PHYSICS EXPERIMENT

Thermal Expansion of Solid Bodies

DETERMINE THE COEFFICIENTS OF EXPANSION FOR BRASS, STEEL AND GLASS

- Measure thermal expansion in length for tubes made of brass, steel and glass.
- Determine linear expansion coefficients for these materials and compare them with values quoted in literature.

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Fig. 1: Experiment set-up

GENERAL PRINCIPLES

In a solid body, each atom vibrates around its equilibrium position. The oscillation is not harmonic because the potential energy is greater when two atoms which have moved from their equilibrium positions happen to get close to one another as opposed to when they are further apart. At higher temperatures, where the oscillation energy is also greater, the atoms vibrate in such a way that the average distance between two neighbouring atoms is greater than the distance between their equilibrium positions. This effect becomes more predominant as the temperature increases, causing the solid body to expand ever more as the temperature rises. It is normal in these circumstances to observe relative changes in length and to calculate the change in volume from this.

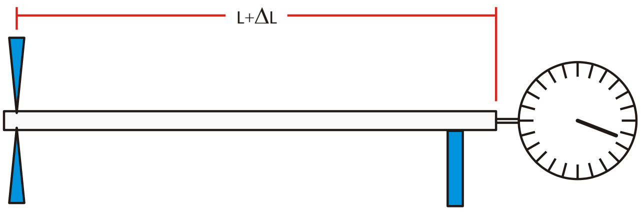

Fig. 2: Schematic of the set-up for the measurements

The coefficient of linear expansion is defined as:

(1) $\alpha = \frac{1}{L(\vartheta)} \cdot \frac{\mathrm{d}L}{\mathrm{d}\vartheta}$

L: length

ϑ: temperature in °C

This coefficient depends strongly on the nature of the material and is usually less responsive to the temperature. This leads to the following conclusion:

(2) $L(\vartheta) = L_0 \cdot \exp(\alpha \cdot \vartheta)$

$L_0 = L(0°C)$

If the temperature is not very high:

(3) $L(\vartheta) = L_0 \cdot (1 + \alpha \cdot \vartheta)$

In this experiment measurements are carried out on thin tubes made of brass, steel and glass, through which hot water is passed in order to increase their temperature. A circulation thermostat is used to ensure that the water temperature can be adjusted to a constant value. Since one end of the tubes will be fixed in the expansion apparatus, a dial gauge can be used to read off the increase in length at the other end, using room temperature as the reference temperature (Fig. 2).

LIST OF EQUIPMENT

1 Linear Expansion Apparatus D	1002977 (U15400)
1 Immersion/Circulation Thermostat @230V	1008654 (U144002-230)
or	
1 Immersion/Circulation Thermostat @115V	1008653 (U144002-115)
1 Gauge with Adapter	1012862 (U8442250)
2 Tubing, Silicone, 6 mm	1002622 (U10146)

SET-UP

Adapting the linear expansion apparatus to use a dial gauge

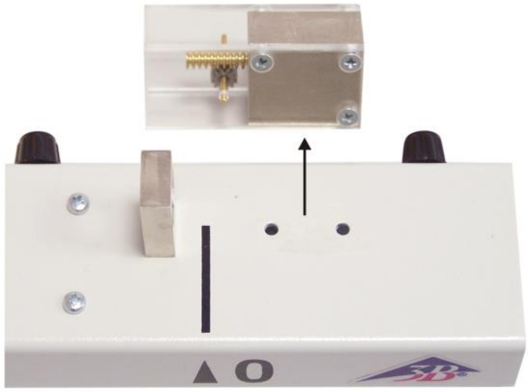

Fig. 3: Undo the screw drive for the needle of the linear expansion apparatus.

Fig. 4: Screw on the gauge adapter.

Fig. 5: Insert the gauge fully into the adapter and secure it in place with the wing nut.

Installing a sample tube

Fig. 6: Attach the fixed bearing to the linear expansion apparatus at about marking 600 using the knurled screw. The steel sample tube should be laid on the apparatus with its open end on the fixed bearing.

Fig. 7: Place the closed end of the sample tube in the guide bearing. Make sure that the flange faces backwards.

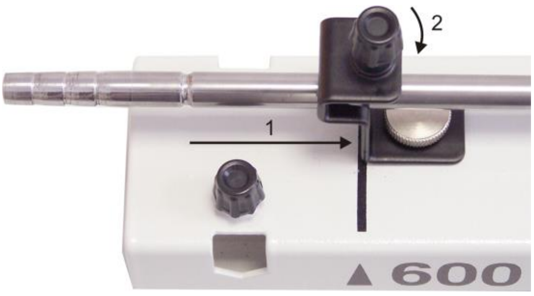

Fig. 8: Move the test rod to the right until the notch at the open end rests upon the fixed bearing (Note: this causes the measuring probe of the gauge to be pre-tensioned). Use the fastening screw to secure the test sample tube in the fixed bearing.

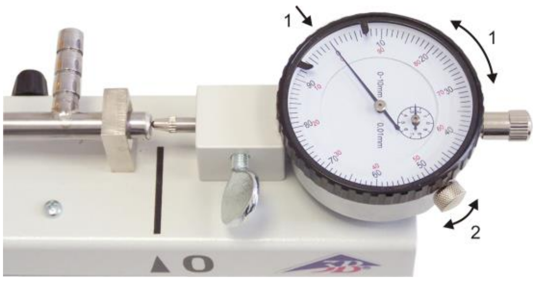

Fig. 9: Turn the scale ring of the gauge until the 0 on the gauge matches the position of the needle. Secure the scale ring with its fastening screw.

Assembly and connection of immersion/circulation thermostat

Safety instructions:
Do not connect the thermostat to the mains before the control head is properly fitted onto the water bath cover.

- Follow the assembly instructions for the water bath cover and fit the bridge of the water bath to the thermostat. Insert the thermostat through the round opening in the bridge of the water bath. Attach it to the side of the pump housing along with the pump outlet and the pump circulation set complete with L-shaped tube. Fit a dummy plate to the opposite side.
- Mount the thermostat with the bridge of the water bath attached into the bath itself and secure the control head of the thermostat and its clamp by turning the knurled screw at the edge of the bath.

Fig. 10: Feed (1) and return (2) for the pump recirculation set.

- Cut the silicone tube into roughly two halves. Use one half to connect the feed for the pump circulation set (Fig. 10) to the open end of the sample tube as shown in Fig. 1. Use the other half to connect the flange of the sample tube to the return line of the pump circulation set (Fig. 10).

PROCEDURE

Safety instructions:
Before operating the immersion/circulation thermostat, make sure you read thoroughly all the instructions and safety information in the operating manual for the thermostat.

- Fill the bath with decalcified (softened) water in such a way that the heating element is fully immersed. Put the cover of the bath on top of the bridge.
- Connect the thermostat to a mains socket with an earth connection. Make sure that the mains voltage matches what is specified on the rating plate.
- Turn on the thermostat by means of the switch on the front panel.

The current temperature of the water bath will be displayed, which at this point will correspond to room temperature.

- Make a note of the current temperature of the bath as the reference temperature in Table 1.
- Ramp up the set-points for the temperature in steps of 4°, waiting at each step until the actual temperature has risen to match the set temperature. Write down this value in Table 1. Work out the difference from the reference temperature and enter that into Table 1 as well.
- For each temperature/temperature difference, read off the change in length relative to the calibrated zero position directly from the scale of the gauge and enter it into Table 1.
- Set up the brass and glass tubes and repeat the measurements. You may need to adjust the step interval for the temperature. Enter the measurements into Table 2 and Table 3 respectively.

SAMPLE MEASUREMENT

Table 1: Thermal expansion of steel, ϑ: set temperature, $\Delta\vartheta$: temperature difference, ΔL: change in length.

ϑ / °C	$\Delta\vartheta$ / °C	ΔL / mm
21.70	0.00	0.00
25.00	3.30	0.02
29.00	7.30	0.05
33.20	11.50	0.07
37.30	15.60	0.11
41.30	19.60	0.13
44.90	23.20	0.16
48.40	26.70	0.19
52.30	30.60	0.22
56.10	34.40	0.24
60.10	38.40	0.27
64.10	42.40	0.29
68.00	46.30	0.32
72.00	50.30	0.35
76.10	54.40	0.38
80.10	58.40	0.41
84.30	62.60	0.44
87.40	65.70	0.46
91.80	70.10	0.49
95.80	74.10	0.52
98.80	77.10	0.54

Table 2: Thermal expansion of brass, ϑ: set temperature, $\Delta\vartheta$: temperature difference, ΔL: change in length.

ϑ / °C	$\Delta\vartheta$ / °C	ΔL / mm
25.3	0.0	0.00
32.9	7.6	0.07
36.2	10.9	0.11
40.9	15.6	0.17
45.1	19.8	0.22
48.8	23.5	0.26
52.6	27.3	0.31
56.6	31.3	0.35
60.6	35.3	0.40
64.4	39.1	0.45
68.3	43.0	0.49
72.7	47.4	0.53
76.1	50.8	0.58
80.3	55.0	0.63
84.1	58.8	0.67
88.4	63.1	0.71
91.9	66.6	0.76
96.2	70.9	0.81
99.5	74.2	0.84

Table 3 Thermal expansion of glass, ϑ: set temperature, $\Delta\vartheta$: temperature difference, ΔL: change in length.

ϑ / °C	$\Delta\vartheta$ / °C	ΔL / mm
23.8	0.0	0.00
26.8	3.0	0.01
33.2	9.4	0.02
39.2	15.4	0.03
44.9	21.1	0.04
50.8	27.0	0.05
56.4	32.6	0.06
62.7	38.9	0.07
68.1	44.3	0.08
74.8	51.0	0.09
80.4	56.6	0.10
86.3	62.5	0.11
92.2	68.4	0.12
97.9	74.1	0.13

EVALUATION

In the temperature range under investigation $\alpha \cdot \vartheta \ll 1$. Equation (3) can therefore be modified

(4) $\Delta L = L(\vartheta_1) \cdot \alpha \cdot \Delta\vartheta$ mit $\Delta\vartheta = \vartheta_2 - \vartheta_1$, $L(\vartheta_1) = 600$ mm

The linear expansion coefficients we are seeking can therefore be determined from the gradient of the straight lines through the origin, as shown in Fig. 11.

(5) $\alpha = \dfrac{a}{L(\vartheta_1)}$

- Plot the measured changes in length for brass, steel and glass (tables 1, 2 and 3) against the values for the temperature difference and in each case match a straight line to the points.
- Determine the coefficients of linear expansion from the gradients of the lines in each case using equation (5). Enter the results into Table 4. Note: since we are considering temperature *changes*, the temperature figures in °C are equivalent to what they would be in kelvins (K).

Table 4: Coefficients of linear thermal expansion for brass, steel and glass along with corresponding values quoted in literature.

Material	a / mm·K^{-1}	α / 10^{-6}·K^{-1} Measured	α / 10^{-6}·K^{-1} Literature
Brass	0.0114	19.0	18.5
Steel	0.0070	11.7	11.5
Glass	0.0018	3.0	3.3

The coefficients of linear expansion determined for brass are well in agreement with the values quoted in literature.

The derivation of equation (3) breaks down, though, when higher temperatures are observed, since α proves to be no longer constant, instead being dependent on the temperature. Indeed, strictly speaking that is also the case at the temperatures we are observing. Since the measurement of the linear expansion is measured to an accuracy of 0.01 mm, precise analysis shows that the measurements are not exactly linear, especially for brass, and that the linear expansion coefficients increase slightly with temperature.

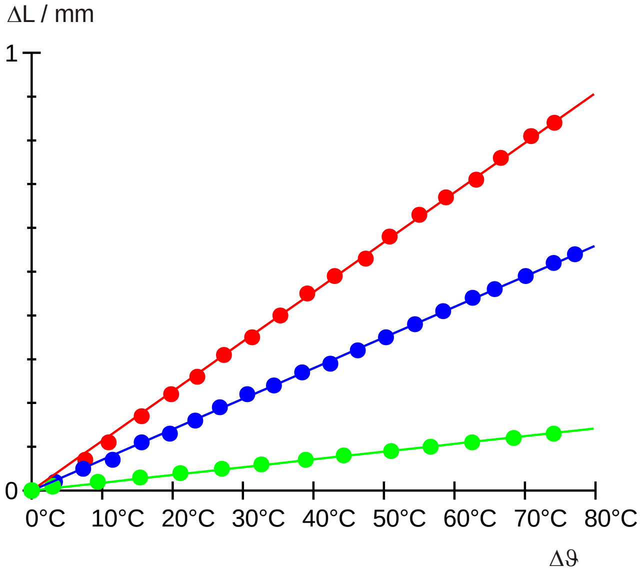

Fig. 11: Changes in length for brass (red), steel (blue) and glass (green) as a function of the difference in temperature.

NOTE

If it is deemed sufficient to measure the difference in length between room temperature and the temperature of boiling water, a steam generator can be used instead of the circulation thermostat bath. The requisite list of accessories can be found under order number UE2010135 (see Fig. 12).

Fig. 12: Set-up with steam generator