Thermal expansion in solids and liquids (Item No.: P2310100)

Curricular Relevance

Area of Expertise: Physics → **Education Level:** University → **Topic:** Thermodynamics → **Subtopic:** Thermal Properties and Processes → **Experiment:** Thermal expansion in solids and liquids

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	30 Minutes	2 Students

Additional Requirements:

- Precision balance, 620 g / 0.001 g

Experiment Variations:

Keywords:

linear expansion, volume expansion of liquids, thermal capacity, lattice potential, equilibrium spacing, Grüneisen equation

Overview

Short description

Principle

The volume expansion of liquids and the linear expansion of various materials is determined as a function of temperature.

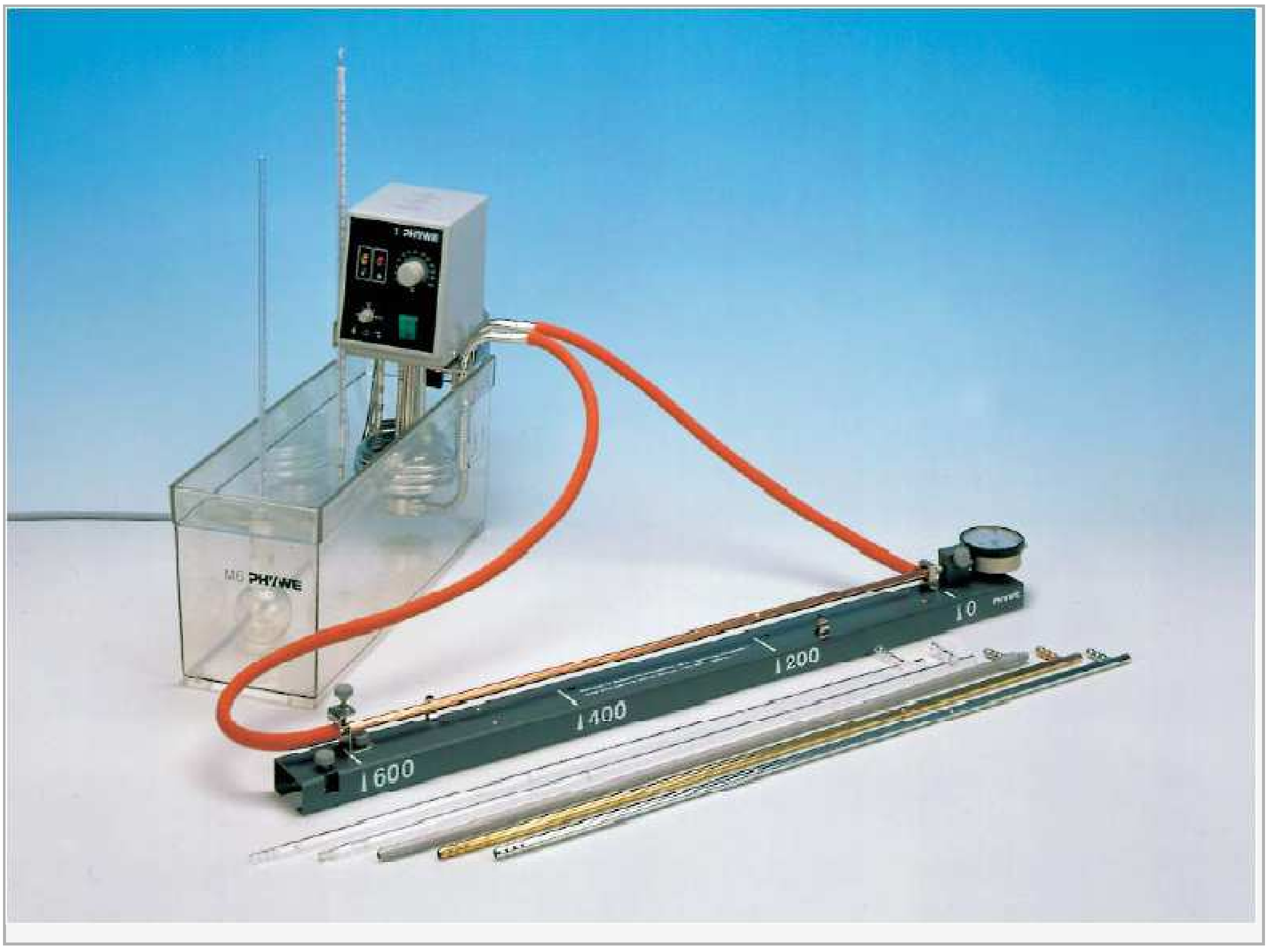

Fig. 1: Experimental set-up for measuring thermal expansion.

Safety instructions

Ethyl acetate
H225: Highly flammable liquid and vapour.
H319: Causes serious eye irritation.
H336: May cause drowsiness or dizziness.
EUH066: Repeated exposure may cause skin dryness or cracking.
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

Equipment

Position No.	Material	Order No.	Quantity
1	Dilatometer with clock gauge	04233-00	1
2	Copper tube for 04231-01	04231-05	1
3	Aluminium tube for 04231-01	04231-06	1
4	Tube, quartz for 04231-01	04231-07	1
5	Immersion thermostat Alpha A, 230 V	08493-93	1
6	External circulation set for thermostat Alpha A	08493-02	1
7	Bath for thermostat, makrolon	08487-02	1
8	Lab thermometer,-10..+100 °C	38056-00	1
9	Rubber tubing, i.d. 6 mm	39282-00	2
10	Syringe 1ml, Luer, 10 pcs	02593-03	1
11	Cannula 0.6x60 mm, Luer, 20 pcs	02599-04	1
12	Measuring tube, l = 300 mm, IGJ 19/26	03024-00	2
13	Wash bottle, 250 ml, plastic	33930-00	1
14	Flat bottom flask, 100ml, IGJ 19/26	35811-01	2
15	Beaker, high, BORO 3.3, 100 ml	46026-00	1
16	Ethyl acetate 250 ml	30075-25	1
17	Glycerol, 250 ml	30084-25	1
18	Olive oil,pure 100 ml	30177-10	2
19	Hose clamp for 5-12 mm diameter	40997-00	4
20	Rubber tubing, i.d. 10 mm	39290-00	1
21	Tubing connector, ID 6-10mm	47516-01	2

Tasks

1. To determine the volume expansion of ethyl acetate ($C_4H_8O_2$), methylated spirit, olive oil, glycerol and water as a function of temperature, using the pycnometer.
2. To determine the linear expansion of brass, iron, copper, aluminium, duran glass and quartz glass as a function of temperature using a dilatometer.
3. To investigate the relationship between change in length and overall length in the case of aluminium.

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Set-up and procedure

- The volume of the pycnometer is determined and the scale calibrated by weighing it empty and then filled with distilled water. The pycnometer, filled with the liquid to be measured, is brought to temperature in the water bath (thermostat). The change in volume is read from the scale on the tube built into its stopper.

- The connecting tube to the thermostat is removed and the dilatometer is connected to the water circuit instead. Keep the feed and discharge lines as far away from the dilatometer as possible so that its body will not heat up.

  Clamp on the measuring tube, set the scale on the dial gauge to “0” and measure the expansion as a function of the temperature. There is so little expansion in the case of duran glass and quartz glass that the heating and expansion of the dilatometer body as a result of radiation and conduction falsifies the measurement considerably. In this case, therefore, the measurement is started at the highest temperature (80 °C) and the hot water in the bath replaced with cold tap water.

  As the temperature changes very quickly with this method, the temperature of the dilatometer body remains constant. Only two values are measured.

- In the case of aluminium, expansion is measured at three different rod lenghts. The rod can be clamped in various places for this.

Theory and evaluation

An increase in temperature T causes the vibrational amplitude of the atoms in the crystal lattice of the solid to increase. The potential curve (Fig. 2) of the bonding forces corresponds only to a first approximation to the parabola of a harmonic oscillation (dotted line); generally it is flatter in the case of large interatomic distances than in the case of small ones. If the vibrational amplitude is large, the centre of oscillation thus moves to larger interatomic distances. The average spacing between the atoms increases, as well as the total volume V (at constant pressure p).

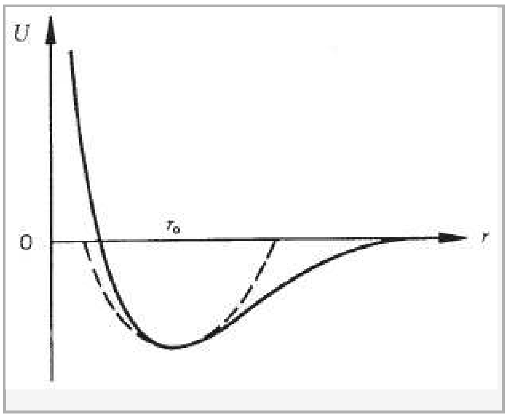

Fig. 2: Potential curve as a function of the interatomic spacing r.

$$\alpha = \frac{1}{V} \cdot \left(\frac{\partial V}{\partial T}\right)_p \tag{1}$$

is called the volume expansion coefficient; if we consider one dimension only, we obtain the coefficient of linear expansion

$$\alpha_1 = \frac{1}{l} \cdot \left(\frac{\partial l}{\partial T}\right)_p \quad (2)$$

where l is the total length of the body.

1. A rise in the temperature causes a greater thermal agitation of the molecules in a liquid and therefore an increase in its volume (water between 0 and 4 °C is an exception to this, however).

The coefficient of expansion of olive oil and water depends on temperature. Measured values at 20 °C are:

	$\alpha / 10^{-3} K^{-1}$
Water	0.20
Glycerol	0.50
Olive oil	0.72
Methylated spirit	1.11
Ethyl acetate	1.37

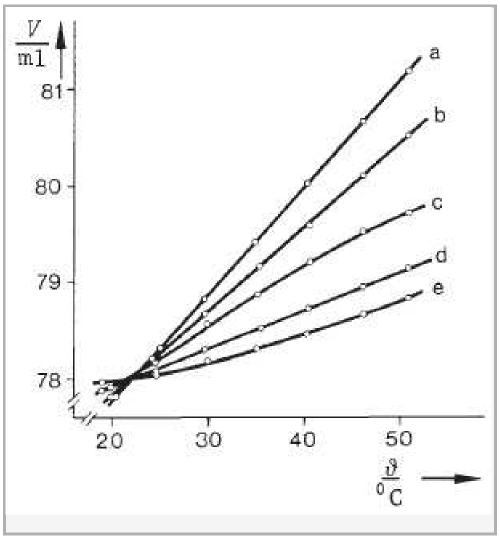

Fig. 3: Relationship between volume V and temperature ϑ of: a) ethyl acetate, b) methylated spirit, c) olive oil, d) glycerol and e) water.

2. Fig 4 shows that the length increases approximately linearly with the temperature in the temperature range observed. Since the changes in length

$$\Delta l = l - l_o$$

are small compared with the original lenght l_o, we can say

$$\alpha_1 = \frac{\Delta l}{l_o} \cdot \left(\frac{1}{\Delta \vartheta}\right) \quad (3)$$

and thus

$$l = l_o\,[1 + \alpha_1(\vartheta - \vartheta_0)] \quad (4)$$

were ϑ_0 is the initial temperature.

The coefficients of linear expansion measured are:

	$\alpha_1\,/10^{-3}K^{-1}$
Aluminium	2.2
Brass	1.8
Copper	1.6
Steel	1.1
Duran glass	0.32
Quartz glass	0.046

The coefficient of expansion of stell and aluminium depends on the composition of the metal used.

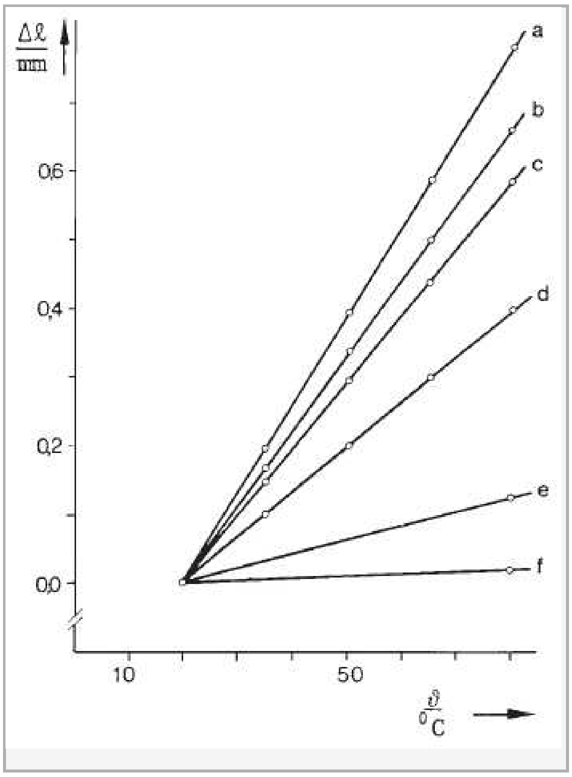

Fig. 4: Relationship between length l and temperature ϑ, for a) aluminium, b) brass, c) copper, d) steel, e) duran glass, f) quartz glass (l_o = 600 mm)

3. If the temperature changes $\Delta\vartheta$ are not too large, the change in length Δl is proportional to the original length l_o (See (3)).

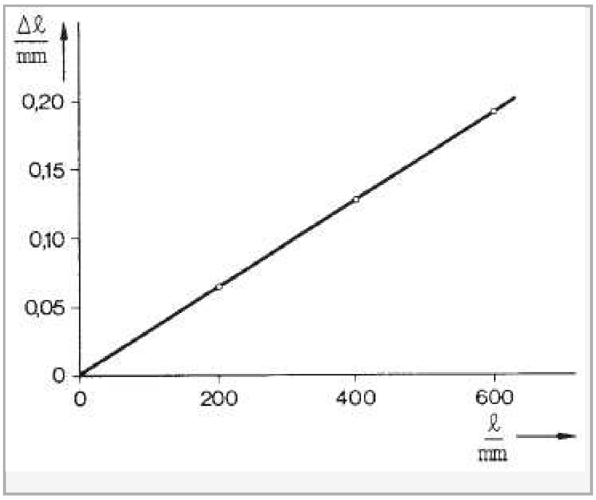

Fig. 5: Change in length Δl as a function of the original length l_o for aluminium at $\Delta\vartheta = 15K$.

Note

The Grüneisen equation

$$\frac{\alpha}{C_p} = y \cdot \left(\frac{\kappa}{V}\right) \quad (5)$$

where

$$\kappa = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$$

is the compressibility and

$$C_p = \left(\frac{\partial U}{\partial T}\right)_p$$

is the thermal capacity of the solid (U = internal energy), signifies a relationship between the mechanical and thermal properties of a solid.

The Grüneisen parameter γ is defined by the change in the frequency ν of lattice vibration with volume:

$$\frac{\Delta\nu}{\nu} = -\gamma\frac{\Delta V}{V}$$

and can be calculated from macroscopic quantities in accordance with (5).

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