# Measuring the linear expansion of solids as a function of temperature

## Objects of the experiment

- Measuring the linear thermal expansion of brass, steel and glass tubes as a function of temperature.
- Determining the linear expansion coefficients of brass, steel and glass.

## Principles

The length $s$ of a solid body is linearly dependent on its temperature $\vartheta$ :

$$s = s_0 \cdot (1 + \alpha \cdot \vartheta) \qquad \text{(I)}$$

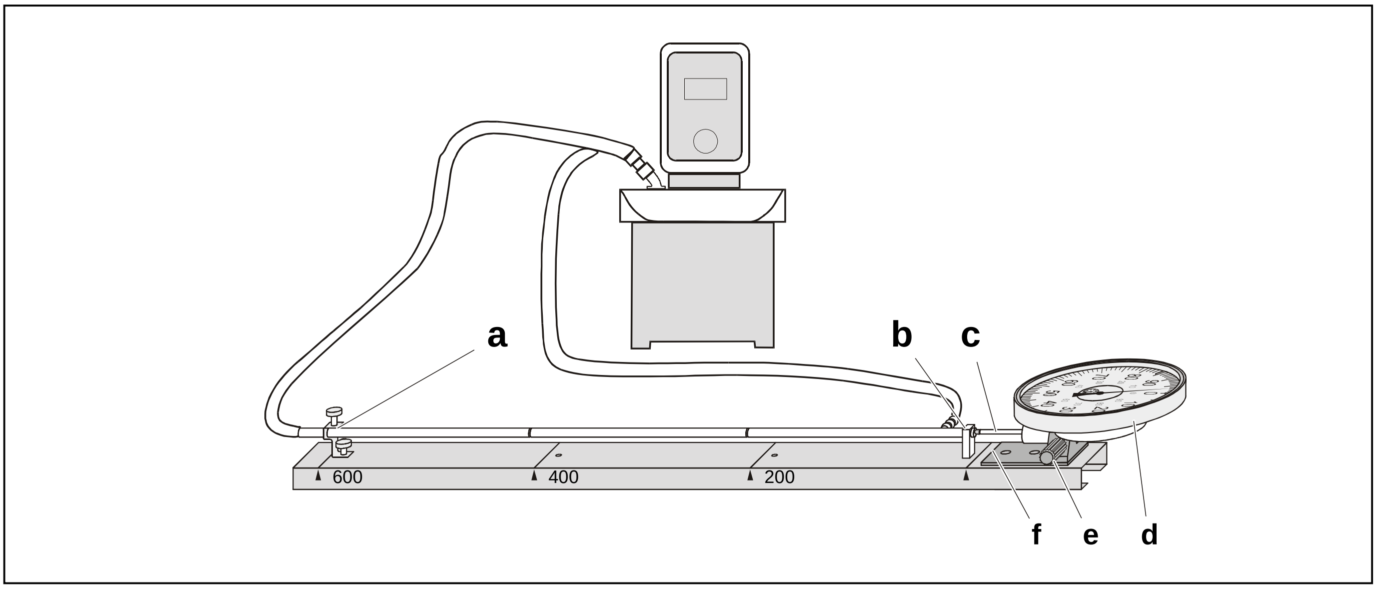
$s_0$: length at room temperature

$\vartheta$: temperature in °C

The linear expansion coefficient $\alpha$ is determined by the material of the solid body.

In this experiment a circulation thermostat is used to heat the water which flows through the various tube samples. A dial gauge with 0.01 mm scale graduations is used to measure the change of length $\Delta s = s - s_0$ as a function of temperature $\vartheta$.

Fig. 1: Schematic representation of the experimental setup to measure the linear thermal expansion of tubes with the expansion apparatus as a function of temperature.

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## Apparatus

1 Longitudinal expansion apparatus D.................. 381 341
1 Dial gauge, 10 mm............................................ 361 15
1 Holder for dial gauge ......................................... 381 36
1 Thermometer -10 ... +110°C............................. 382 34
1 Circulation thermostat +25 ... +100 °C.............. 666 768
1 Pump set ........................................................... 666 7703
2 Silicone tubing, 7 mm Ø.................................... 667 194
2 Water, pure, 5 l .................................................. 675 3410

## Setup

The set up of the experiment is shown in Fig. 1 schematically.

- Screw on the holder for dial gauge 381 36 **(e)** (for details refer to instruction sheet 381 341 of expansion apparatus) and clamp the dial gauge in place 361 15 **(d)**.
- Attach the fixed bearing **(a)** of the expansion apparatus at the 600 mark and slide the open end of the brass tube into the fixed bearing.
- Slide the closed end of the brass tube into the guide fitting **(b)** so that the hose nipple **(f)** is pointing laterally downwards.
- Tighten the screw to fix the brass tube in the fixed bearing (the screw must engage the ring groove of the tube).
- Insert the extension piece **(c)** (see instruction sheet for dial gauge 361 15).
- Prepare the circulation thermostat and the pump set. For a detailed description refer to instruction sheet 666 768.

*Note: Be sure to read the instruction sheet of the circulation thermostat 666 768 before using this device.*

- Fill the water bath of the circulation thermostat with distilled water.
- Connect the expansion apparatus to the circulation thermostat using the silicone tubing, i.e. connect the open end of the brass tube and the hose nipple **(f)** to the hose nipples of the pump set of circulation thermostat.
- Use the thermometer 382 34 to measure the temperature $\vartheta$ of the water bath.

### Safety notes

- Check the seating of the silicone tubing every time before putting the apparatus into operation, to ensure that no hot water can escape in an uncontrolled manner and cause damage or injury.
- Follow the safety hints of the circulation thermostat.
- When using the glass tube follow the instructions printed on the thermal expansion apparatus.

## Carrying out the experiment

- Turn the housing of the dial gauge to set the zero position.
- Measure the initial temperature, i.e. room temperature $\vartheta_0$.
- Switch on the circulation thermostat and set the temperature about 5 °C above $\vartheta_0$.
- Wait until a thermal equilibrium has been established.
- Measure the temperature $\vartheta$.
- Read off and write down the pointer deflection of the dial gauge.
- Increase the temperature $\vartheta$ in steps of approx. 5° C until approx. 100° C.

- Allow the brass tube to cool down to room temperature.
- Replace the brass tube with the steel tube, i.e. attach the fixed bearing **(a)** of the expansion apparatus at the 600 mark and slide the open end of the steel tube into the fixed bearing.
- Conduct such a measurement on the glass tube. For this measurement increase the temperature $\vartheta$ in steps of approx. 10° C

## Measuring example

Table 1: Measured change of length $\Delta s$ as a function of the temperature $\vartheta$.

| brass | | steel | | glass | |
|---|---|---|---|---|---|
| $\frac{\vartheta}{°C}$ | $\frac{\Delta s}{mm}$ | $\frac{\vartheta}{°C}$ | $\frac{\Delta s}{mm}$ | $\frac{\vartheta}{°C}$ | $\frac{\Delta s}{mm}$ |
| 20.0 | 0.03 | 24.1 | 0.07 | 30.4 | 0.02 |
| 25.0 | 0.09 | 26.0 | 0.09 | 39.9 | 0.04 |
| 30.0 | 0.13 | 30.5 | 0.12 | 49.9 | 0.05 |
| 35.0 | 0.18 | 34.1 | 0.15 | 60.3 | 0.08 |
| 40.0 | 0.24 | 40.7 | 0.20 | 70.3 | 0.09 |
| 45.0 | 0.30 | 44.3 | 0.22 | 79.9 | 0.11 |
| 50.0 | 0.35 | 49.7 | 0.26 | 90.5 | 0.12 |
| 57.0 | 0.41 | 52.7 | 0.28 | 98.9 | 0.15 |
| 59.8 | 0.46 | 62.8 | 0.35 | – | – |
| 64.0 | 0.50 | 66.8 | 0.38 | – | – |
| 70.0 | 0.55 | 69.1 | 0.39 | – | – |
| 75.0 | 0.60 | 72.9 | 0.42 | – | – |
| 80.0 | 0.67 | 76.8 | 0.45 | – | – |
| 85.0 | 0.71 | 80.1 | 0.47 | – | – |
| 90.0 | 0.77 | 84.9 | 0.51 | – | – |
| 95.0 | 0.82 | 89.6 | 0.55 | – | – |
| 99.8 | 0.86 | 92.8 | 0.56 | – | – |
| – | – | 98.6 | 0.60 | – | – |

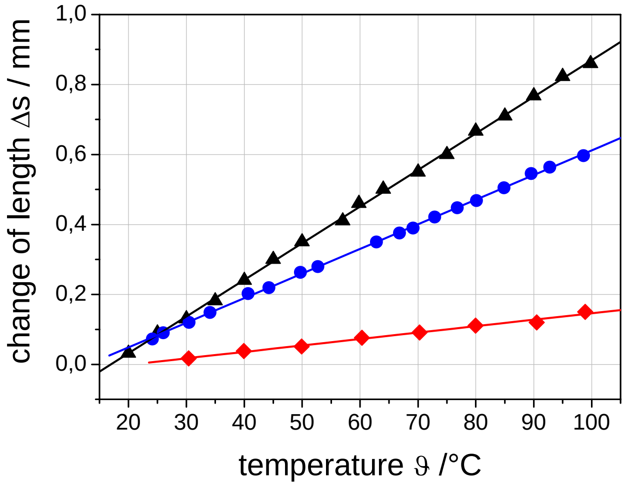


Fig. 2: Change of length Δs as a function of temperature ϑ : brass (▲), steel (●), glass (◆). The solid lines correspond to a fit according equation (II).

## Evaluation and results

The various measurements are summarized in Table 1. To determine the linear expansion coefficient α the change of length Δs is plotted as a function of temperature ϑ (Fig. 2).

Subtracting the initial length $s_0$ at room temperature at both sides of equation (I) gives the change of length Δs:

$$s - s_0 = s_0 \cdot \alpha \cdot \vartheta$$

$$\Delta s = k \cdot \vartheta \qquad \text{(II)}$$

with

$$k = s_0 \cdot \alpha$$

The linear fit of equation (II) to the measured data gives the linear expansion coefficients α (Fig. 2). The results are summarized in Table 2.

Table 2: Linear expansion coefficients α determined from Fig. 2 according equation (II).

| **Material** | $\frac{\Delta s}{\text{mm}}$ | **Measurement** $\frac{\alpha}{K^{-1}}$ | **Literature** $\frac{\alpha}{K^{-1}}$ |
|---|---|---|---|
| brass | 600 | $17.8 \cdot 10^{-6}$ | $18 \cdot 10^{-6}$ |
| steel | 600 | $11.7 \cdot 10^{-6}$ | $11 \cdot 10^{-6}$ |
| glass | 600 | $3.1 \cdot 10^{-6}$ | $3 \cdot 10^{-6}$ |

## Supplementary information

Additionally, the linear thermal expansion can be measured as function of the overall tube length $s_0$. The experimental procedure to determine the linear thermal expansion from a temperature difference $\Delta\vartheta = \vartheta_1 - \vartheta_0$ is described in the leaflet P2.1.1.2.

Instead of using the steam generator of P2.1.1.2 the circulation thermostat can be used to determine the change in length Δs. Thus the linear expansion coefficient e.g. of brass tubes of different lengths (200 mm, 400 mm, 600 mm) can be determined as shown in Fig. 2 in leaflet P2.1.1.2 by measuring the initial temperature $\vartheta_0$ and the final temperature $\vartheta_1$ by setting the temperature with the circulation thermostat (see also instruction sheet 381 341 of expansion apparatus).

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