

**Experiment № 7****STUDY OF BASIC PRINCIPLES OF THERMODYNAMICS. DETERMINATION OF  $C_p/C_v$  FRACTION FOR AIR**

**Objective:** to master the basic principles of molecular physics and thermodynamics. To determine  $C_p/C_v$  fraction for air experimentally.

**1 EQUIPMENT**

1. Hermetic container.
2. Manometer.
3. Pump.

**2 THEORY****2.1 Ideal gas law.**

The relation between gas parameters is known as ideal gas equation of state (ideal gas law). Only those gases we can treat as ideal in which, first, molecules are very small comparatively to volume of the container and, second, one can neglect interaction between molecules at distance. Equation of state for an ideal gas has the form

$$pV = \frac{m}{M} RT, \quad (2.1)$$

where  $p$  stands for gas pressure on the walls of container (the unit of pressure is pascal,  $1 \text{ Pa} = 1 \text{ N/m}^2$ ),  $V$  is volume of the container (in cubic meters),  $m$  is mass of the gas (in kilograms),  $M$  is molar mass (the mass of one mole of gas, is measured in kilograms per mol),  $R = 8,31 \text{ J/(mol}\cdot\text{K)}$  is the universal gas constant,  $T$  is absolute temperature (in kelvins, K).

If the gas pass from one state ( $p_1, V_1, T_1$ ) to another ( $p_2, V_2, T_2$ ) at constant temperature ( $T_1 = T_2$ ), the process is isothermal, and

$$p_1 V_1 = p_2 V_2 \quad (pV = \text{const}).$$

If the process take place at constant volume ( $V_1 = V_2$ ), then the process is isochoric (isovolumetric), and

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}.$$

If  $p_1 = p_2$  (isobaric process), then

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}.$$

**2.2 Internal energy of an ideal gas**

Internal energy is the total energy of all the thermal motions of molecules and their interactions. For one mole of ideal gas one can calculate the internal energy as a product of the mean kinetic energy of molecules  $\langle e_k \rangle$  and Avogadro's number  $N_A$ , and obtain

$$U = \langle e_k \rangle N_A;$$

$$\langle e_k \rangle = \frac{i}{2} kT,$$

where  $i$  is the number of degrees of freedom for a molecule ( $i=3$  for one-atomic molecules,  $i=5$  for two-atomic one and  $i=6$  otherwise).

For arbitrary mass of a gas we have

$$U = \frac{i}{2} \cdot \frac{m}{m} RT. \quad (2.2)$$

2.3 The first law of thermodynamics is the law of energy conservation in application to thermal processes. It reads as

$$Q = DU + A, \quad (2.3)$$

where  $Q$  is the heat, obtained by the system from outside,  $DU$  is the change of internal energy of system,  $A$  is the work, done by the gas.

In any process the total work done by external forces is

$$A = \int_{V_1}^{V_2} p dV. \quad (2.4)$$

2.4 The heat transferred to the gas in isochoric process can be expressed as

$$Q = \frac{m}{m} C_V DT. \quad (2.5)$$

The quantity  $C_V$  is an important physical characteristic of a gas, namely a molar specific heat at constant volume

$$C_V = \frac{Q}{\frac{m}{m} DT}; \quad (2.6)$$

from the above equation one can see that  $C_V$  is determined by heat needed to warm up 1 mole of an ideal gas by 1 kelvin. Unit of molar specific heat is 1 J/(mol·K).

Analogously, in isobaric process, molar specific heat at constant pressure is

$$C_p = \frac{Q}{\frac{m}{m} DT}; \quad (2.7)$$

so, the molar specific heat at constant pressure is the heat needed to warm up 1 mole of an ideal gas by 1 kelvin.

For an ideal gas

$$U = \frac{i}{2} \cdot \frac{m}{m} RT,$$

or

$$U = \frac{m}{m} C_V T,$$

where

$$C_V = \frac{i}{2} R \quad (2.6)$$

is called the molar specific heat at constant volume

$$dU = \frac{m}{m} C_V dT.$$

In isobaric process we have

$$Q = \frac{m}{m} (C_V + R) DT,$$

where  $DT = T_2 - T_1$ . And

$$C_p = C_v + R. \quad (2.9)$$

is the molar specific in isobaric process, so as

$$Q = \frac{m}{m} C_p DT. \quad (2.10)$$

### 3 DESCRIPTION OF EXPERIMENTAL APPARATUS AND COMPUTATION FORMULA

In this experiment we calculate the fraction  $C_p/C_v$  by method of Clemand and Desormes.

Container A is connected with manometer M and faucet K. The container can also be connected with the pump to fill it with air.

By the method of Clemand and Desormes one can calculate  $C_p/C_v$  as

$$\gamma = C_p/C_v = h_1/(h_1 - h_2). \quad (3.12)$$

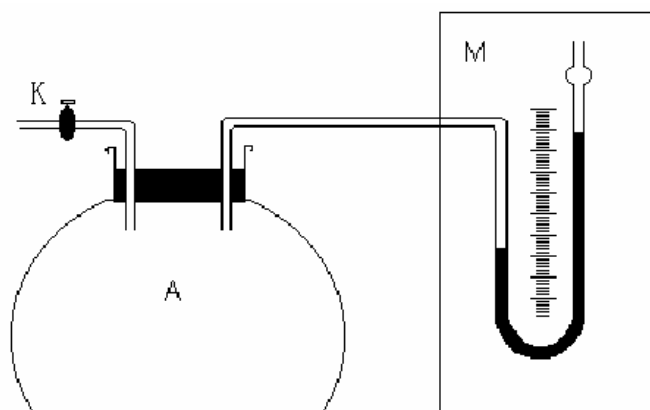


Figure 3.1

### 4 PROCEDURE AND ANALYSIS

- 4.1 Turn on a faucet K and let the levels of liquid in both legs of manometer M to be equal.
- 4.2 Join the container and the pump and fill the container with air until the difference of levels in manometer reaches 18-20 cm.
- 4.3 Turn off a faucet K and wait until the levels difference does not change (at these instance temperatures inside and outside the container are equal). Determine the difference of levels  $h_1$  in manometer's legs.
- 4.4 For an instance, turn the faucet K to make levels in manometer equal and turn the faucet off quickly.
- 4.5 Wait 2-3 minutes until the air within the container is heated up to the room temperature (the levels in manometer stop changing). Determine the difference of levels  $h_2$ .
- 4.6 Repeat the experiment 4 times more.
- 4.7 Calculate the mean value  $\gamma = C_p/C_v$  by formula (3.12).
- 4.8 Estimate the errors of measurements and calculations.
- 4.9 Express results of the calculation in the form  $g = g_c \pm \Delta g_c$  and specify the value of relative error  $\varepsilon$ .
- 4.10 Fill the table 4.1 with results of experiments and calculations.

Table 4.1

	$h_1,$ $10^{-2} \text{ m}$	$h_2,$ $10^{-2} \text{ m}$	$\gamma$	$D\gamma$	$e,$ %
1					
2					
3					
4					
5					
Mean value					