Expansion of a railroad track. A steel railroad track was 30.0 m long when it was initially laid at a temperature of −6.70 °C. What is the change in length of the track when the temperature rises to 35.0 °C?

The coefficient of linear expansion for steel is $\alpha_{steel} = 1.20 \times 10^{-5}/°C$. The change in length becomes

$$\Delta L = \alpha L_0 \Delta t$$
$$= (1.20 \times 10^{-5}/^0C)(30.0 \text{ m})(35.0\,^0C - (-6.70\,^0C)$$
$$= 0.0150 \text{ m} = 1.50 \text{ cm}$$

The new length of the track becomes

$$L = L_0 + \Delta L$$
$$= 30.0 \text{ m} + 0.0150 \text{ m} = 30.0150 \text{ m}$$

The force necessary to compress the rail is

$$F = AY \frac{\Delta L}{L_0}$$
$$= (0.013 \text{ m}^2)\left(2.10 \times 10^{11} \frac{\text{N}}{\text{m}^2}\right)\left(\frac{0.0150 \text{ m}}{30.0 \text{ m}}\right)$$
$$= 1.37 \text{ x } 10^6 \text{ N}$$

The change in area. An aluminum sheet 2.50 m long and 3.24 m wide is connected to some posts when it was at a temperature of −10.5 °C. What is the change in area of the aluminum sheet when the temperature rises to 65.0 °C?

The coefficient of linear expansion for aluminum is $\alpha_{Al} = 2.4 \times 10^{-5}/\,°C$. The original area of the sheet

$$A_0 = L_1 L_2$$
$$A_0 = (2.50\text{ m})(3.24\text{ m}) = 8.10\text{ m}^2$$

The change in area

$$\Delta A = 2\alpha A_0 \Delta t$$
$$= 2(2.4 \times 10^{-5}/^0\text{C})(8.10\text{ m}^2)(65.0\,^0\text{C} - (-10.5\,^0\text{C})$$
$$= 0.0294\text{ m}^2 = 294\text{ cm}^2$$

The new area of the sheet becomes

$$A = A_0 + \Delta A$$
$$= 8.10\text{ m}^2 + 0.0294\text{ m}^2 = 8.13\text{ m}^2$$

The expansion of the solid can be explained by looking at the molecular structure of the solid. The molecules of the substance are in a lattice structure. Any one molecule is in equilibrium with its neighbors, but vibrates about that equilibrium position. As the temperature of the solid is increased, the vibration of the molecule increases. However, the vibration is not symmetrical about the original equilibrium position. As the temperature increases the equilibrium position is displaced from the original equilibrium position. Hence, the mean displacement of the molecule from the original equilibrium position also increases, thereby spacing all the molecules farther apart than they were at the lower temperature. The fact that all the molecules are farther apart manifests itself as an increase in length of the material. Hence, linear expansion can be explained as a molecular phenomenon. The large force associated with the expansion comes from the large molecular forces between the molecules.

Fitting a small wheel on a large shaft. We want to place a steel wheel on a steel shaft with a good tight fit. The shaft has a diameter of 10.010 cm. The wheel has a hole in the middle, with a diameter of 10.000 cm, and is at a temperature of 20 °C. If the wheel is heated to a temperature of 132 °C, will the wheel fit over the shaft? The coefficient of linear expansion for steel is $\alpha = 1.20 \times 10^{-5}/°C$.

The present area of the hole in the wheel is not large enough to fit over the area of the shaft. We want to heat the wheel so that the new expanded area of the heated hole in the wheel will be large enough to fit over the area of the shaft. With the present dimensions the wheel can not fit over the shaft. If we place the wheel in an oven at 132°C, the wheel expands. We can solve this problem by looking at the area of the hole and the shaft, but it can also be analyzed by looking at the diameter of the hole and the diameter of the shaft. When the wheel is heated, the diameter of the hole increases by

$$\begin{aligned} \Delta L_H &= \alpha L_0 \Delta t \\ &= (1.20 \times 10^{-5}/^0C)(10.000 \text{ cm})(132\ ^0C - 20\ ^0C) \\ &= 1.34 \times 10^{-2} \text{ cm} \end{aligned}$$

The new hole in the wheel has the diameter

$$\begin{aligned} L = L_0 + \Delta L &= 10.000 \text{ cm} + 0.013 \text{ cm} \\ &= 10.013 \text{ cm} \end{aligned}$$

Because the diameter of the hole in the wheel is now greater than the diameter of the shaft, the wheel now fits over the shaft. When the combined wheel and shaft is allowed to cool back to the original temperature of 20 0C, the hole in the wheel tries to contract to its original size, but is not able to do so, because of the presence of the shaft. Therefore, the enormous forces associated with the thermal compression when the wheel is cooled, are exerted on the shaft by the wheel, holding the wheel permanently on the shaft.

Object

Measure the coefficient of linear expansion of aluminum.

SAFETY WARNING

This experiment uses steam heating. Be careful to avoid touching the hot surfaces of the steam generator, plastic tubing and the expansion coefficient apparatus. Make sure that the steam outlet tube from the apparatus goes to a sink.

Introduction

Most materials expand as they get warmer and shrink as they get cooler (this is true for solids, liquids and gases). In solids, the linear dimensions of an object (such as length, height, depth of a hole or width of an aperture) changes with temperature according to the following formula:

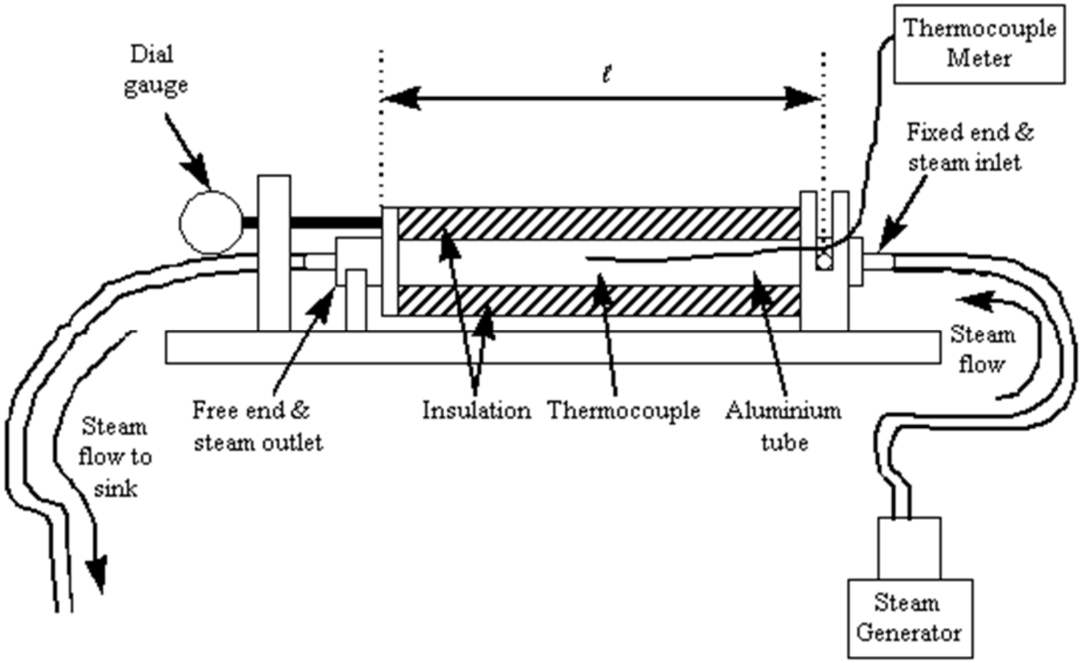
$$\Delta l = \alpha l \, \Delta T \qquad \text{(Equation 1)}$$

where Δl is the change in length, α is the average coefficient of linear expansion over the temperature change ΔT and l is the original length.

In this experiment you will use a dial gauge (see figure) to measure the change in length Δl of an aluminum tube of length l (see figure). The insulated aluminum tube is heated by passing steam through it and its average temperature is measured by a thermocouple placed half way along the tube (see figure). The aluminum tube is fixed at one end and insulated from the base. The other end is free to move when the tube expands, this movement is measured by the dial gauge attached to the base.

Apparatus

Thermal expansion apparatus with thermocouple attached, steam generator, stop watch, digital thermocouple meter.



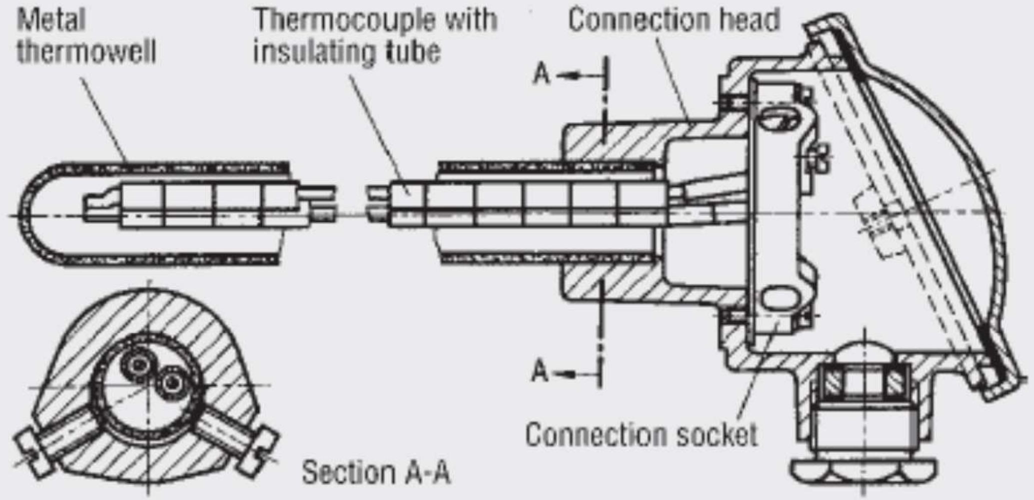


Figure 2.104 Thermo-element with non-precious metal thermocouple

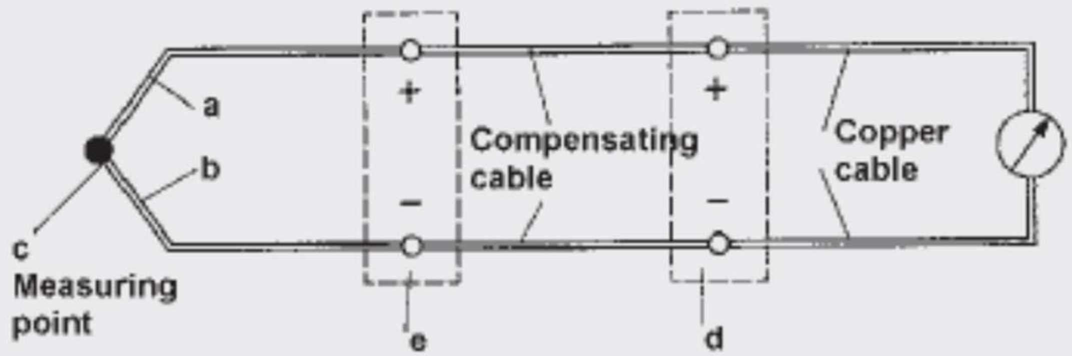
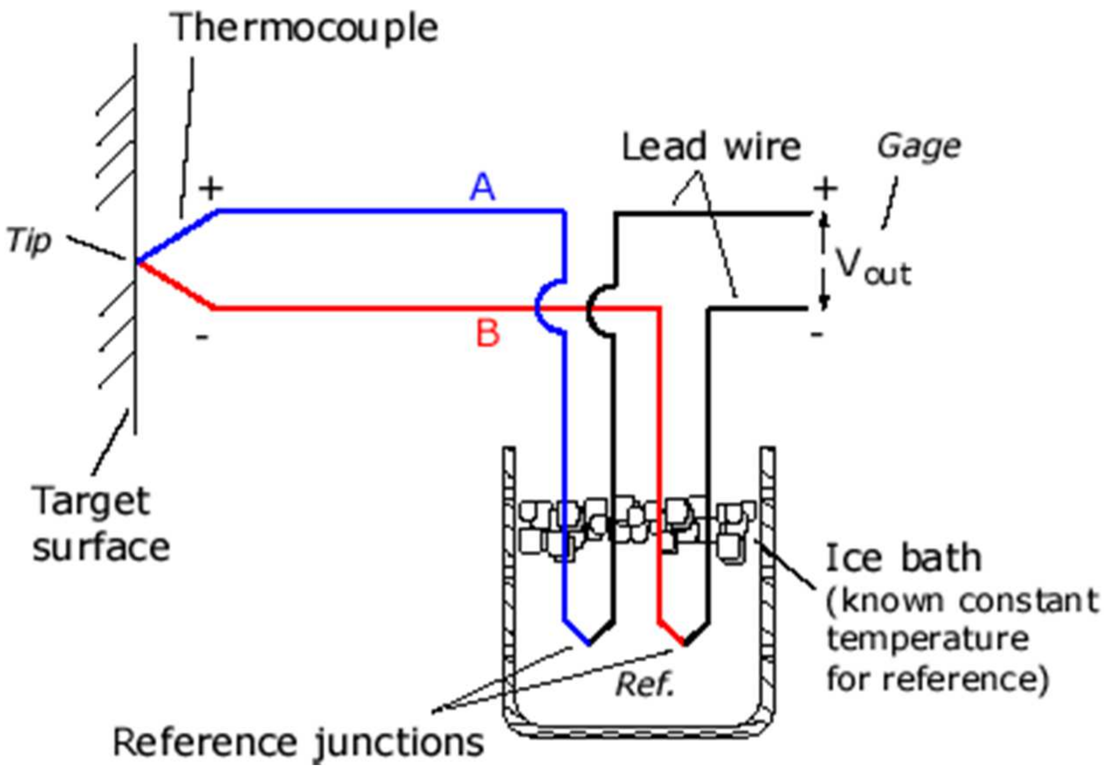
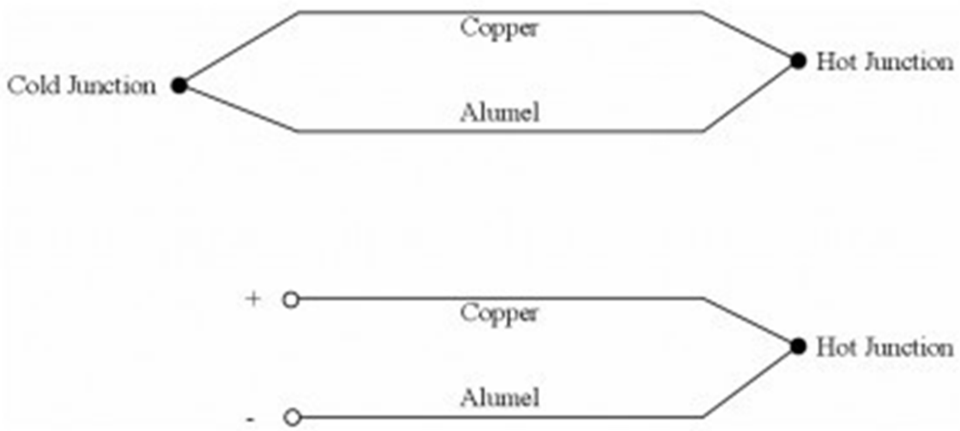


Figure 2.105 Circuit diagram of a thermocouple



The basis of thermocouples was established by Thomas Johann Seebeck in 1821 when he discovered that a conductor generates a voltage when subjected to a temperature gradient. To measure this voltage, one must use a second conductor material which generates a different voltage under the same temperature gradient. Otherwise, if the same material was used for the measurement, the voltage generated by the measuring conductor would simply cancel that of the first conductor. The voltage difference generated by the two materials can then be measured and related to the corresponding temperature gradient. It is thus clear that, based on Seebeck's principle, thermocouples can only measure **temperature differences** and need a known reference temperature to yield the absolute readings.

In a thermocouple circuit the current continues to flow as long as the two junctions are at different temperatures. The magnitude and direction of the current depends on the temperature difference between the junctions and the properties of the metals used in the circuit. This is known as the Seebeck effect.



If this circuit is broken at the center, the net open circuit voltage (the Seebeck voltage) is a function of the junction temperature and the composition of the two metals.

If the hot and cold junctions are reversed, current will flow in the opposite direction. Any two dissimilar metals can be used and the thermocouple circuit will generate a low voltage output that is almost (but not exactly) proportional to the temperature difference between the hot junction and the cold junction. The voltage output is between 15 and 40µV per degree C, dependant on the thermocouple conductor metals used. The actual metals used in industrial thermocouples depend on the application and temperature measurement range required.

$$V = a(T_h - T_c)$$

The voltage difference, V, produced across the terminals of an open circuit made from a pair of dissimilar metals, A and B, whose two junctions are held at different temperatures, is directly proportional to the difference between the hot and cold junction temperatures, $T_h - T_c$. The voltage or current produced across the junctions of two different metals is caused due to the diffusion of electrons from high electron density region to low electron density region as the density of electrons is different in different metals. Due to this the current flows in opposite direction. If both the junctions are kept at same temperature, equal amount of electron diffuses at both the junctions. Therefore the current at both the junctions are equal and opposite and the net current is zero, and if both the junctions are kept at different temperature then diffusion at both the junctions are different and hence different amount of current is produced. Therefore the net current is not zero. This is known as the phenomena of **thermoelectricity**.

Designation	Type	Temperature range	Signal (µV/K)	Basic value set
Cu-CuNi	T	-250 to 400°C (600°C) -420 to 750°F(1100°F)	23 to 69	DIN IEC 584
Fe-CuNi	J	-200 to 700°C (900°C) -330 to 1300°F(1650°F)	34 to 69	DIN IEC 584
NiCr-CuNi	E	-200 to 700°C(1000°C) -330 to 1300°F(1800°F)	40 to 80	DIN IEC 584
NiCr-Ni	K	-200 to 1000°C(1300°C) -330 to 1800°F(2400°F)	41 to 36	DIN IEC 584
NiCr-Ni	N	-200 to 1000°C(1300°C) -330 to 1800°F(2400°F)	41 to 36	DIN IEC 584
PtRh10-Pt	S	0 to 1300°C(1600°C) 32 to 2400°F(2900°F)	6 to 12	DIN IEC 584
PtRh13-Pt	R	0 to 1300°C(1600°C) 32 to 2400°F(2900°F)	5 to 14	DIN IEC 584
PtRh30-PtRh 6	B	0 to 1600°C(1800°C) 32 to 2900°F(3300°F)	0 to 11	DIN IEC 584
Cu-CuNi	U	-250 to 400°C (600°C) -420 to 750°F(1100°F)	19 to 70	DIN 43710
Fe-CuNi	L	-200 to 700°C (900°C) -330 to 1300°F(1650°F)	30 to 70	DIN 43710

Table 2.21 Operating temperatures and sensitivities of standardized thermocouples. The temperatures in brackets apply to operation under inert gas, all others to air.