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THERMAL EXPANSION

Thermal expansion is the increase in volume of solids, fluids and gases when subjected to heat changes.

In this experiment we measure the thermal expansion of metals (aluminium, steel, copper, brass) as well as of fluids (water, ethylacetate, glycerine).

1 Thermal expansion

Temperature changes (at constant pressure) of solids, fluids and gases are accompanied with a change in specimen volume. To describe this we use the volumetric expansion coefficient γ which is specific for a material

$$\gamma = \frac{1}{V_0} \cdot \left(\frac{\partial V}{\partial T}\right)_P$$

At small temperature changes as compared to the absolute temperatures (in Kelvin) used in our experiment, the relative change in volume

$$\frac{\Delta V}{V_0} = \frac{V - V_0}{V_0}$$

(V_0-initial volume, V-final volume) depends linearly on the change in temperature

$$\Delta T = T - T_0.$$

(T_0-initial temperature,T-final temperature). From this we can estimate the (average) volumetric expansion parameter

$$\overline{\gamma} = \frac{V - V_0}{V_0 \cdot \Delta T} = \frac{1}{V_0} \cdot \frac{\Delta V}{\Delta T}$$

The volume after a temperature change can be calculated by solving for V:

$$V = V_0 + \overline{\gamma} \cdot V_0 \cdot \Delta T$$

For simplicity in case of solids one prefers the relative change in length (why?)

$$\frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

Associated with the temperature change by the longitudinal expansion parameter α

$$\alpha = \frac{1}{L_0} \cdot \left(\frac{\partial L}{\partial T}\right)_P \quad \text{and} \quad \overline{\alpha} = \frac{L - L_0}{L_0 \cdot \Delta T} = \frac{1}{L_0} \cdot \frac{\Delta L}{\Delta T}$$

The length after the change in temperature is accordingly

$$L = L_0 + \overline{\alpha} \cdot L_0 \cdot \Delta T \ .$$

2 Background

The building blocks of matter (molecules, atoms, ions) are bound together by long-ranged attractive forces such as the

- electrostatic attraction in ion crystals (e.g. NaCl),
- hydrogen bonds as in water,
- van-der-Waals bonds in crystalline inert gases,
- metallic bonds.

At small distances a repulsive force (Coulomb interaction, Pauli's exclusion principle) comes into play so that particles are kept at an equilibrium distance. At this distance r_0 the attractive and repulsive forces cancel. Neglecting quantum fluctuations, at absolute zero (T = 0 K) both particles would be at rest.

At finite temperatures the particles oscillate around their equilibrium position with amplitude growing with temperature. This oscillation being in general slightly asymmetric is accompanied by a shift in the equilibrium position to larger values. This effect is called thermal expansion. A similar effect can as well be observed in fluids.

3 Preparation (written)

1. Find the thermal expansion coefficients of glycerine, ethylacetate, brass, steel and aluminium in the literature.
2. Show that α and γ are related by $\gamma \approx 3a$. For this consider a cube of volume V and edge length L expanding with temperature.

4 Performing the experiment

1. The volumetric expansion of fluid shall be examined. To do this, fill the pycnometer (recipient with riser) up to the zero reference marking (= 50 ml) with the respective fluid. The pycnometer is then submerged in water which can be heated up. Do the measurement for all fluids (water, glycerine und ethylacetate) in parallel. Record the change in volume of the fluids between room temperature and some 80 °C (take around 7 values).
2. At the same time examine the longitudinal expansion of the different metals. A pump presses water through the metal pipes (length 600 mm). The pipes are suspended on one end with a meter at the other (1 unit equals 1/100 mm). Note down the change in length of the pipes depending on temperature.

5 Analysis

1. Plot the relative volumetric expansion of the fluids and the relative longitudinal expansion of the pipes.

2. Estimate the expansion coefficients of the metals, glycerine and ethylacetate and compare them to values in the literature. Determine the metals the pipes are made out of. Use linear regression or draw a best fit line by hand.

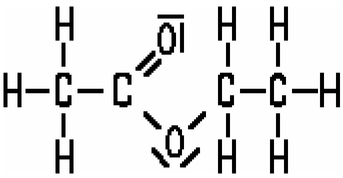
3. For water examine the expansion coefficient as a function of temperature. For this at each temperature the change in volume has to be taken from the previous temperature. Plot the results into a diagram together with the curve from the literature.

4. Compare the expansion coefficient of water and other materials between room temperature and 80°C. What are the differences? Think about reasons for them.

5. Discuss errors (which systematic and statistical errors may occur, what are the errors of the measurands?)

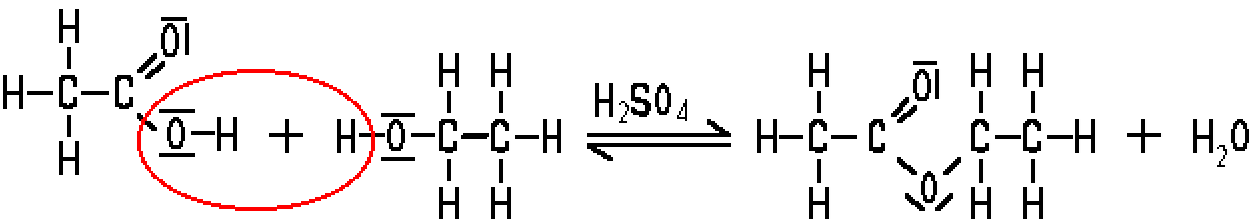
6 Appendix

(Ethylacetate) **$H_3C–COOC_2H_5$**

 colourless fluid	**F** **highly flammable** **Xi** **irritating** 	**Risk and Safety-Notices:** R 11-36-66-67, S 16-26-33, E 10-12 **Disposal:** G 1 **MAK:** 400 ml/m^3 **MG:** 88,1 g/mol **Density:** 0,9 g/cm^3 **Melting point:** -83 °C **Boiling Point:** 77 °C **Water solubility:** one in 10 parts of water **Other solubilities:** Alcohol, Diethylether, Chloroform **Explosive at:** 2,1-11,5 Vol.-% (air)

Features:
The vapor is irritating for respiratory system and eyes. Higher concentrations can lead to unconsciousness and death. The substance is hardly soluble in water where it slowly degenerates into ethanol and acetic acid. Oils, fats, varnishes and resins are well dissolved in the substance.

Production:
Synthesis of ethanol and acetic acid in presence of sulfuric acid and heat.



Usage:
Aroma in liquors, sweets and lemonades; resolvent, in glues (UHU), nail varnish removers, explosives, etc.

T in °C	γ in 10^{-5} K^{-1}
5	1,60
10	8,80
15	15,1
20	20,7
25	25,7
30	30,3
35	34,5
40	38,4
45	42,0
50	45,4
55	48,6
60	51,6
65	54,4
70	57,1
75	59,7
80	62,1

Table 1 cubic expansion coefficients of water at various temperatures (adapted from Kell, G. S. *J. Chem. Eng. Data* **1975**, *20*, 97–105.)