# Heat

Kinetic theory of gases
*Gas laws*

***Physics Leaflets***

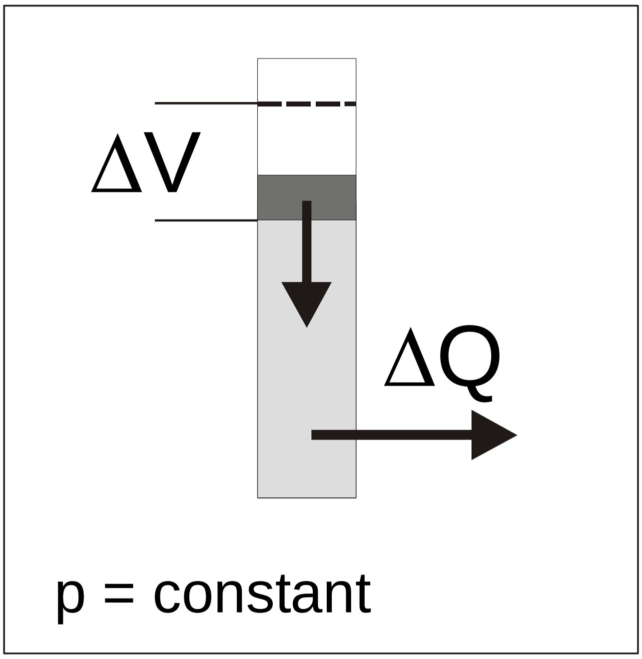
**P2.5.2.2**

## Temperature dependency of the volume of a gas at a constant pressure (Gay-Lussac's law)

### Objects of the experiment

- Determination of the temperature dependency of the volume of a gas at constant pressure
- Defining the absolute temperature scale by extrapolation towards low temperature

Fig. 1: Schematic representation of the thermodynamic process




### Principles

The state of a quantity of ν moles of an ideal gas is completely described by the measurable quantities pressure, volume and temperature. The relation between these three quantities is given by the general gas law:

$$p \cdot V = \nu \cdot R \cdot T \qquad \text{(I)}$$

p: pressure

V: volume

T: temperature

ν: quantity of ideal gas in moles

R = 8.31 JK-1mol-1 (universal gas constant)

If one of the quantities p, V or T remains constant, then the other two quantities cannot be varied independently of each other. At a constant pressure p, for example, Gay-Lussac's relationship states:

$$V \propto T \qquad \text{(II)}$$

This relationship is confirmed in this experiment by means of a gas thermometer. The gas thermometer consists of a glass capillary open at one end. A certain quantity of air is enclosed by means of a mercury seal. At an outside pressure $p_0$, the enclosed air has a volume $V_0$. The gas thermometer is placed in a water bath of a temperature of about $\vartheta \approx 90°$ C which is allowed gradually to cool (Fig. 1). The open end of the gas thermometer is subject to the ambient air pressure. Thus the pressure of the enclosed air column remains constant during the experiment. It's volume is given by:

$$V = \pi \cdot \frac{d^2}{4} \cdot h \qquad \text{(III)}$$

d: 2.7 mm (inside diameter of capillary)

h: height of gas volume

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## Apparatus

1 Gas thermometer ............................................ 382 00
1 Hand vacuum and pressure pump .................... 375 58
1 Stand base. V-shaped 20 cm ............................ 300 02
1 Stand rod, 47 cm ............................................ 300 42
2 Clamp with jaw clamp ...................................... 301 11

1 Hot plate ........................................................ 666 767
1 Beaker, 400 ml, hard glass .............................. 664 103

**P2.5.2.2(a)**
1 Digital thermometer .......................................... 666 190
1 Temperature sensor, NiCrNi ............................. 666 193

**P2.5.2.2(b)**
1 Mobile-CASSY .................................................. 524 009
1 NiCr-Ni Adapter S ............................................ 524 0673
1 NiCr-Ni temperature sensor 1.5 mm .................. 529 676

## Setup

### Collecting the mercury globules

- Connect the hand vacuum pump to the gas thermometer, and hold the thermometer so that its opening is directed downward (see Fig. 2).
- Generate maximum underpressure Δp with the hand vacuum pump, and collect the mercury in the bulge (a) so that it forms a drop.
  The manometer of the hand vacuum pump displays the underpressure Δp as a negative value.
- If there are mercury globules left, move them into the bulge (a) by slightly tapping the capillary.
  A small mercury globule which might have remained at the sealed end of the capillary will not affect the experiment.

### Adjusting the gas volume $V_0$

- Slowly turn the gas thermometer into its position for use (open end upward) so that the mercury moves to the inlet of the capillary.
- Open the ventilation valve (b) of the hand vacuum pump carefully and slowly to reduce the underpressure Δp to 0 so that the mercury slides down slowly as one connected seal.
- Mount the gas thermometer in the stand material and the large test tube like shown in Fig. 3 and remove the tubing with the hand vacuum pump.

  If the mercury seal bursts due to strong ventilation or vibration: Recollect the mercury.

### Measuring the temperature with the digital thermometer (demonstration measuring instrument)

- Introduce the temperature sensor NiCrNi into the large test tube parallel to the gas thermometer and connect it to the digital thermometer.

### Measuring the temperature with Mobile-CASSY (hand-held measuring instrument)

- Introduce the temperature sensor NiCrNi into the large test tube parallel to the gas thermometer and connect it to the Mobile CASSY.

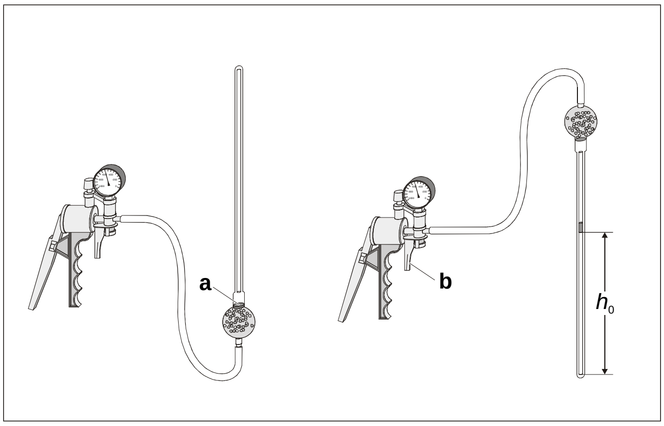


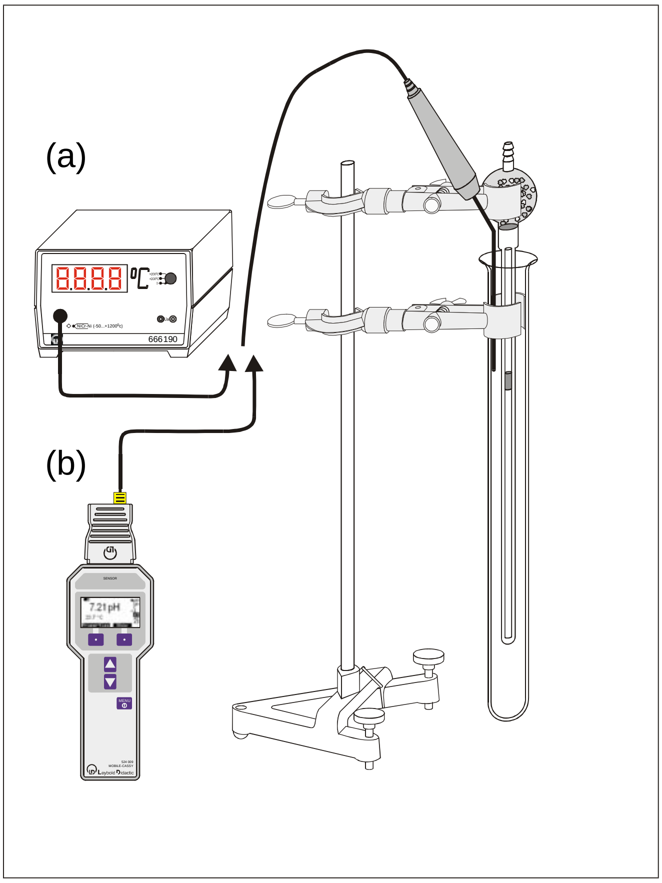

Fig. 2: Collecting the mercury globules and adjusting the initial gas volume $V_0$

## Safety notes

The gas thermometer contains mercury.

- Handle the gas thermometer with care.
- Avoid glass breakage

Fig. 3: Schematic representation of the experimental setup.: Measuring the temperature with the digital thermometer (a) or with Mobile CASSY (b), respectively.



## Carrying out the experiment

- Heat about 400 ml of water in the beaker to a temperature of about 90°C by means of the hot plate.
- Carefully fill the hot water into the large test tube. Due to the increasing temperature the initial gas volume will increase.
- Observe the increase of the temperature and wait with reading off the temperature and height until the temperature starts to decrease.
- Measure the temperature ϑ and the height h of the enclosed gas volume of the gas thermometer while the heat bath (water in the test tube) cools down gradually.

## Measuring example

Table. 1: Height h of the enclosed quantity of air as function of the temperature ϑ.

| $\frac{\vartheta}{°C}$ | $\frac{h}{cm}$ |
|---|---|
| 87.2 | 49.5 |
| 80.9 | 48.5 |
| 75.2 | 47.5 |
| 67.7 | 46.5 |
| 58.7 | 45.5 |
| 51.4 | 44.5 |
| 42.3 | 43.5 |
| 35.7 | 42.5 |
| 30.2 | 41.5 |
| 25.0 | 40.5 |

## Evaluation and results

Using equation (III) the volume can be calculated from the measured height (Table 2).

Fig. 4 shows a plot of the values listed in Table 2. The straight line is calculated by linear regression:

$V = 214.2\ mm^3 + (0.79\ mm^3/°C) \cdot \vartheta$

From the extrapolation of the linear regression towards negative temperatures the absolute temperature zero (T = 0 K) can be defined by the intersection point of the regression line with the temperature axis (V = 0):

$\vartheta_0 = -271\ °C \pm 8\ °C$

$\vartheta = T + \vartheta_0$

$V = (0.79\ mm^3/K) \cdot T$

Table. 2: The volume V (calculated according equation (III) from the measuring values h of table 1) as function of the temperature ϑ.

| $\frac{\vartheta}{°C}$ | $\frac{V}{mm^3}$ |
|---|---|
| 87.2 | 283.4 |
| 80.9 | 277.7 |
| 75.2 | 272.0 |
| 67.7 | 266.5 |
| 58.7 | 260.5 |
| 51.4 | 254.8 |
| 42.3 | 249.1 |
| 35.7 | 243.3 |
| 30.2 | 237.6 |
| 25.0 | 231.9 |

At a constant pressure, the temperature and the volume of an ideal gas are proportional to each other (Gay-Lussac's law).

Fig. 4: The volume V of the enclosed air column as function of the temperature ϑ. The red line corresponds to the linear regression results.