State behaviour of gases

Task objective: Validation of the equation of state under different conditions.

Measurement objective
For constant gas (air) amount investigate:
1) Volume and pressure behaviour at constant temperature Boyle-Mariott's law.
2) Volume and temperature behaviour at constant pressure Guy-Lussac's law.
3) Pressure and temperature behaviour at constant volume Charles-Amonton's law.
4) Evaluate the results obtained and indicate the main causes of measurement inaccuracies.

Task principle
The kit enables the measurement of state quantities of gases and their relationships. The gas state is determined by temperature, pressure and volume. These quantities are called state quantities and their relationship is described by the so-called equation of state. From the obtained relations it is also possible to calculate the universal gas constant, the gas expansion coefficient, etc.

Task theoretical basis

The state behaviour of a gas is a function of the state variables temperature T, pressure *p* and volume *V*, the mass *n*, which are determined by the state of the others. The dependence of volume on temperature, pressure and mass is given by the total differential:

$$\mathrm{d}V = \left(\frac{\partial V}{\partial T}\right)_{p,n} \mathrm{d}T + \left(\frac{\partial V}{\partial p}\right)_{T,n} \mathrm{d}p + \left(\frac{\partial V}{\partial n}\right)_{T,p} \mathrm{d}n \tag{1}$$

For given amount of matter (n = const., dn = 0; in closed volume (glass syringe)) and isobaric change (p = const., dp = 0) it is possible to state:

$$\mathrm{d}V = \left(\frac{\partial V}{\partial T}\right)_{p,n} \mathrm{d}T \tag{2}$$

Formula $\left(\frac{\partial V}{\partial T}\right)_{p,n}$ corresponds to tangent function V = f(T) and characterizes temperature and pressure dependence. Coefficient of thermal expansion is defined for V or V_0 at T_0 = 273,15 K as:

$$\gamma_0 = \frac{1}{V_0}\left(\frac{\partial V}{\partial T}\right)_{p,n} \tag{3}$$

For ideal gas, we can state:

$$\frac{V_0}{T_0} = \frac{V}{T} = \text{konst.} \tag{4}$$

These relations were defined by Gay-Lussac.

Similarly, it is possible to deduce relations defined by Charles and Amonton:

$$\frac{p_0}{T_0} = \frac{p}{T} = \text{konst.} \tag{5}$$

For cases of constant amount of substance and isothermal process:

$$p_0 \cdot V_0 = p \cdot V = \text{konst.}, \tag{6}$$

which was experimentally proven first by Boyle and Mariott.

For an ideal gas, the following applies

$$p \cdot V = n \cdot R \cdot T, \tag{7}$$

where R is molar gas constant.

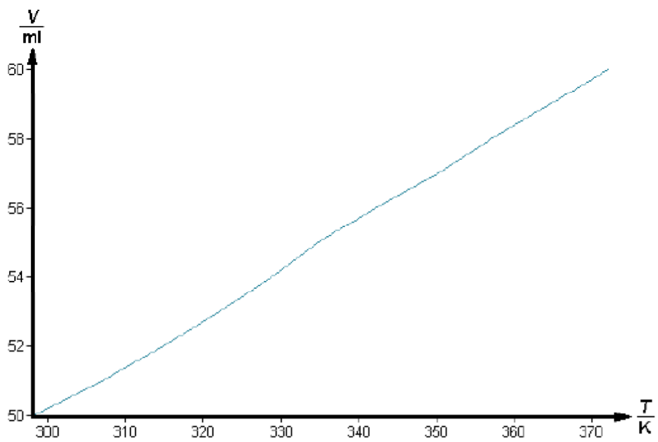

Figure 1: Example of experimental result of volume versus temperature measurement under constant pressure.

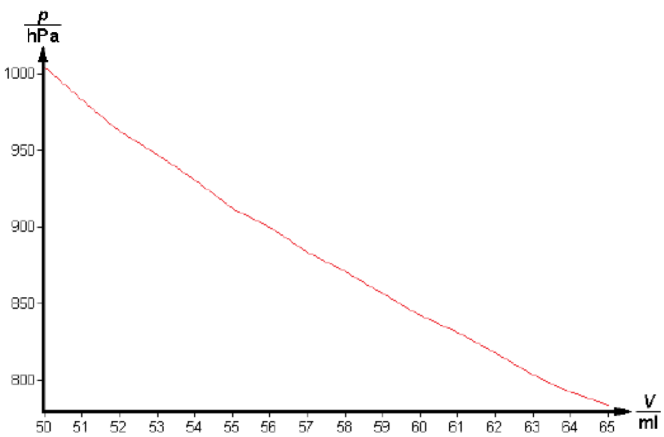

Figure 2: Demonstration of the experimental result of the measurement of pressure versus volume at constant temperature.

Kit description and measurement preparation

The closed container (cylinder with plunger) in the task is represented by a 100ml glass syringe fixed in a glass container. The syringe is equipped with a pressure sensor connected via a Cobra3 system, connected via a silicone tube and linked to a PC for online display on a monitor.

A digital or analogue thermometer can be used to measure the temperature inside the glass casing. An infrared radiator is used for heating, controlled by a 10-stage power switch or by a PID controller.

Measurement procedure

Verification of the Boyle-Mariott's law Figure 3:

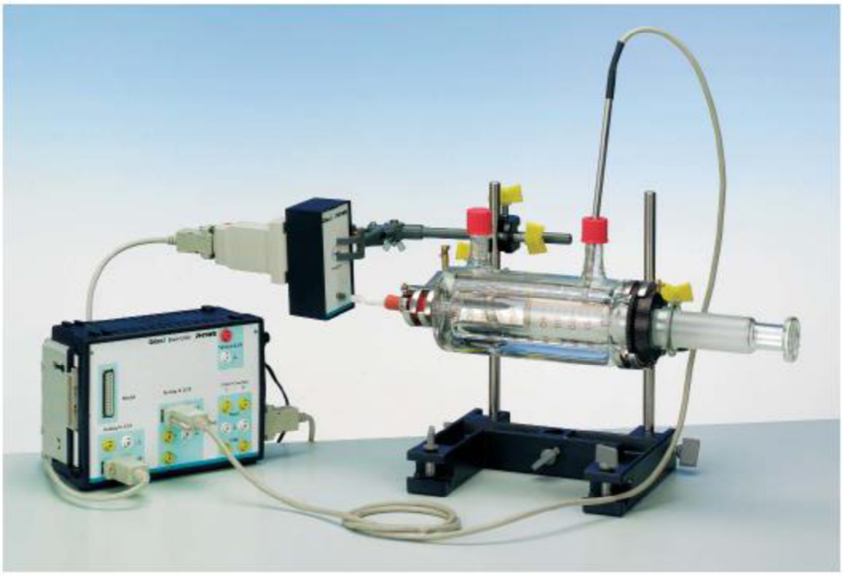

Figure 3. Boyle-Mariott's law

In our measurement we will not use the Cobra3 module to determine the temperature, but we will use an analogue or digital thermometer. It is important for our measurement that the piston and the whole apparatus are as tight as possible, so it is necessary to lubricate the piston with a small amount of oil before the measurement. Fill the glass casing with water (to reduce thermal fluctuations). Insert the thermometer as close as possible to the glass syringe. Set the volume to 50 ml and connect the syringe to the pressure sensor using a reducer and silicone tubing. Secure the connection on both sides. Calibrate the sensor using the measurement program. Change the volume in the syringe in small increments. Record the pressure and volume values.

Guy-Lussac's law:

The set-up of the experiment is similar to the previous one, now it is necessary to insert a magnetic stirrer into the glass cylinder and connect the infrared heater, see Figure 4.

Figure 4. Experiment configuration for Guy-Lussac's and Charles-Amonton's law

Set the initial volume again to 50 ml. Check the freedom of the overflow tube to drain excess liquid during heating! Read off the first values and then switch on the IR heating. During heating, gently stir the heated water in the glass cylinder using magnetic stirring. Read the values for each change of 1 ml. Stop measurement when 60 ml is reached.

Charles-Amonton's law:
The set-up of the apparatus corresponds to Figure 4. Now you need to connect a better-quality digital thermometer. Set the syringe volume to 50 ml. Read the baseline values and connect the heater. Proceed in 5°C increments until the temperature reaches approximately 55°C. Check for leaks! At each step, abruptly return the measured volume to the original 50 ml.

Reference:

[1] Ideal and Real Gases (Thermodynamics) - Laboratory Experiments Physics. PHYWE series of publications, © PHYWE SYSTEME GMBH & Co. KG, 2016.