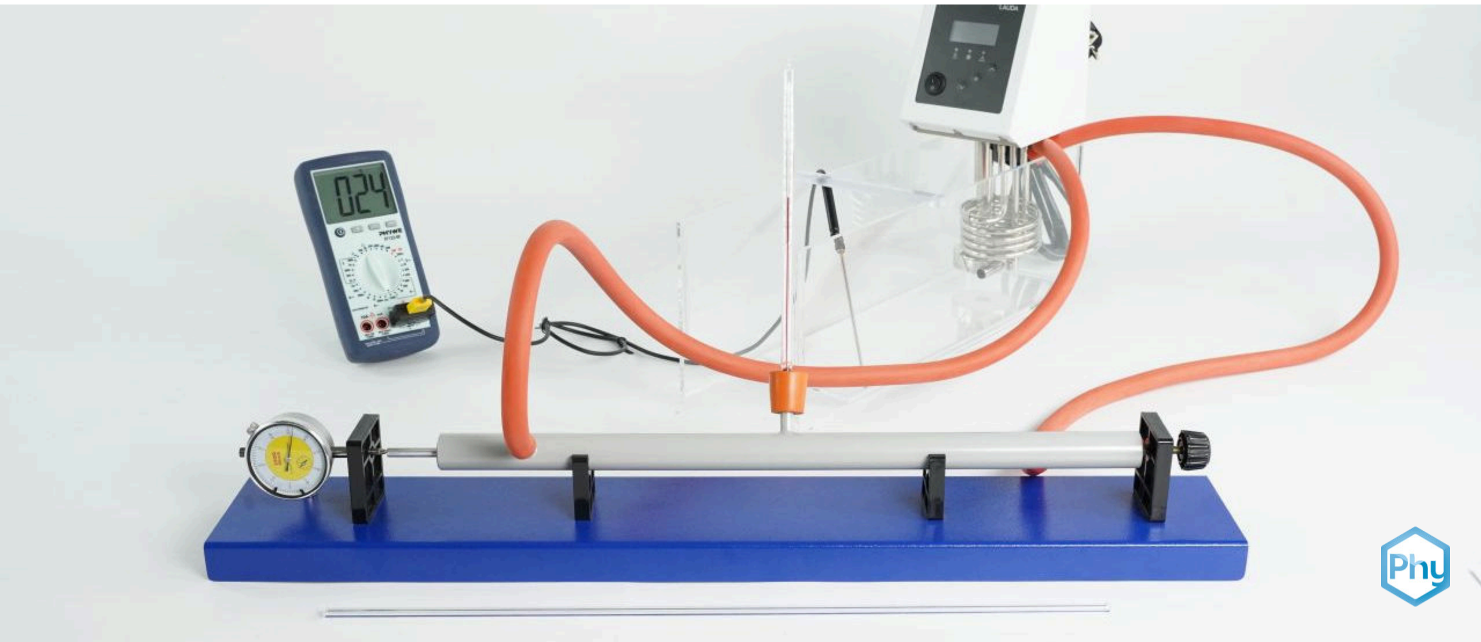
Thermal expansion in solids and liquids



Physics | Thermodynamics | Temperature & Heat

Difficulty level	Group size	Preparation time	Execution time
hard	-	20 minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/63c1483a3809aa000348c3fa

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General information

Application

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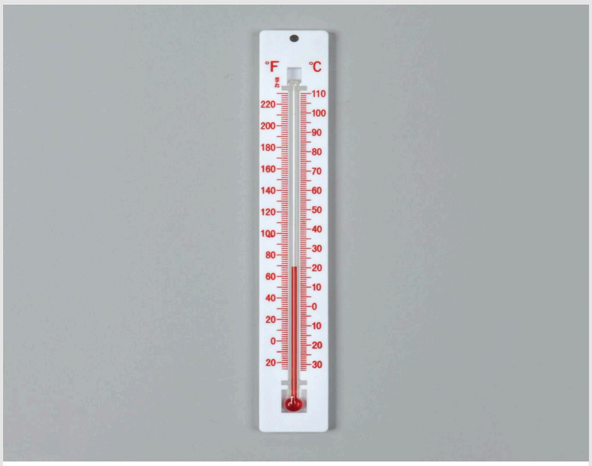

Fig.1 a mercury thermometer

The expansion and contraction of materials must be considered when designing sructures or mechanical applications, because a change in weather or surrounding temperature may lead to defects, malfunctions or even severe accidents.

For examples, this principle is really important in railways and aircrafts designing, bridges building, riveting of two metals, liquid thermometer and many more.

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Other information (1/2)

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Prior knowledge

In a solid or liquid, there is a dynamic balance between the cohesive forces holding the atoms or molecules together and the conditions created by temperature. Different materials have different bonding forces between the atoms.

Scientific principle

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

Other information (2/2)

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Learning objective

To learn about the thermal expansion in solids and liquids.

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, aluminium, steel as a function of temperature using a dilatometer.

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Safety instructions

For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

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.

Theory (1/4)

An increase in temperature *T* causes the vibrational amplitude of the atoms in the crystal lattice of the solid to increase. The potential curve 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*).

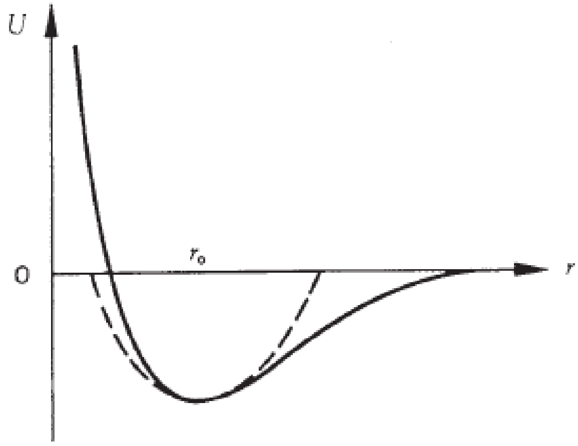

Fig 2. Potential curve as a function of the interatomic spacing *r*

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Theory (2/4)

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$$\alpha = \frac{1}{V}(\frac{\partial V}{\partial T})_p$$

is called the volume expansion coefficient; if only one dimension is considered, the coefficient of linear expansion can be defined by

$$\alpha_1 = \frac{1}{l}(\frac{\partial l}{\partial T})_p$$

where *l* is the total length of the body.

Theory (3/4)

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Since the changes in length

$$\Delta l = l - l_0$$

are small compared with the original length l_0

$$\alpha_1 = \frac{\Delta l}{l_0}(\frac{l}{\Delta \theta})$$

and thus

$$l = l_0[1 + \alpha_1(\theta - \theta_0)]$$

where θ_0 is the initial temperature.

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Theory (4/4)

Note: The Grüneisen equation

$$\frac{\alpha}{C_p} = y(\frac{\kappa}{V})$$

where

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

is the compressibility and

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

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:

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

and can be calculated from macroscopic quantities.

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Equipment

Position	Material	Item No.	Quantity
1	Dilatometer with clock gauge	04233-10	1
2	Immersion thermostat Alpha A, 230 V	08493-93	1
3	External circulation set for thermostat Alpha A	08493-02	1
4	Bath for thermostat, makrolon	08487-02	1
5	Lab thermometer,-10..+110 °C	38056-00	1
6	Rubber tubing, i.d. 6 mm	39282-00	2
7	Syringe 1ml, Luer, 100 pcs	02593-10	1
8	Cannula 0.6x60 mm, Luer, 20 pcs	02599-10	1
9	Wash bottle, 250 ml, plastic	33930-00	1
10	Flat bottom flask, 100ml, IGJ 19/26	35811-01	2
11	Beaker, Borosilicate, tall form, 100 ml	46026-00	1
12	Ethyl acetate 250 ml	30075-25	1
13	Glycerol, 250 ml	30084-25	1
14	Olive oil,pure 100 ml	30177-10	2
15	Hose clamp for 8-12 mm diameter	41000-00	4
16	Rubber tubing, i.d. 10 mm	39290-00	1
17	Tubing connector, ID 6-10mm	47516-01	2
18	Pycnometer, calibrated, 25 ml	03023-00	1
19	PHYWE Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C…760°C	07122-00	1
20	Portable Balance, OHAUS YA102	49212-00	1

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Setup and procedure

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Setup (1/2)

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Experiment for volume thermal expansion

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).

Fig.3. Experimental set-up for measuring thermal expansion

Setup (2/2)

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Experiment for linear thermal expansion / Experiment for linear dimensional change

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.

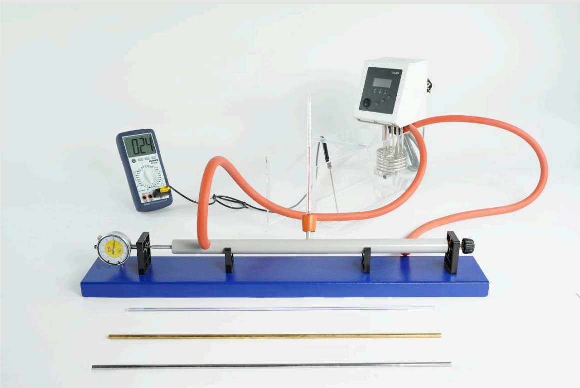

Fig. 4 The dilatometer is connected to the water circuit

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Procedure

Experiment on linear thermal expansion

The measuring tube is clamped open, the scale of the dial gauge is set to "0" and the expansion is measured as a function of temperature. Choose one of the appropriate materials such as brass, aluminum or steel (optional glas or copper). Start the circulation pump and select a temperature of 80° C. In each case, measure the linear expansion at 20° C, 30° C, 40° C until 80° C in steps of ten degree.Note the linear expansion in a table

Evaluation (1/6)

Experiment for volume thermal expansion

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

Tab. 1: Measured coefficient of volume

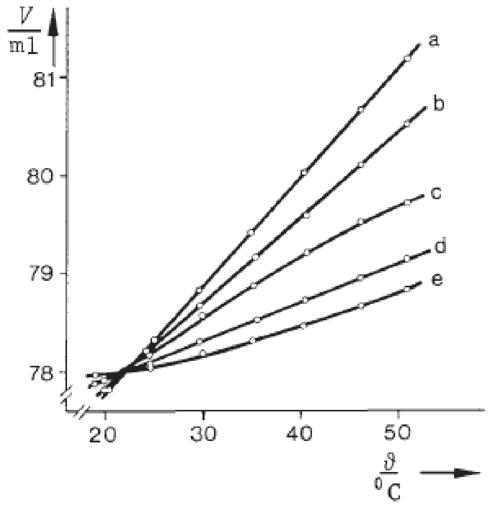

Fig 5. Relationship between volume V and temperature θ

Evaluation (2/6)

Fig 5. use the pyknometer for this partof this experiment

A pycnometer is a measuring device for determining the density of solids or liquids by weighing. It works as follows:

The empty, dry pycnometer is first weighed to determine its empty mass. Then filled the pycnometer to the brim with the liquid to be measured. Take care that there are no air bubbles in the vessel. The filled pycnometer is weighed again to obtain the total mass. The difference between the two weighings gives the mass of the liquid. As the volume of the pycnometer is known exactly, the density of the liquid can now be calculated:

Evaluation (4/6)

Experiment for linear thermal expansion

Materials	$\alpha/10^{-3}K^{-1}$
Aluminium	2.2
Brass	1.8
Steel	1.1

Tab.3: Measured coefficients of linear

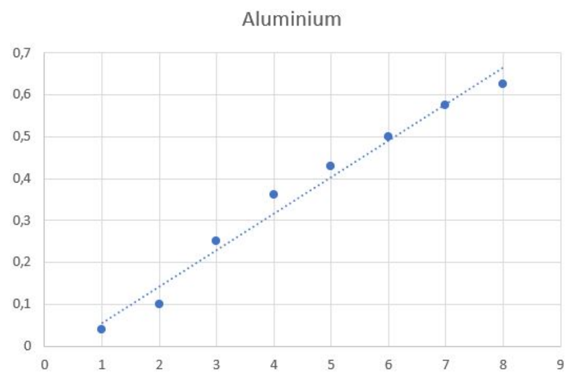

Fig 6. Relationship between length *l* and temperature θ for aluminium. Please use the measurement setup as shown in Figure 4 for this measurement.

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Evaluation (4/6)

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Fig 7. Relationship between length l and temperature θ for brass

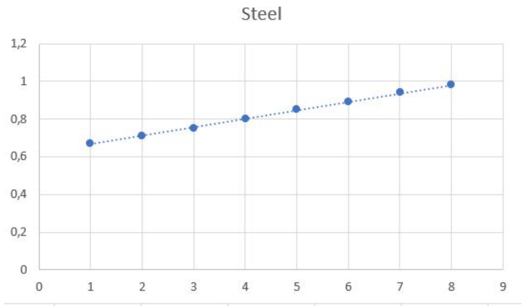

Fig 8. Relationship between length l and temperature θ for steel

Evaluation (5/6)

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Describe about the thermal expansion:

In general, thermal expansion is the tendency of matter to change in volume in response to ______ alterations, which can be described by the volume ______. It describes a fractional change in length or volume per unit temperature change. Thermal expansion generally ______ with increasing bond energy, which also has an effect on the melting point of solids. So, ______ melting point materials are more likely to have ______ thermal expansion.

- decrease
- temperature
- lower
- coefficient expansion
- high

Check

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Evaluation (6/6)

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Which statements are correct to explain thermal expansion of solid?

- [ ] The expansion of solid is uniform in all dimensions for an isotropic material
- [ ] The thermal stress of solid is proportional to the change in temperature
- [ ] Volumetric expansion coefficient is usually used in describing the expansion of solid

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