Skript zum Versuch

A46

Internal Friction of Gases: Gas Viscosity

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1 The task

Measure the viscosity of H_2 and CO_2 at 20 °C and 70 °C. Determine the mean free path and the collision cross section of these gases.

2 Introduction

For the viscosity, η, of a dilute gas the kinetic gas theory yields the following expression:

$$\eta = \frac{1}{3}\rho\Lambda\overline{c}\,, \tag{1}$$

with gas density ρ, mean free path Λ and mean molecular velocity $\overline{c}$:

$$\rho = \frac{pM_m}{RT}\,, \tag{2}$$

$$\overline{c} = \left(\frac{8RT}{\pi M_m}\right)^{\frac{1}{2}}\,, \tag{3}$$

$$\Lambda = \frac{1}{\sqrt{2}\pi\sigma^2\left(\frac{N}{V}\right)}\,. \tag{4}$$

With p pressure, M_m molar mass, R universal gas constant, T absolute temperature, (N/V) number density and σ collision cross section.

Combining equations (1) to (4) and substituting factor 1/3 in equ. (1) through a more precise value $5\pi/32$, resulting from a more elaborate theory[1] one finds with Avogadro's constant N_A:

$$\eta = \frac{5\pi}{16} \left(\frac{M_m RT}{\pi} \right)^{\frac{1}{2}} \frac{1}{N_A \pi \sigma^2} \,, \tag{5}$$

Therefore, viscosity measurements can be used to determine the mean free path Λ as well as the collision cross section σ which is a measure for the molecular diameter.

3 Experimental Procedure

The apparatus used is sketched in fig. 2. The compressed gas cylinders for hydrogen and carbon dioxide must first be taken from the gas cylinder cabinet. Then the pressure regulators have to be mounted. These have to be adjusted in the following way (see fig. 1): completely unscrew the pressure adjustment handle, close the needle valve an then open the main gas cylinder valve. Screw the pressure adjustment handle until the outlet pressure gauge reads between 0,5 to 1 bar. Open the needle valve to start the gas flow. The fine adjustment of the gas flow is obtained with the needle valve of the rotameter. The gas flows through the thermostatted measuring capillary and builds up an pressure which can be measured with the Glycerol containing U-tube differential manometer. The height difference should roughly be set to $\Delta h \approx 8{,}5\,\mathrm{cm}$. The gas leaves the capillary with the measuring temperatur T_M and it will be quenched to room temperature T_R in the beaker with the Copper coil. To determine precisely the flow rate the gas enters the soap lamella flow meter. If the level of the soap liquid is suitably adjusted the flow produces soap-bubbles that enter the measuring tube as soap lamellas. These lamellas move nearly frictionless from the lower to the upper marker (blue rings). The volume between the markers is $28{,}5\,\mathrm{cm}^3$ in both apparatus.

At the desired temperature, let the gas flow through the apparatus for about 5 min, then measure the flow time of 10 lamellas moving between the markers. During this time keep Δh constant. Write down the flow time t and Δh.

After the experiments the pressure regulator has to be dismounted: disconnect the plastic tube, close the main gas cylinder valve and open the needle valve until both pressure gauges show zero pressure. Unscrew the pressure adjustment handle. Dismount the pressure regulator and put the gas cylinders back into the gas cylinder cabinet.

Advantageously, the gasses should be studied in the following sequence:

		Gruppe A	Gruppe B
1.	$T = 20\,^\circ\mathrm{C}$	H_2	CO_2
2.	$T = 20\,^\circ\mathrm{C}$	CO_2	H_2
3.	$T = 70\,^\circ\mathrm{C}$	CO_2	H_2
4.	$T = 70\,^\circ\mathrm{C}$	H_2	CO_2

[1] Siehe z. B. : Berry, Rice, Ross, *Physical Chemistry*, Wiley, New York 1980, S. 1073

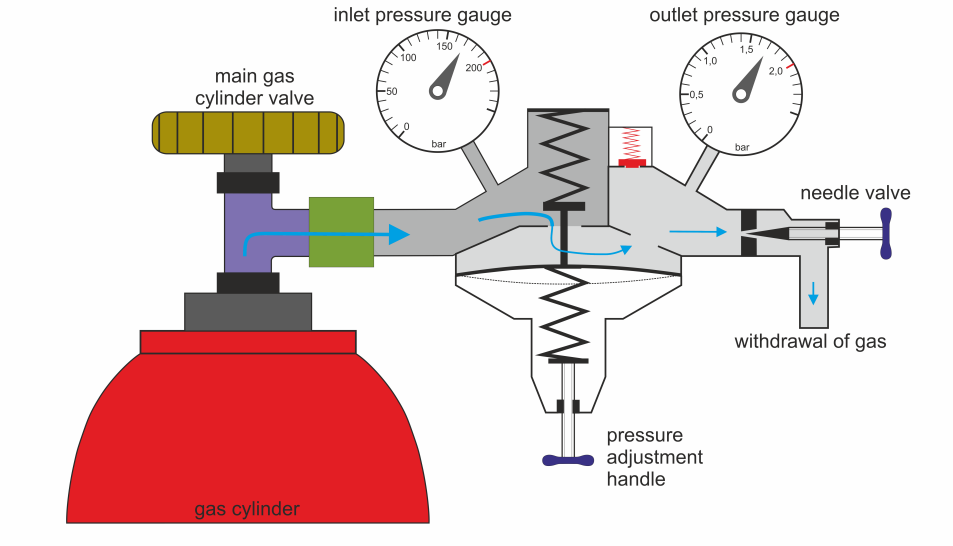

Fig. 1: Pressure regulator

4 Data evaluation

The viscosity of the gases is determined applying Hagen-Poiseuille's law.[2] For a laminar flow they found:

$$\eta = \frac{r^4 \pi t \Delta p}{V L} \tag{6}$$

with the following abbreviations:

- η: viscosity in $\mathrm{kg{\cdot}(m{\cdot}s)^{-1}} = \mathrm{Pa{\cdot}s}$
- r: radius of the measuring capillary (0,355 mm or 0,400 mm, respectively)
- t: flow time in s
- Δp: pressure drop (at the Glycerol manometer)
- V: gas volume, streaming at temperature T_M during the time intervall t through the capillary
- L: length of the capillary, $L = 0{,}3\,\mathrm{m}$

The pressure drop Δp is determined with the U-tube manometer, filled with Glycerol:

$$\Delta p = \rho g \Delta h \tag{7}$$

with the density of Glycerol ($\rho = 1260\,\mathrm{kg/m^3}$), gravitational acceleration $g = 9{,}81\,\mathrm{m/s^2}$ and Δp in Pascal.

[2] Gotthilf Heinrich Ludwig Hagen (1797–1884), Jean Louis Marie Poiseuille (1797–1869)

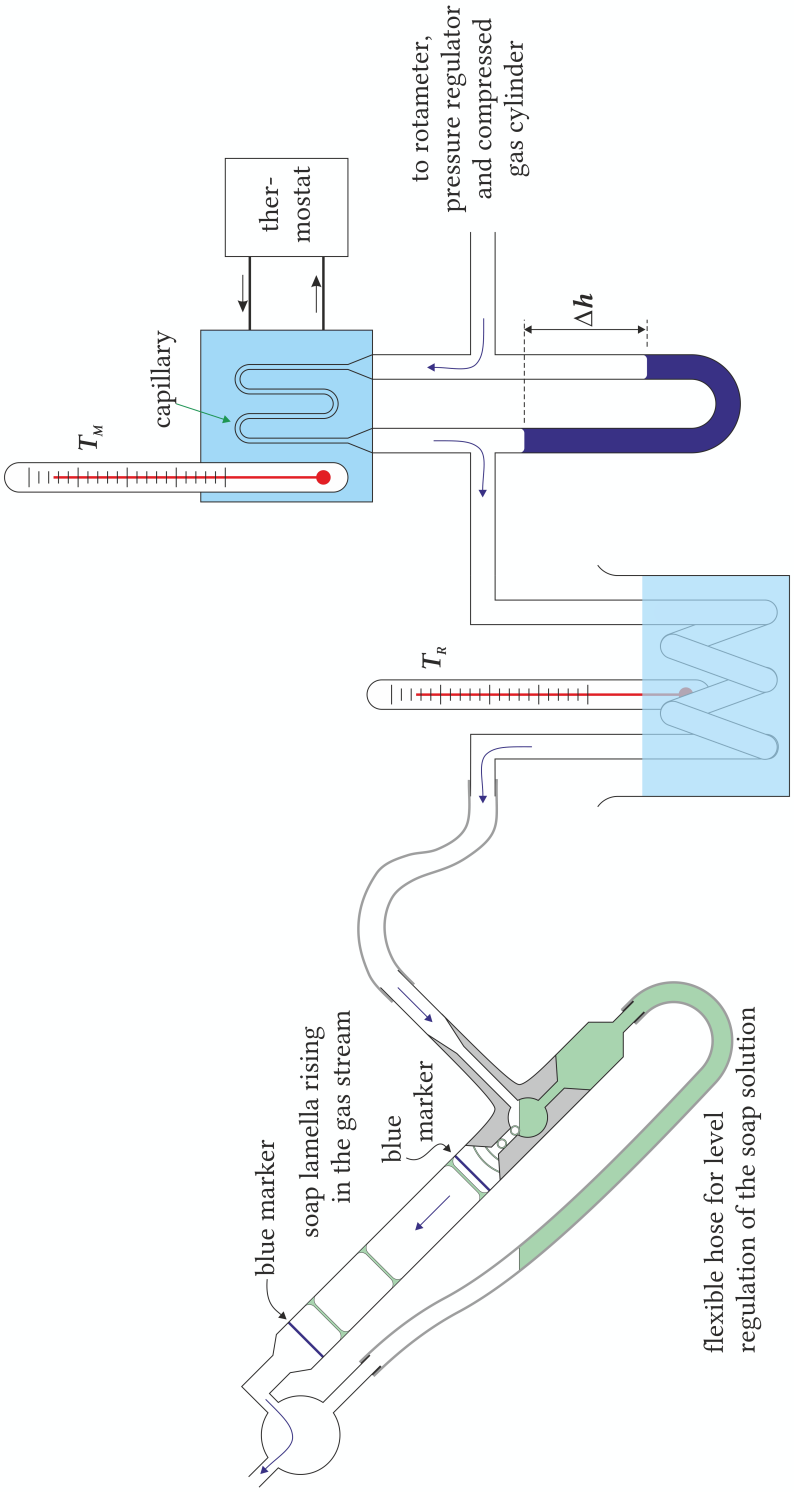

Fig. 2: Apparatus for the determination of gas viscosity

5 Presentation of the results

1. Prepare a table with the following data:
   a) Temperatures T_M and T_R,
   b) the volume at T_M (V is temperature dependent). Recalculate the volume of $28{,}5\,\mathrm{cm}^3$ at T_R to the volume at T_M.
   c) the flow time Δt in s,
   d) the pressure drop Δp in Pa,
   e) the calculated viscosity of the gases at T_M.
2. Show with your results that the viscosity is proportional to $\sqrt{T}$.
3. Calculate for both gases at $20\,^\circ\mathrm{C}$ the collision cross section and the mean free path at $p = 1\,\mathrm{bar}$.
4. Compare the collision cross section with the molecular diameter estimated from the van der Waals constant b (use tables in text books)
5. Report the pressure and temperature dependence of the transport coefficients (diffusion, viscosity and heat conductivity) of gases and compare them to those of liquids.

6 What you should know

Basics of the kinetic gas theory, transport properites of ideal gases, Newton's fluid, laminar flow, Fick's laws.

7 Hints for the risk assessment

Analyze potential hazards that arise from the methods and substances used in this experiment (high pressure, H_2 and CO_2).

Discuss:

- suggest rules of conduct (organizational and administrative rules)
- suggest technical savety precautions
- what personal protective equipment should be used?