Linear expansion of solid bodies (Item No.: P1291500)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physics	Age 14-16	Thermal physics	Thermal expansion of solids, liquids and gases	Linear expansion of solid bodies

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	20 Minutes	30 Minutes	1 Student

Additional Requirements:

- Matches or lighter
- kitchen towel

Experiment Variations:

Keywords:

metal, linear expansion, heat expansion

Overview

Introduction

A solid changes its geometrics under influence of heat, the effect is called heat expansion. In this experiment different metal tubes are heated with steam to investigate their linear expansion. The linear expansion is made visual by a rotating shaft with a pointer, over which the tube can glide. The expansion of different materials is compared.

Educational objective

The amount of expansion differs with the material. The expansion can be described with the material specific coefficient of linear expansion α. Furthermore, the way of functioning of the rolling shaft with pointer shall be understood.

Equipment

Position No.	Material	Order No.	Quantity
1	PHYWE Demo Physics board with stand	02150-00	1
2	Clamp.holder d=28-36mm fix.magn.	02151-06	1
3	Clamping holder, 0-13 mm, fixing magnet	02151-07	1
4	Scale for demonstration board	02153-00	1
5	Pointers f. Demonst.Board, 4 pcs	02154-01	1
6	Support plate on fixing magnet	02155-00	1
7	Burner-holder on fixing magnet	02162-00	1
8	Wire gauze holder on fix. magnet	02163-00	1
9	Wire gauze with ceramic, 160 x 160 mm	33287-01	1
10	Collar for linear expansion	04231-55	1
11	Brass tube	04234-01	1
12	Iron tube	04234-02	1
13	Aluminium tube	04234-03	1
14	Rotating shaft with pointer	04236-01	1
15	Erlenmeyer flask, stopper bed, 100 mlSB 29	MAU-EK17082301	1
16	Glass tube, straight, l=80 mm, 10/pkg.	36701-65	1
17	Rubber stopper 26/32, 1 hole 7 mm	39258-01	1
18	Silicone tubing, ID 6 mm	47530-00	1
19	Butane burner with cartridge, 220 g	32180-00	1
20	Glycerol, 250 ml	30084-25	1
21	Boiling beads, 200 g	36937-20	1
22	Immersion probe NiCr-Ni, steel, -50...400 °C	13615-03	1
23	Cobra4 Sensor-Unit 2 x Temperature, NiCr-Ni	12641-00	1
24	Cobra4 Wireless/USB-Link incl. USB cable	12601-10	1

Tasks

1. Qualitative comparison of the linear expansion of different metal tubes.
2. Geometric derivation of the functionality of the rolling shaft with pointer.
3. Calculation of the material specific coefficient of linear expansion α.

Set-up and procedure

Set-up

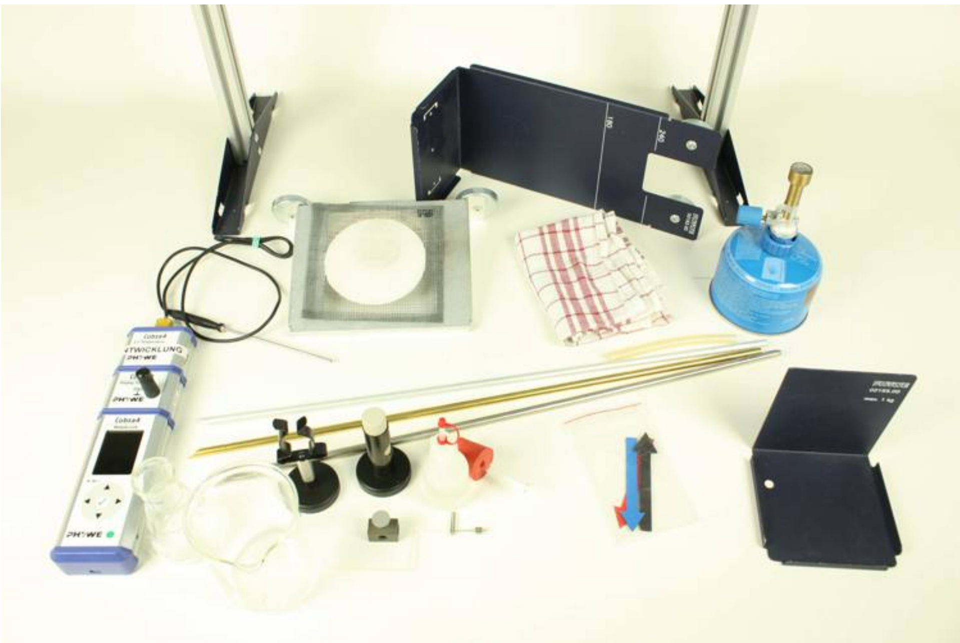

Figure 1: Equipment

1. Place the holder for the burner bottom left on the demo board, see figure 2.
2. Mount wire gauze holder with wire gauze either at the 240 (butane burner) or 180 (Bunsen burner) mark.
3. Fill half of the Erlenmeyer flask with water, add two boiling chips.
4. Use glycerine to slide the 80 mm glass tube into the rubber stopper. Tightly seal the Erlenmeyer flask with it.
5. Slide the silicone hose over the other end of the tube.
6. Place the Erlenmeyer flask in the magnetic clamping holder (28 to 36 mm) to have it sit on the wire gauze.
7. The tubes have two indentations l = 500 mm apart from ecah other and one slanted end. As shown in figure 2, mount the collar for linear expansion on the indentation at the side with the slanted end and use the other indentation to mount the tube in a clamping holder (0 - 13 mm).
8. Place the support plate with its flat side to the top right on the board. The tube is mounted central on the board and connected to the silicone hose with its normal end. With its right side it lies on the support plate.
9. The tube should incline to the right, so that condensating water can run off.
10. Now the rolling shaft is prepared, see figure 3. Stick the counterweight of the pointer through the hole in the support plate. The rolling shaft lies on the plate. Make sure there is a right angle between shaft and board, so that the pointer can move freely.
11. The tube is turned by the clamping holder onto the rolling shaft. Make sure it has enough contact pressure. The rolling shafts position can be optimized afterwards.
12. To measure the room temperature the Cobra4 Mobile-Link 2 is used. Connect the Sensor-Unit 2x Temperature and the NiCr-Ni temperature sensor.

Figure 2: Set-up

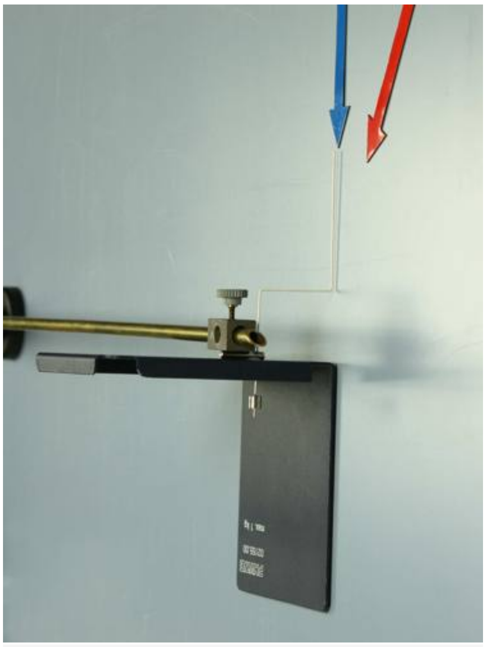

Figure 3: Close up of the rolling shaft with pointer

Procedure

Attention! Tube and steam, which will exit the tube, are hot.

1. The pointer is set vertical. Marks its initial position with a blue magnetic arrow. Do not bump tube or pointer during experiment!
2. Ignite burner and wait until steam is leaving the tube. Put a beaker underneath to catch dripping water.
3. Watch the pointer and wait until it stopped moving. Mark the end position with a red arrow. Turn off burner.
4. Measure the distance s between the red and blue arrow.
5. Let the tube cool down a while. Now it can be removed with a towel.
6. Repeat the experiment with the two other tubes.

Furthermore:

1. Measure the room temperature on the Cobra 4 Mobile-Link 2
2. Measure length of pointer a from the center of the shaft to the tip.

Observation and results

Observations

The pointer moves while the tube is beeing warmed up and reaches a maximum deflection. Aluminium causes the gratest deflection, steel the smallest.

Evaluation

Example measurements:

Material	s in mm
aluminium	23
brass	19
steel	12

Length of metal tubes l_0 = 500 mm
radius of rolling shaft r = 2 mm
length of pointer a = 102 mm
room temperature T_0 = 23 °C
boiling temperature T_1 = 100 °C

a) Geometry of the rolling shaft

1. A correlation between the deflection of the pointer on the rolling shaft s and the linear expansion Δl needs to be drawn. Figure 4 and 5 help.

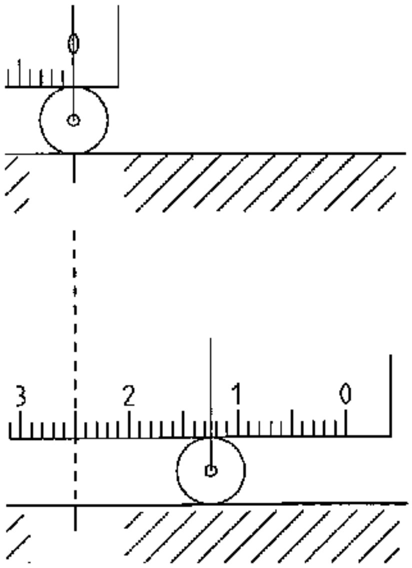

Figure 4: Rolling movement

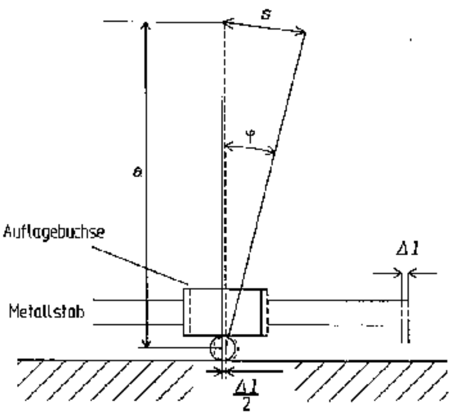

Figure 5: Geometry of the rolling shaft with pointer

2. In order to get used to the funktionality, students should use a ruler (representative of the tube) to turn the rolling shaft on an tables edge by 360 °. The result is explained in figure 4:
   Movement of the ruler 2,5 cm
   Movement of the rolling shaft 1,25 cm
   Circumference of the rolling shaft 1,25 cm
3. When the ruler moves by Δl, the rolling shaft only moves by $\Delta l/2$. The rolled distance can be correlated to the angle of deflection ϕ by the circumference of the rolling shaft $2\pi r$:

   $\Delta l/2 = 2\pi \cdot r \cdot \frac{\phi}{360^\circ}$
4. Now the distance s is correlated the angle ϕ. s is equivalent to the circular arc, which belongs to the angle ϕ. Here, we ignore the distance $\Delta l/2$. (A calculation with sine and cosine gave similar results in the range of reached accuracy.)

   $\phi = s \cdot \frac{360^\circ}{2\pi \cdot a}$

b) Now the linear expansion Δl as well as the coefficient α will be calculated.

1. The linear expansion depends on the difference in temperature $(T_1 - T_0)$ and the lenght of the heated tube l_0. Both values are correlated by the coefficient of linear expansion α:

   $\Delta l = \alpha \cdot l_0 \cdot (T_1 - T_0)$
2. The equations above can be merged into:

   $\alpha = s \cdot \frac{2 \cdot r \cdot s}{a \cdot l_0 \cdot (T_1 - T_0)}$

The final results are listed in the following table, as well as literature values for α:

Material	s in mm	ϕ in Deg	Δl in mm	α in 10^{-6} 1/K	Literature value α in 10^{-6} 1/K
aluminium	23	12,9	0,90	23	23,7
brass	19	10,7	0,75	19	18,3
steel	12	6,7	0,47	12	10