatible computers

> ➤ **NOTE**: Operation with the Apple II series of computers is severely limited by the speed of the computer. If there is any other computer you can use rather than an Apple II, please do so.

① Connection and calibration procedures are as described for the IBM. We do not recommend calibrating the apparatus in SI units, since the round-off error introduced by the Apple will be greater than the volume of the cylinder in m^3.

② Because of the input limitations of the Apple II, it is not possible to graph all three traces in oscilloscope mode. Instead, choose "C" for fast data collection.
Enter the delay between data points as 1.0 ms, and collect about 100 data points. (Actual delay between readings on individual channels will be 3.0 ms, since the computer alternates channels for each reading.) Press the space bar when you are ready, and *simultaneously* change the volume. The input is *not* automatically triggered.

③ Once the data is obtained, return to the main menu and choose "P" to plot the data. The best graphs are obtained when the inputs are uncalibrated; otherwise the difference in scales between data sets may result in only one of the lines being visible.

Expansion of a Gas

To perform a qualitative demonstration of the adiabatic expansion of a gas, do the following:
Clamp the front foot of the apparatus base to the table. Fill 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), press "S" for Single Sweep, 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.
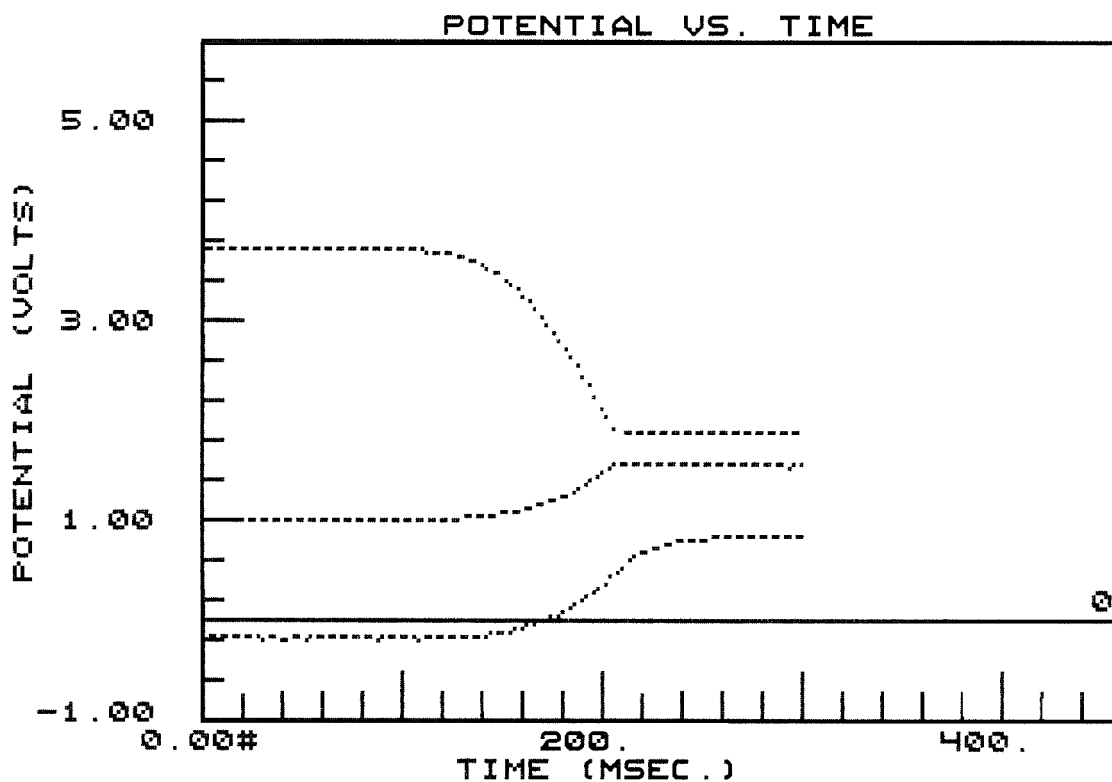

Figure: Graph of Voltage vs. time (Apple II version)

Notes:

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Experiment: Measurement of Work to Compress Gases Adiabatically

EQUIPMENT NEEDED: **Optional:**

– Adiabatic Gas Law Apparatus,   -Monatomic, Diatomic,
– Series 6500 Computer Interface.   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.

Theory

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

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 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 gas cocks before performing the experiments. If during the experiment some gas escapes simply add more.

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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.

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.

Schematic
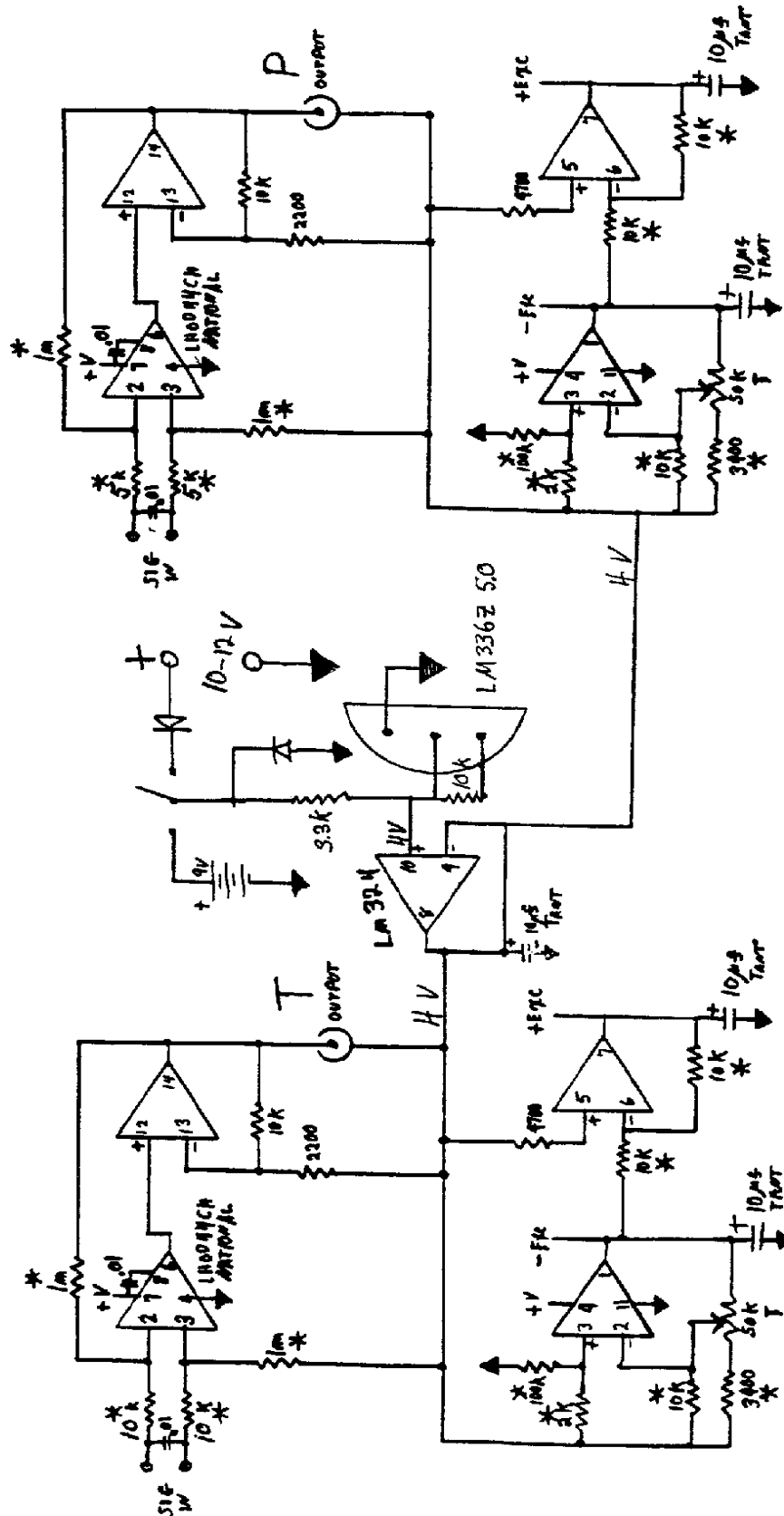
Specifications / Sample Data

Specifications

Operating Voltage:
9-15 volts DC or 9 volt battery. Higher voltage will provide capability of increased range in temperature and pressure measurements. A floating power supply is required.
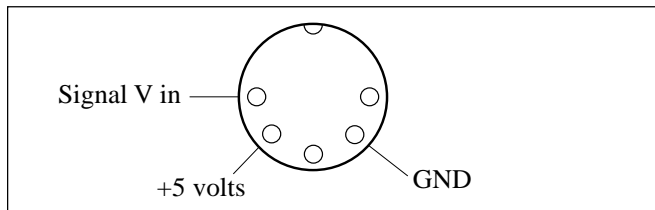
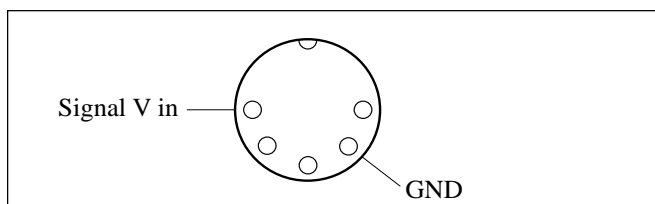Operating Current:
    10-12 mA.

Temperature Measurement:
    ± 2 K

Pressure Measurement:
    ± 2 kPa

**DIN connector pin configuration: (Pins pointed at you)**

Volume Cable (flat)

Signal V in

+5 volts   GND

Pressure and Temperature Cables (grey)

Signal V in

GND

➤**NOTE**: The Adiabatic Gas Law apparatus operates ideally with a 12 V DC floating external supply. However, for most measurements it will operate satisfactorily with a 9 volt battery. If the supply voltage is low or the signals very large, either the pressure or temperature signal amplifier may saturate and truncate the output signal. If this occurs either increase the operating voltage or decrease the compression ratio in the experiment which will reduce the output signal voltage.

Sample Data

Data taken with an IBM PC and a PASCO Series 6500 Interface.

$f(x) = 1.433039E+0 * (x^{\wedge}-1.341016E+0)$
$R^2 = 9.998867E-1$
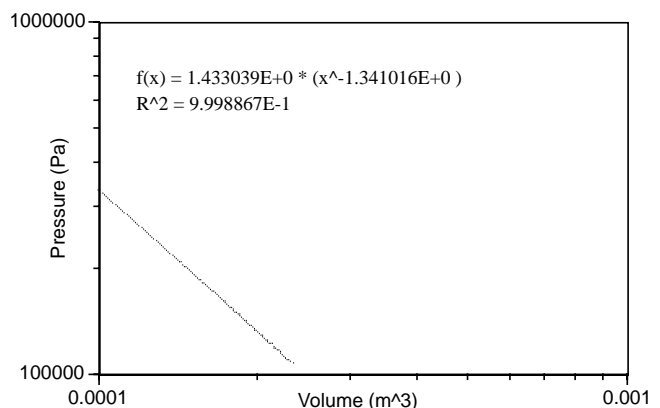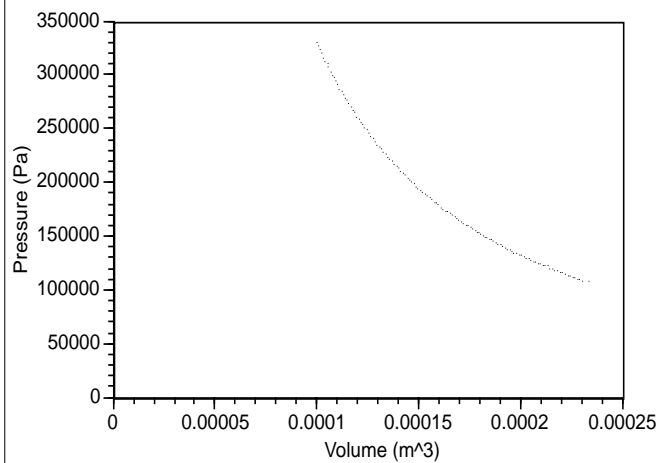
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Technical Support

Feed-Back

If you have any comments about this product or this 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 feed-back. 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.

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. This makes descriptions of individual parts much easier.

• 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.