Temperature dependency of the pressure of a gas at a constant volume (Amontons' law)

Objects of the experiment

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

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 an ideal gas in moles

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

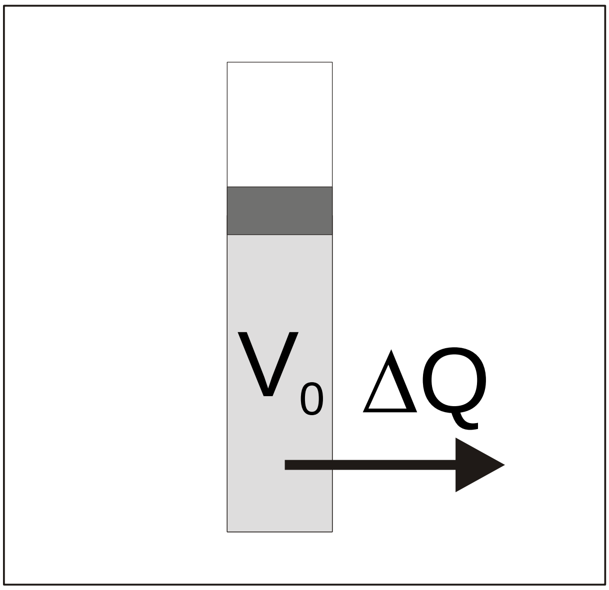

Fig. 1: Schematic representation of the thermodynamic process

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 volume V, for example, Amonton's relationship states:

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

This relationship is confirmed in this experiment by means of a gas thermometer. The gas thermometer consists of a glass capillary. 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.

By pumping off air with a hand vacuum pump, an underpressure Δp with respect to the outside pressure p_0 is generated at the open end of the capillary so that the pressure there is $p_0 + \Delta p$. The mercury seal itself exerts a pressure p_{Hg} on the enclosed air:

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$p_{Hg} = \rho_{Hg} \cdot g \cdot h_{Hg}$ (III)

ρHg = 13.6 g cm^{-3}: density of mercury

g = 9.81 m s^{-2}: acceleration of free fall

h_{Hg}: height of the mercury seal

Thus the total pressure of the enclosed air is given by:

$p = p_0 + p_{Hg} + \Delta p$ (IV).

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). By pumping off air with a hand vacuum pump the enclosed gas volume V_0 is kept constant during the process of cooling.

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.

  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.

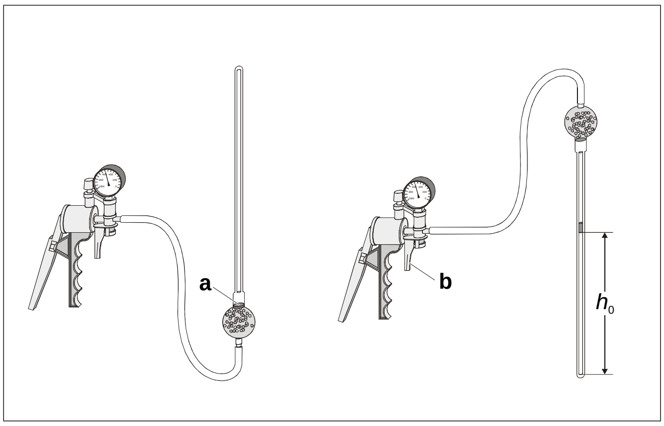


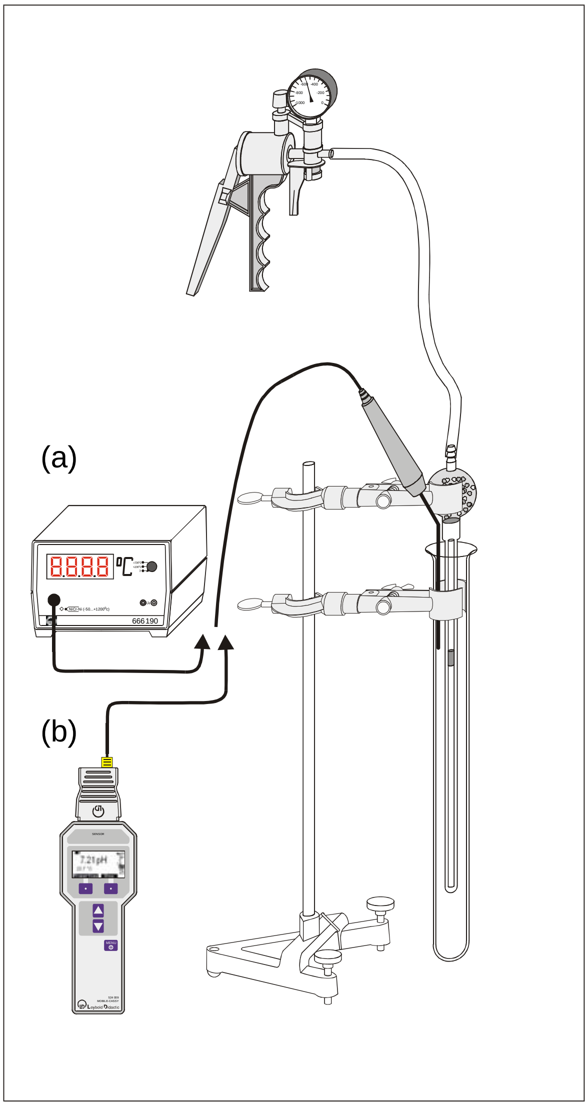
Fig. 2: Collecting the mercury globules and adjusting the initial gas volume *V*0

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 until the temperature starts to decrease.
- Read off the height h_0 of the mercury seal. This value defines the enclosed volume V_0.

While the heat bath (water in the test tube) cools down gradually repeat the following steps:

- Increase the underpressure Δp by pumping with the hand vacuum pump until the mercury seal reaches the initial height h_0 (i.e. thus the volume, which is decreasing during the cooling process, is readjusted to perform each measurement at a constant volume V_0).
- Read off the temperature ϑ and the underpressure Δp.

Measuring example

Table. 1: Pressure Δp of the enclosed quantity of air V_0 as function of the temperature ϑ.

$\frac{\vartheta}{°C}$	$\frac{\Delta p}{hPa}$
81.5	0
65.2	-20
55.2	-50
45.5	-80
39.9	-100
35.3	-120
29.7	-140
23.3	-160
18.3	-175

P_0 = 1011 hPa

h_{Hg} = 11 mm

Evaluation and results

Using equation (VI) the pressure can be calculated from the measured underpressure (Table 2).

$$p_{Hg} = 13.6\ \frac{g}{cm^3} \cdot 9.81\ \frac{m}{s^2} \cdot 11\ mm = 15\ hPa$$

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

$$p = 802.3\ hPa + (2.96\ hP/°C) \cdot \vartheta$$

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

$\frac{\vartheta}{°C}$	$\frac{p}{hPa}$
81.5	1026
65.2	1006
55.2	976
45.5	946
39.9	926
35.3	906
29.7	886
23.3	866
18.3	851

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 (p = 0):

ϑ = -271 °C ± 8 °C

$\vartheta = T + \vartheta_0$

p = (2.96 hP/K) · T

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

Fig. 4: The pressure p of the enclosed air column V_0 as function of the temperature ϑ. The red line corresponds to the linear regression results.