THE UNIVERSITY OF HONG KONG

Department of Physics

PHYS2261 Introductory heat and thermodynamics

Laboratory report 2261-1: Adiabatic gas

1 Ideal gas law

Equipment required:
Adiabatic gas law apparatus

Purpose:
To show that $\frac{PV}{T} = nR$ for an ideal gas and determine the value of R.

Theory:
The ideal gas law is the equation of state of an ideal gas. The well-known relationship between pressure, volume and temperature of an ideal gas is

$$PV = nRT \; .$$

For a closed system with n fixed, placing all variables on the left-hand side of the equation yields a constant, i.e.

$$\frac{PV}{T} = nR \; .$$

Setup:

A. Connections:

1. The Adiabatic gas law apparatus should have already been connected to *Science Workshop* 500 interface: the pressure, volume and temperature din connectors are inserted into analog channels A, B and C of the interface, respectively.
2. Open *Capstone* on the computer. Indicate that a voltage sensor is connected to each channel in the *Hardware Setup*. Adjust the common sample rate to $1000\,\mathrm{Hz}$.
3. In the Calculator tool, click *New* and define the pressure according to the linear calibartion expression on the label on the side of the Adiabatic gas law apparatus. Provide the unit also.
4. Do the same for volume and temperature.

B. Graphical display:

1. Drag and drop the *Graph* icon from the display menu onto the page. On the y-axis, select measurement to be pressure that is defined under the equations/constants label. Select time in second for the x-axis.
2. Repeat for volume and temperature. In this way, graphs of pressure, volume and temperature will all be displayed with a common time axis.

Procedure:

1. With a stopcock valve open, set the piston to the approximate middle of its range at the $10\,\mathrm{cm}$ mark and close both stopcocks.
2. Record the height of the piston at atmospheric pressure.

3. Raise the piston to its highest position, click on *Record* and over a space of approximately five seconds, slowly and steadily move the piston to its lowest position, then click *Stop*. Notice that the graphs plotted show the pressure increasing as the volume decreases.

Analysis:

A. Conversions from voltages to P, V and T

1. Use the *Calculator* to define $nR = PV/T$ and choose *Properties* to ensure that the numeric display shows at least three significant figures. Plot a graph of nR by selecting the appropriate title on the vertical axis.

2. Use the $\sum$ icon on the *Graph* menu to display the mean value of nR as well as the standard deviation.

3. Record the mean value and also the standard deviation of nR. Estimate the random error associated with the experiment.

B. Number of moles n

1. Calculate the volume of air in cm^3 at the initial $10\,\mathrm{cm}$ height when the stopcock was opened to the atmosphere using $V_0 = \pi r^2 h_0$.

2. Calculate the number of moles of gas with density of air at standard temperature and pressure (STP) of $\rho = 0.001\,29\,\mathrm{g\,cm^{-3}}$, the volume V_0 and the molecular weight of air.

3. Compute your measured value of R.

4. Compare your measurement with the generally accepted value of R.

2 Adiabatic gas law

Equipment required:
Adiabatic gas law apparatus, helium or argon gas and carbon dioxide gas.

Purpose:
To observe the adiabatic gas law $PV^\gamma = \mathrm{constant}$ and measure the ratio of specific heats γ for different gases.

Theory:
When a process occurs quickly enough that no heat is exchanged with the environment, the process is called "adiabatic". For such process, the relation between pressure and volume is given by

$$PV^\gamma = \mathrm{constant}\ ,$$

where γ is the ratio of specific heats at cosntant pressure and constant volume, i.e. $\gamma = C_p/C_v$. A measurement of γ can reveal important physical information about the structure of gas molecules. The equipartition theorem tells us that the molar specific heat at constant volume C_v is related to the number of degress of freedom f available to each molecule through the relation

$$C_v = \frac{f}{2} R\ ,$$

where $f = 3$ for a monatomic gas with three translational directions in motion and $f = 5$ for a diatomic gas with three translational plus two rotational contributions to the internal energy.

The specific heat at constant pressure C_p is related to the specific heat at constant volume by

$$C_P = C_V + R\ .$$

Experimentally, you will determine γ by observing the relation between pressure and volume. Since we have

$$\ln P = -\gamma \ln V + b$$

for some constant b, we expect that a plot of $\ln P$ versus $\ln V$ should be a straight line of slope $-\gamma$.

Procedure:

1. With a stopcock valve open, set the piston to the approximate middle of its range at the $10\,\mathrm{cm}$ mark and close both stopcocks.
2. Raise the piston to its highest position, click on *Record* and quickly move the piston to its lowest postion, then click *Stop*. The gas should be compressed as rapidly as possible to make the experiment approximately adiabatic.

Procedure:

1. Use the *Calculator* to compute $\ln P$ and $\ln V$. Make a graph of $\ln P$ versus $\ln V$. Perform linear fit and record the slope. Compare your result against 1.40, the theoretical value for air.
2. Repeat the experiment using carbon dioxide as well as helium or argon.

3 Work done by an adiabatic process

Equipment required:
Adiabatic gas law apparatus,.

Purpose:
To observe that the work performed on a gas is given by $W = \int P\,dV$, i.e. the area under a P-V curve.

Theory:
When a gas is compressed under constant pressure, the work performed on the system is simply the product of force times displacement:

$$W = -F\Delta y = -PA\Delta y = -P$$

- - - - END OF LABORATORY SESSION - - - -

Discussion

A few questions have been listed below for you to ponder:

- Based on the results in Task 2, discuss about Greenhouse Effect.
- Inverse-square law is derived by assuming point source. Apparently, the Stefan-Boltzmann lamp we are using in Task 3 is not a point source. Discuss how would this affect the result.

Discuss them in your report under the "Discussion" section. Feel free to include more constructive comments.