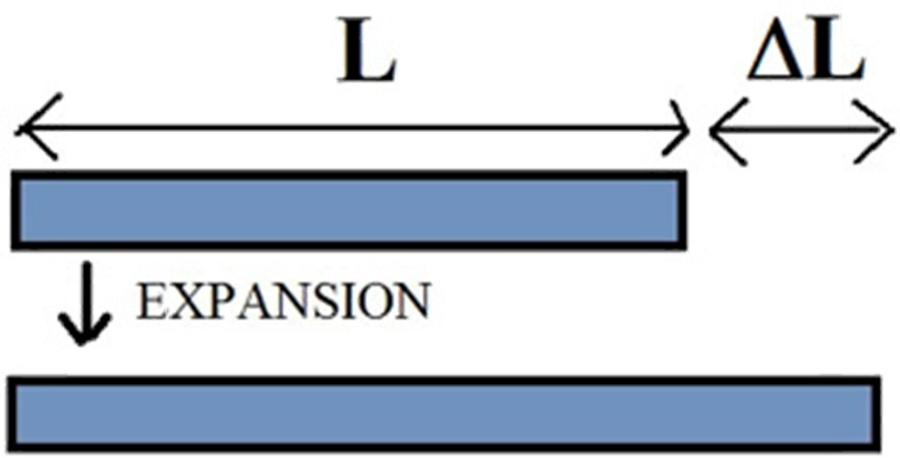
Coefficient of Linear Expansion

- Most materials expand as the temperature increases.
- A temperature change of ΔT produces a change in length of ΔL

$$\Delta L = L\alpha\,\Delta T$$

- where α is the "coefficient of linear expansion".
- The change in length is proportional to the origin length – why?
- Typically $\alpha \approx 10^{-5}/°C$ for metals.



- The change in length will occur for all dimensions of an object. Since Volume = Length^3, the change in volume is $\Delta V = V \beta \Delta T$, where β = “coefficient of volume expansion” = 3α.

THERMAL EXPANSION OF MATERIALS

- Most materials expand as they are heated
  - Some more than others
- Refractory metals and ceramics
  - Expand less
- Polymers
  - Expand more
- Some materials expand very little
  - SiO_2 glass
  - b-spodumene, $Li_2O.Al_2O_3.4SiO_2$
- Complex systems with more than one material must have matched or compensated thermal expansions

Thermal Expansion Values of Materials

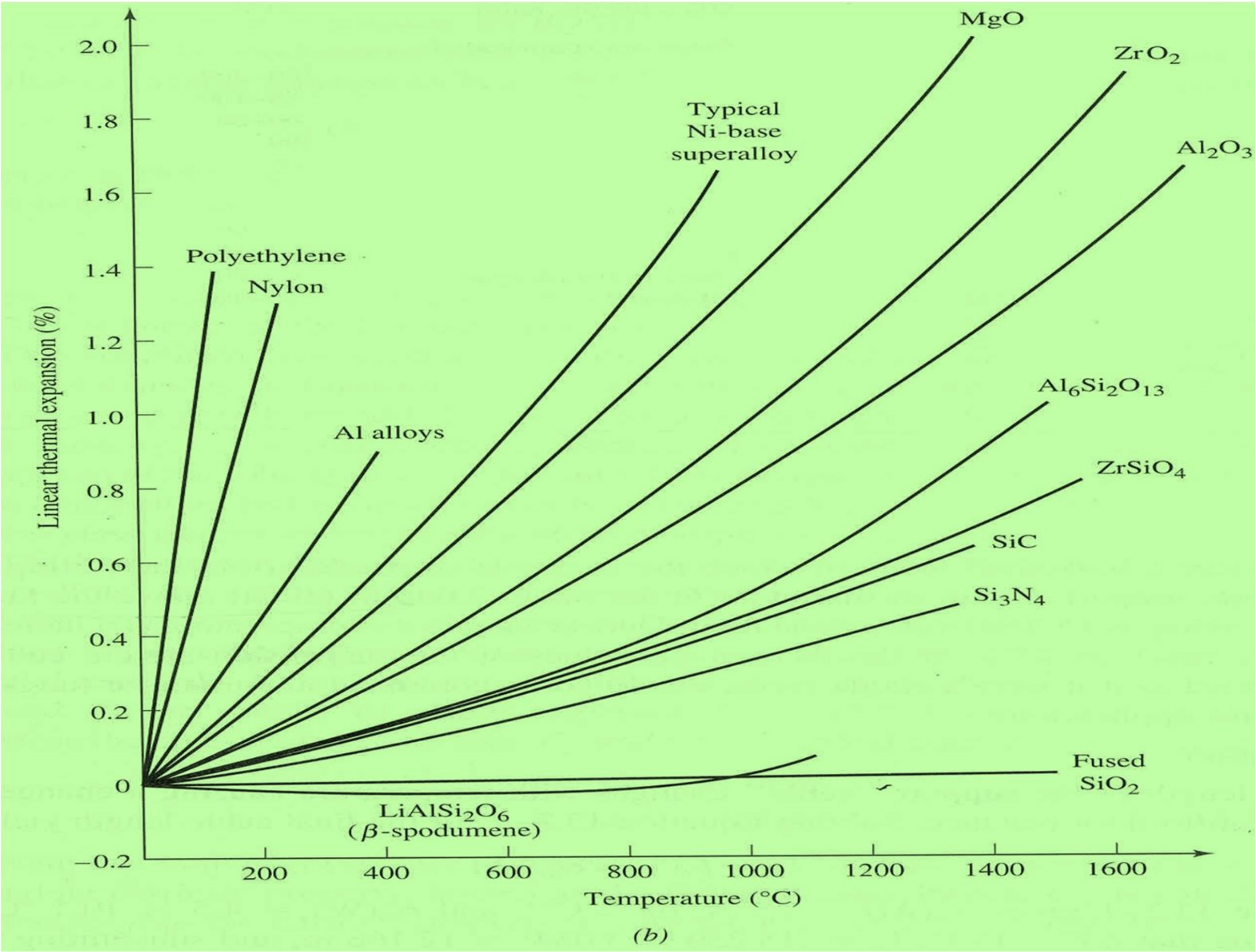
Material	α_{th} ($\times 10^{-6}$ °C^{-1})	Material	α_{th} ($\times 10^{-6}$ °C^{-1})
Metals		**Ceramics**	
Al	25	Al_2O_3	6.5–8.8
Cr	6	BeO	9
Co	12	MgO	13.5
Cu	17	SiC	4.8
Au	14	Si	2.6
Fe	12	Si_3N_4 (α-phase)	2.9
Pb	29	Si_3N_4 (β-phase)	2.3
Mg	25	Spinel ($MgAl_2O_4$)	7.6
Mo	5	Soda-lime-silicate glass	9.2 (used in light bulbs)
Ni	13	Borosilicate glass	4.6 (used with Kovar)
Pt	9	Silica (96% pure)	0.8
K	83	Silica (99.9% pure)	0.55
Ag	19		
Na	70	**Polymers (unoriented)**	
Ta	7	Polyethylene	100–200
Sn	20	Polypropylene	58–100
Ti	9	Polystyrene	60–80
W	5	Polytetrafluoroethylene	100
Zn	35	Polycarbonate	66
1020 steel	12	Nylon (6/6)	80
Stainless steel	17	Cellulose Acetate	80–160
3003 aluminum alloy	23.2	Polymethylmethacrylate	50–90
2017 aluminum alloy	22.9	Epoxy	45–90
ASTM B152 copper alloy	17	Phenolformaldehyde	60–80
Brass	18	Silicones	20–40
Pb-Sn solder (50-50)	24		
AZ31B magnesium alloy	26		
ASTM B160 nickel alloy	12		
Commercial titanium	8.8		
Kovar (Fe-Ni-Co)	5		

Dependence Of Linear Expansion Coeffient

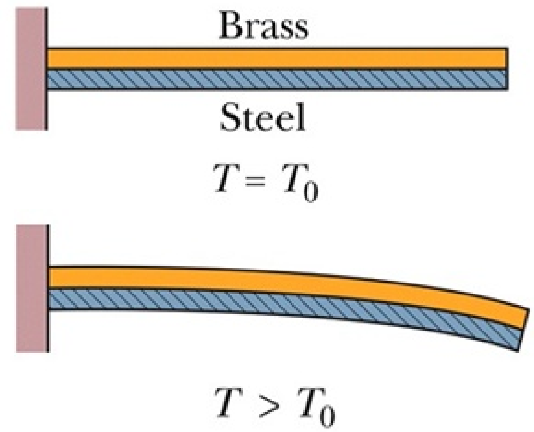
$$\Delta L = L\alpha\,\Delta T$$

- For materials that are not isotropic (e.g., an asymmetric crystal), can have a different value depending on the axis along which the expansion is measured.
- Also, can vary somewhat with temperature so that the degree of expansion depends not only on the change in the temperature, but on the absolute temperature as well.

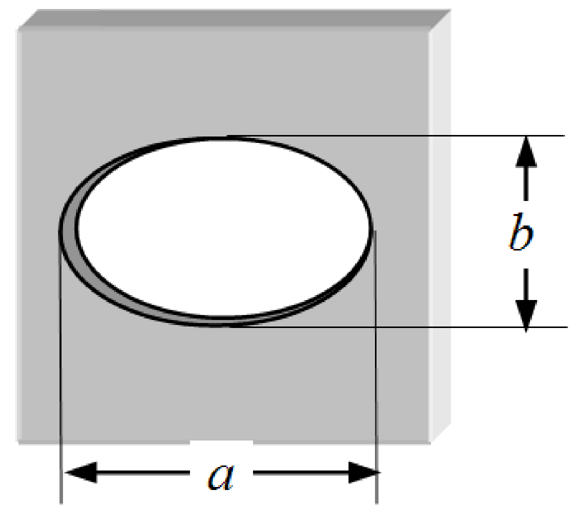
Typical Thermal Expansion Coefficients of Materials



- An engineering application of thermal expansion is the bimetal strip thermostat.
- If you bond together two different materials with different thermal expansion coefficients, then they will bend as the temperature changes.
- Many thermostats use a bimetal strip, or more usually a bimetal coil, as the temperature sensing elements. A mercury switch turns on/off according to the ambient temperature.



A square plate made of lead has an oval-shaped hole. The oval may be described by the lengths *a* and *b* as shown in the drawing. Which of the following correctly describes the plate after its temperature is increased by two hundred Celsius degrees?



A) The size of the plate will increase, but *a* and *b* will both decrease.

B) The size of the plate will remain unchanged, but *a* and *b* will both increase.

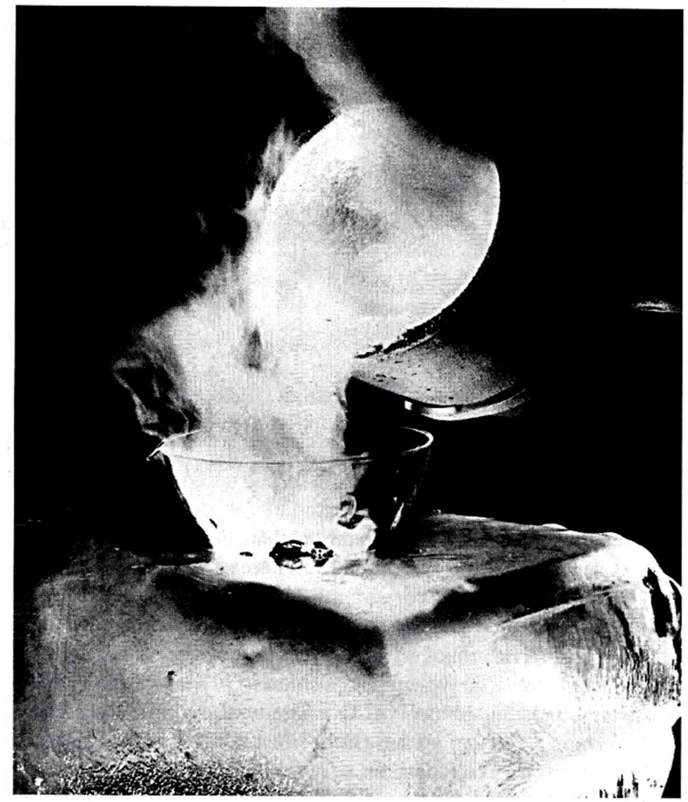
C) The size of the plate will increase, and *a* and *b* will both increase.

D) The size of the plate will remain unchanged, but *a* and *b* will both decrease.

E) The size of the plate will increase, but only *a* will increase.

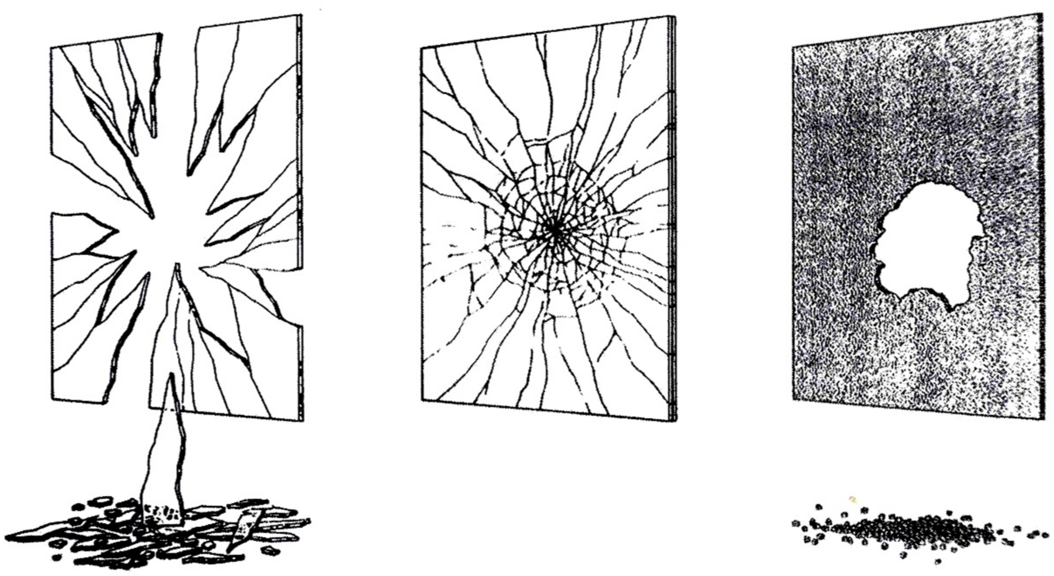
Thermal Expansion of Glass

- Thermal expansion determines if a glass will be shock resistant, able to withstand high thermal stresses
- Thermal expansion also determines if a glass will have low thermal shock resistance
- Small thermal expansion coefficient leads to high thermal shock resistance
- Large thermal expansion leads to low thermal shock resistance



Thermal Expansion of Glass

- Thermal Expansion also determines whether a glass can be thermally "tempered" to increase its strength
- High thermal expansion leads to high tempering ability
- Low thermal expansion leads to low tempering ability
- Thermal tempering increases strength and reduces large dangerous shards to fine small particles



Measurement of the thermal expansion

To determine the thermal expansion coefficient, two physical quantities (displacement and temperature) must be measured on a sample that is undergoing a thermal cycle.

Three of the main techniques used for thermal expansion coefficient measurement are:

- ❖ dilatometry,
- ❖ interferometry,
- ❖ thermomechanical analysis.
- ❖ Optical imaging can also be used at extreme temperatures.

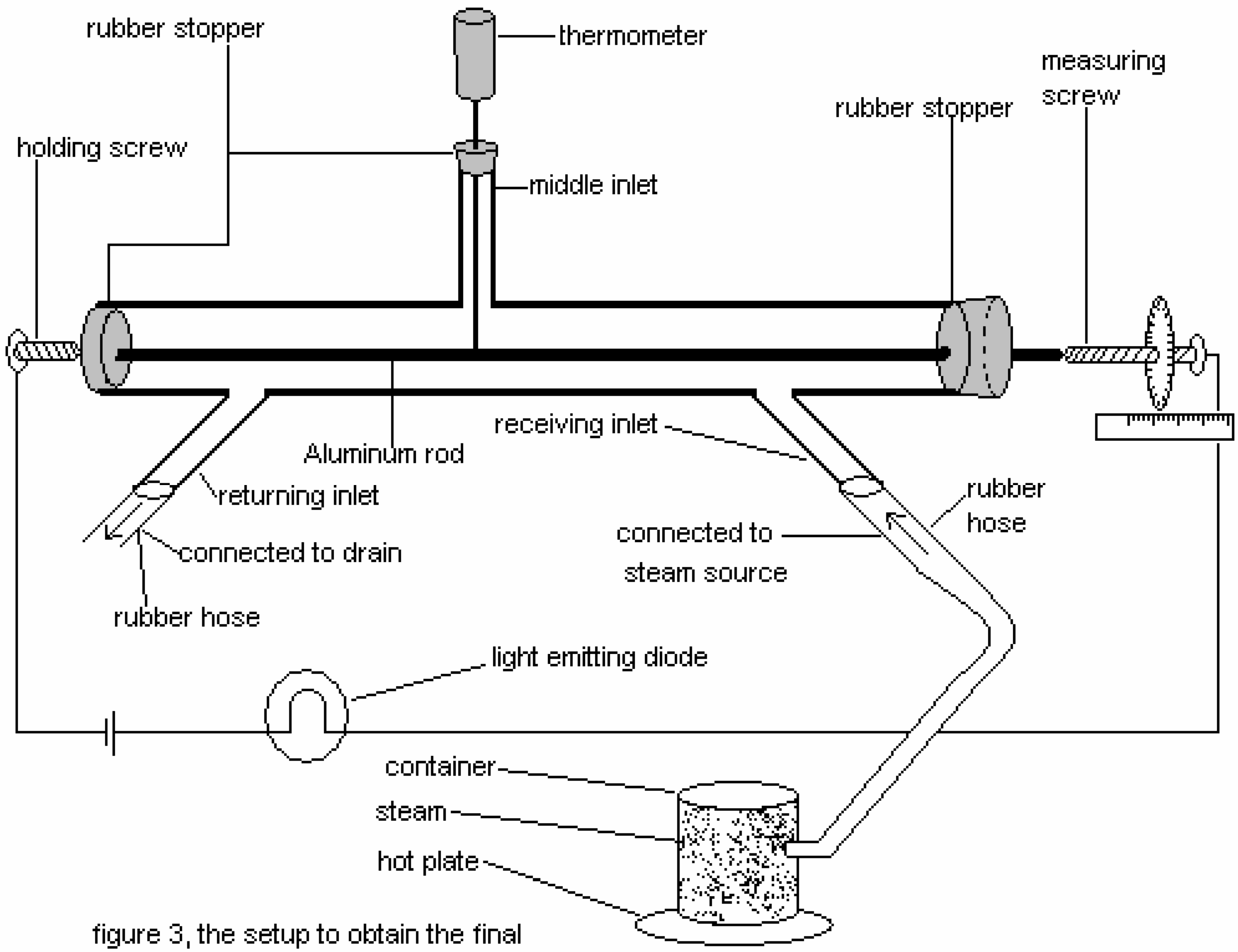


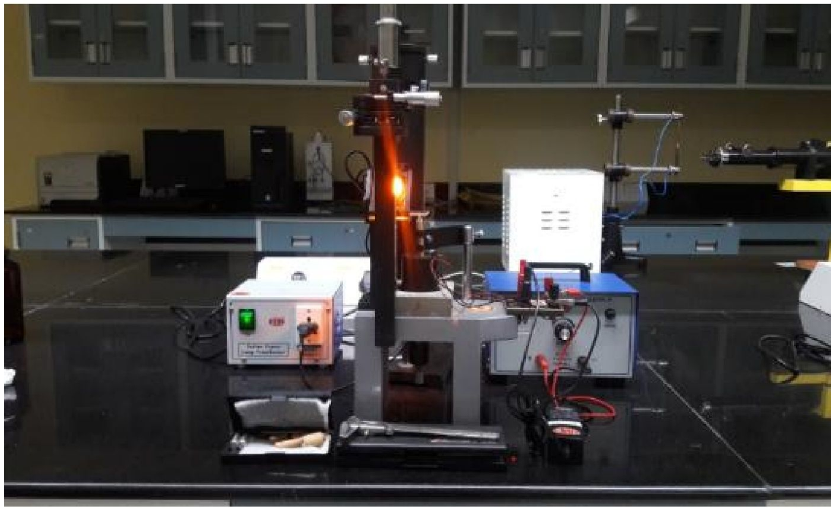
figure 3, the setup to obtain the final temperature.

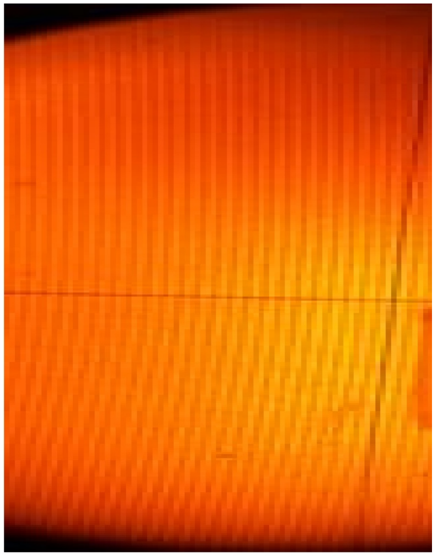
Dilatometry:

- Mechanical dilatometry techniques are widely used.
- With this technique, a specimen is heated in a furnace and displacement of the ends of the specimen are transmitted to a sensor by means of push rods.
- The precision of the test is lower than that of interferometry.

Interferometry:

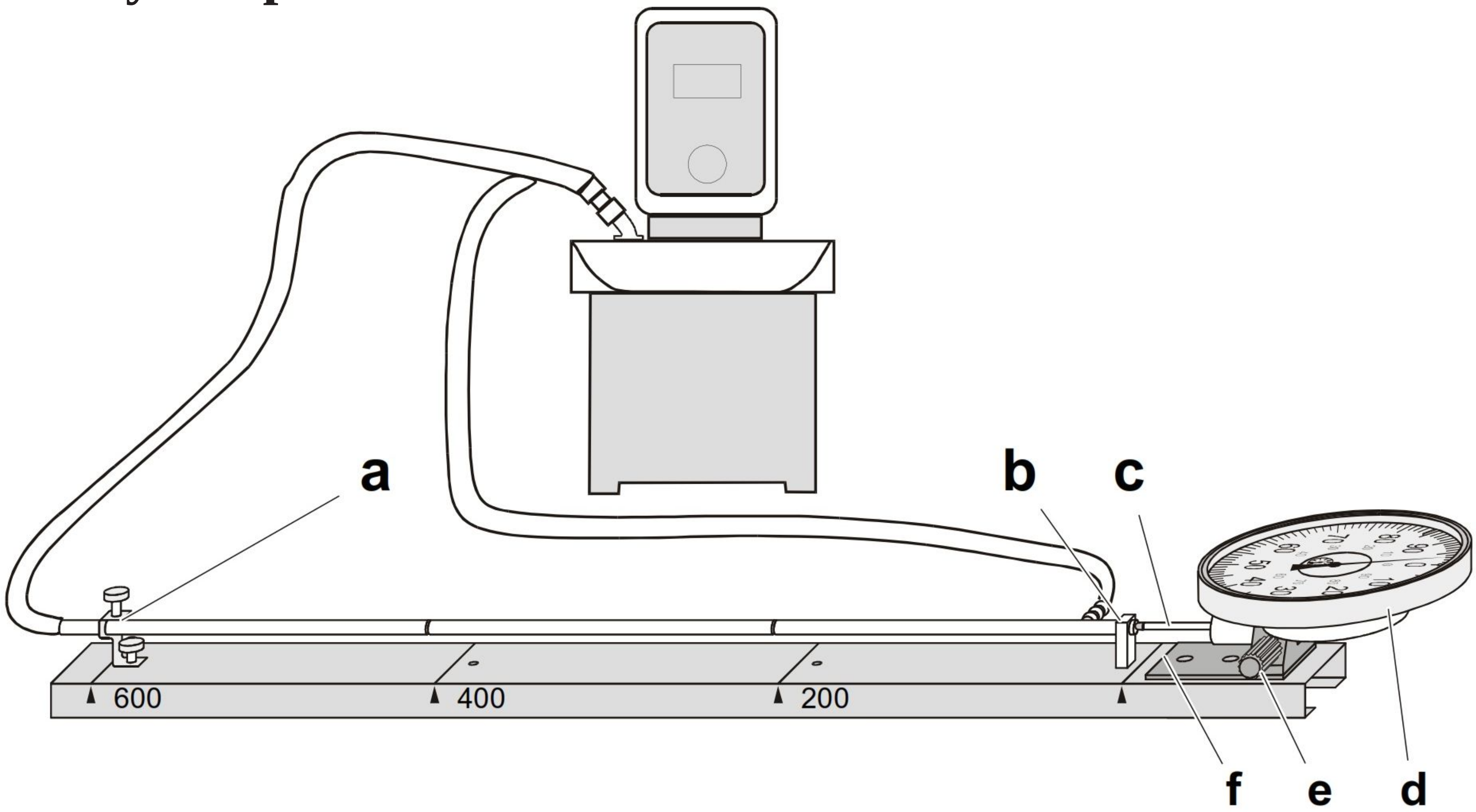
With optical interference techniques, displacement of the specimen ends is measured in terms of the number of wavelengths of monochromatic light.





- ✓ Precision is significantly greater than with dilatometry.
- ✓ the technique relies on the optical reflectance of the specimen surface,
- ✓ interferometry is not used much above 700 °C

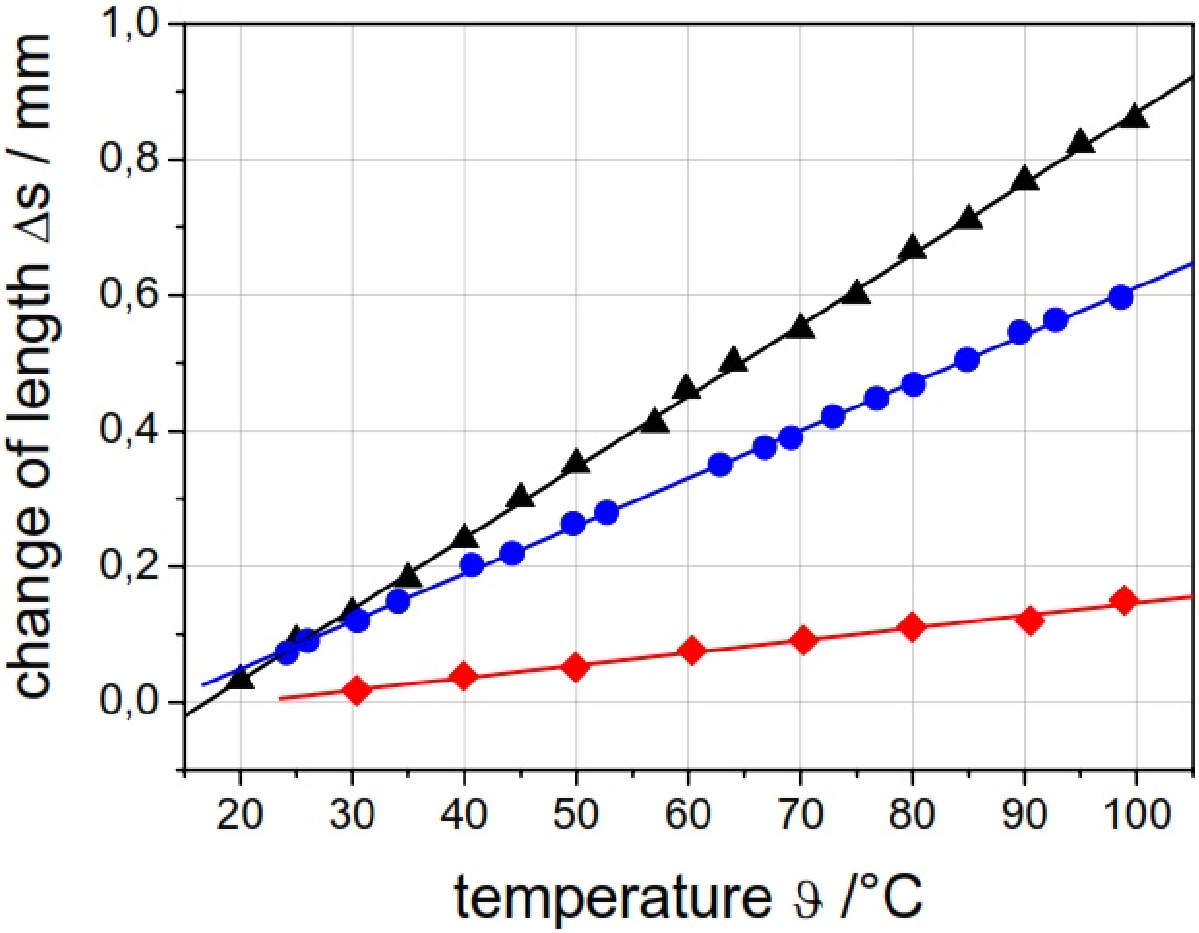
Dilatometry setup



Measuring example

Table 1: Measured change of length Δs as a function of the temperature ϑ.

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	–	–



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