22.1: Temperature

We measure temperature by a variety of means. The most primitive measurement is direct sensing by the human body. We immediately discern whether something we touch is hot or cold relative to our own body. Furthermore, we can detect a hot stove from a distance by the feeling of warmth on our skin. In the case of direct contact, heat is transferred to our hand by conduction, whereas in the latter case the transfer takes place by thermal radiation. Our body considers something to be hot if heat is transferred from the object to our body, whereas it is perceived as being cold if the transfer of heat is from our body to the object.

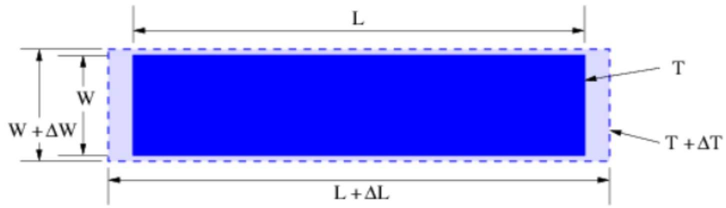

Figure 22.1.1:: Most solid bodies expand by the same fractional amount in all directions when their temperature increases, so that $\Delta\mathrm{L}/\mathrm{L} = \Delta\mathrm{W}/\mathrm{W}$. Thus, the ratio $\alpha = \Delta L/(LdT)$ is the same for all objects constructed of the same material, generally over a considerable range of temperature.

A more objective measure of temperature is obtained by using the fact that ordinary material objects expand when they become warmer and contract when they cool. Empirically it is found that the fractional change in the length of a solid body, $\Delta\mathrm{L}/\mathrm{L}$, is related to the change in temperature $\Delta\mathrm{T}$, as illustrated in Figure 22.1.1::

$$\frac{\Delta L}{L} = \alpha\Delta T \tag{22.1.1}$$

where α is called the linear coefficient of thermal expansion.

For liquids the fractional change in volume, $\Delta\mathrm{V}/\mathrm{V}$, is easier to relate to the change in temperature than the fractional change in linear dimension:

$$\frac{\Delta V}{V} = \beta\Delta T \tag{22.1.2}$$

where β is the volume coefficient of thermal expansion. The quantities α and β depend on the material properties and on the temperature scale being used. The ordinary thermometer is based on the thermal expansion of a liquid such as mercury.

The most commonly used temperature scales in science are the Celsius and Kelvin scales. Roughly speaking, water freezes at 0° C and it boils (at sea level) at 100° C. More precise definition of the Celsius scale depends on a detailed understanding of the phase changes of water, which we won't develop here.

There is a limit to how cold something can be. The Kelvin scale is designed to go to zero at this minimum temperature. The relationship between the Kelvin temperature T and the Celsius temperature $\mathrm{T_C}$ is

$$T = T_C + 273.15. \tag{22.1.3}$$

Thus, water freezes at about 273 K and boils at about 373 K. (Notice that the little circle or degree sign is used for Celsius temperatures but not Kelvin temperatures.) Unless otherwise noted, we will use the Kelvin scale. Table 22.1 gives values of β and β for some common materials.

Material	α (K^{-1})	β (K^{-1})
steel	12×10^{-6}	—
copper	16×10^{-6}	—
aluminum	23×10^{-6}	—
invar	0.7×10^{-6}	—
glass	9×10^{-6}	—

lead	29×10^{-6}	—
methyl alcohol	—	1.22×10^{-3}
glycerine	—	0.53×10^{-3}
mercury	—	0.182×10^{-3}
water (15° C)	—	0.15×10^{-3}
water (35° C)	—	0.35×10^{-3}
water (90° C)	—	0.70×10^{-3}

Table 22.1: Values of the linear coefficient of thermal expansion for common solids and the volume coefficient of expansion for common liquids. Invar is an alloy that is specificially formulated to have a low coefficient of thermal expansion.

Accurate temperature measurements depend in practice on a knowledge of the properties of materials under temperature changes. However, we shall find later that the concept of temperature can be defined in a way that is completely independent of material properties.