The volume expansion of gases at constant pressure

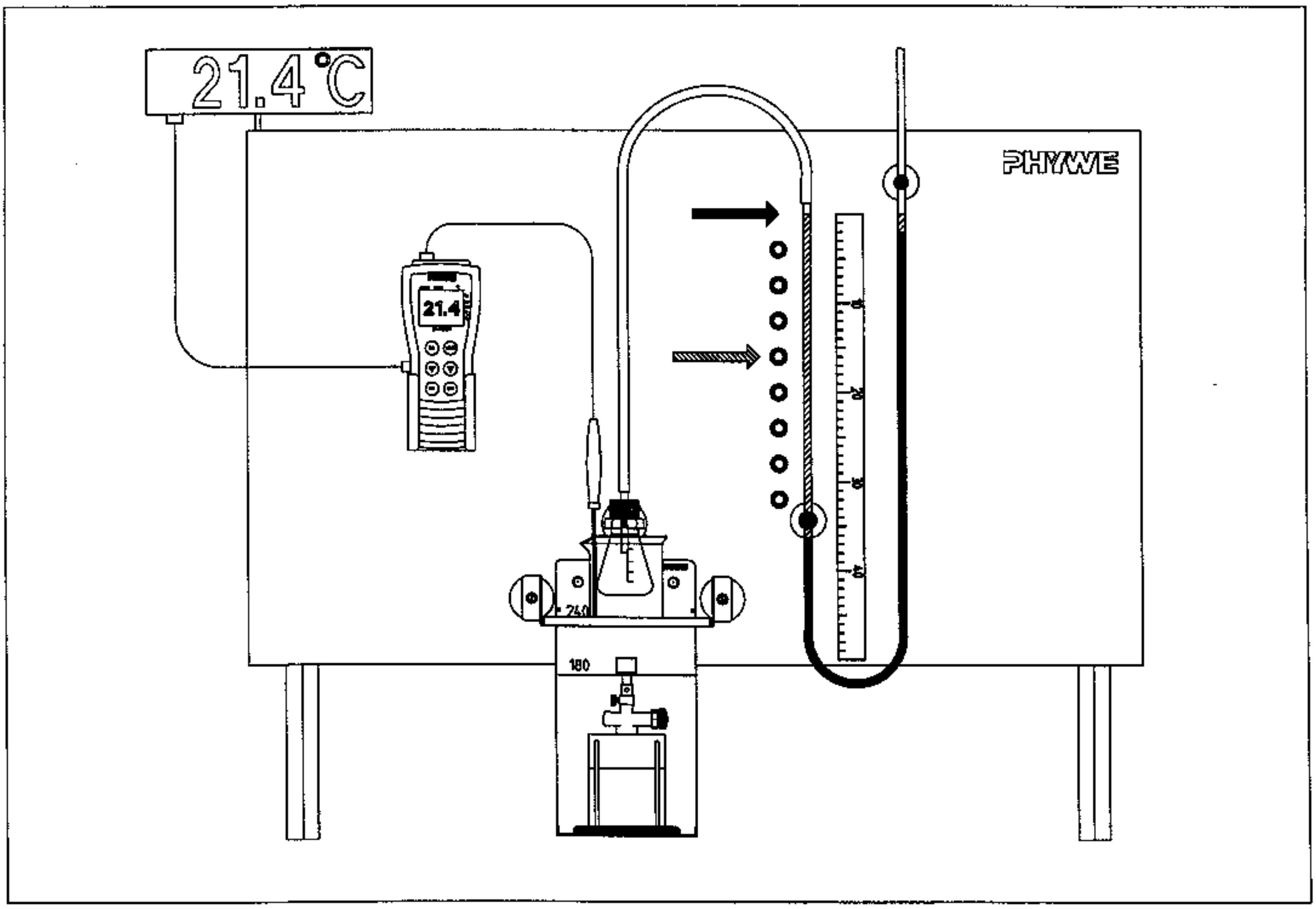
Heating a volume of air can result both in an increase in volume as well as in an increase in pressure. The change is shown by a manometer with movable arms.
In this experiment, the pressure is held constant by bringing the levels of the water in the two arms of the manometer back to the same height before reading off the change in volume.

Materials

Demo-Board Physics	02150.00	1
Clip, *d* = 26 ... 36 mm, with magnetic base	02151.06	1
Clip, *d* = 0 ... 13 mm, with magnetic base	02151.07	2
Rule for demo-board	02153.00	1
Pointer for demo-board, 4 pcs	02154.01	1
Point markers for demo-board, 24 pcs	02154.02	1
Holder for hand-held measuring instruments, magnetic	02161.00	1
Holder for burner, with magnetic base	02162.00	1
Holder for wire gauze, with magnetic base	02163.00	1
Wire gauze square, ceramic centre	33287.01	1
Beaker, 100 ml, low form, plastic	36011.01	1
Glass beaker, short, 400 ml	36014.00	1
Erlenmeyer flask, wide neck, 100 ml	36428.00	1
Glass tubes, straight, 80 mm, 10	36701.65	1
Glass tubes, straight, 400 mm, 10	36701.67	1
Rubber stopper, d 32/26 mm, 1 hole	39258.01	1
Silicone hose, i.d. 7 mm	39296.00	2
Funnel, plastic, dia. 50 mm	36890.00	1
Immersion probe NiCr-Ni	13615.03	1
Hand-held measuring instrument 2xNiCr-Ni	07140.00	1
Digital large-scale display	07157.93	1
Data cable RS 232, SUB-D/USB	07157.01	1
Butane burner, Labogaz 206	32178.00	1
Butane cartridge C 206	47535.00	1
Microspoon, special steel	33393.00	1
Food colour, patent blue V (E131)	48376.04	1
Glycerol 250 ml	30084.25	1
Water soluble pen for overheads		
Right-angled triangle		
Matches		

For the preliminary experiment:
Laboratory balance, 410 g (45030.93)
Rubber caps (2 caps from 02615.03)

Fig. 1



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Preliminary experiment

The volume of the Erlenmeyer flask and the relationship between the change in volume ΔV and the change in the water level in the glass tubes which are used as manometer must be known for the experiment. These measurements can be made most accurately by weighing the parts empty and filled with water:

Empty Erlenmeyer flask	68.72 g
Flask filled up to the stopper	196.97 g
Mass of water	128.25 g
Which gives a volume up to the stopper of $V_0 = 128\ cm^3$	
Empty glass tube with rubber caps	23.97 g
Glass tube filled with water	33.74 g
Mass of water	9.77 g

From the length of the glass tube $l = 37.5$ cm, we have the following relationship to the change in volume:

Water level change	corresponds	to volume change
$\Delta l = 1$ cm	$\hat{=}$	$\Delta V = 0.26\ cm^3$

With the help of the equation

$$\Delta V = \frac{d_i^2}{4} \cdot \pi \cdot \Delta l$$

we determine the internal diameter of the glass tube to be $d_i = 0.576$ cm.

Experimental set-up

see Fig. 1

- Fit on the holder for the burner to the left at the bottom of the board.
- When a butane burner is to be used, position the holder for the wire gauze on the board at the marked height 240 and place the wire gauze on it (when a bunsen burner is to be used, select height 180).
- Place the glass beaker on the wire gauze.
- Insert the small glass tube in the rubber stopper, using glycerol, and fit the stopper tightly on the Erlenmeyer flask, so that no air can escape past it.
- Hold the Erlenmeyer flask with the clip and lower it as far as possible into the glass beaker.
- Fill the beaker completely with water.
- Use the magnetically attaching holder to fit the hand-held measuring instrument onto the board. Connect the instrument to the large-scale display.
- Immerse the immersion probe in the beaker and connect it to the measuring instrument.
- Prepare the manometer from the two 37.5 cm long glass tubes and an approx. 70 cm length of transparent tubing.
- Use 0...13 mm clips to position the left glass tube in about the middle of the board, and the right glass tube at the upper edge, so that it protrudes up above the board (for exact positions, see Fig. 1).
- Fill the manometer with coloured water, so that only about 1 cm of air remains in the left arm, and only about 1 to 2 cm of water are held in the right arm (filling aid: funnel and tubing).
- Connect the Erlenmeyer flask to the left arm of the manometer with a piece of tubing.
- Move the right arm of the manometer down, so that the water levels in the two arms are at the same height.
- Mark the water level in the left arm with a pen (as a check, in case the tube should inadvertently slip), and also with a blue arrow (cold initial condition). Position the rule with its zero mark at this height.
- The extent of the volume expansion can be demonstratively displayed with marker points placed approx. 4 cm (corresponding to $\Delta V = 1\ cm^3$) apart.

Procedure

- Measure the initial temperature ϑ_0 of the water bath.
- Heat the water bath with the burner for about 30 s.
- Stir the water bath for 2 to 3 minutes, so that the air in the Erlenmeyer flask attains the temperature of the water bath.
- Move the right arm of the manometer down until the water levels in the two arms are again at the same height.
- Mark the water level with a red arrow. The right-angled triangle assists in projecting the level onto the surface of the board.
- Read off on the left arm the distance Δl from the pen mark to the water level. You can also utilize the marker points to refer to the corresponding change in volume.
- Note Δl and the corresponding temperature ϑ of the water bath.
- Stepwise determine further measurement values, recording the temperature and change in the water level at each step.

Results

Table 1

Initial temperature $\vartheta_0 = 21.4$°C

ϑ / °C	Δl / cm	$\Delta\vartheta$ / K	ΔV / cm³
25.8	8.0	4.4	2.1
29.2	13.5	7.8	3.5
32.3	19.3	10.9	5.0
35.3	24.0	13.9	6.2
39.5	31.5	18.1	8.2

Evaluation

See Fig. 2

Using the relationship determined in the preliminary experiment

$\Delta l = 1$ cm correspnds to $\Delta V = 0.26\ cm^3$

the change in volume ΔV can be calculated and entered in the Table, alongside the change in temperature $\Delta\vartheta$.

Fig. 2 shows, that the change in volume is proportional to the change in temperature. A straight line can be drawn through the plotted points.

$$\Delta V = V_0 \cdot \gamma \cdot \Delta\vartheta \tag{1}$$

The initial volume was

$V_0 = 128\ cm^3$,

the slope of the straight line is

$$\frac{\Delta V}{\Delta\vartheta} = 0.453\ cm^3/K$$

From which we can calculate the coefficient of volume expansion as

$\gamma = 3.5 \cdot 10^{-3}/K$.

The behaviour of air on heating it is given by the Ideal Gas Law

$$\frac{p_1 V_1}{T_1} = \frac{p_0 V_0}{T_0} \tag{2}$$

From this, we have at constant pressure $p_1 = p_0$

$$V_1 - V_0 = (T_1 - T_0) \cdot \frac{V_0}{T_0} \tag{3}$$

The coefficient of volume expansion is therefore equal to the reciprocal of the absolute temperature.

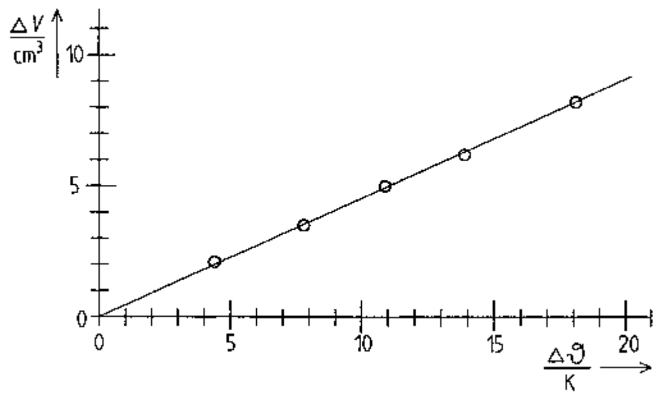
$\vartheta_0 = 21.4°C$ => $T_0 = 294.6$ K

$$\gamma = \frac{1}{T_0} = 3{,}4 \cdot 10^{-3}/K$$

Note

In this experiment, the temperature of the heated air is important. As the thermal contact between the immersion probe and air is very bad, however, the temperature in the water bath is measured. This necessitates a careful temperature equalization, i.e. stirring while waiting for 2 to 3 minutes. The temperature of the water bath should be measured in the region in which the Erlenmeyer flask is situated, it can be a little higher at the bottom of the beaker.

Fig. 2: The change in volume ΔV in dependence on the change in temperature $\Delta\vartheta$



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Space for notes