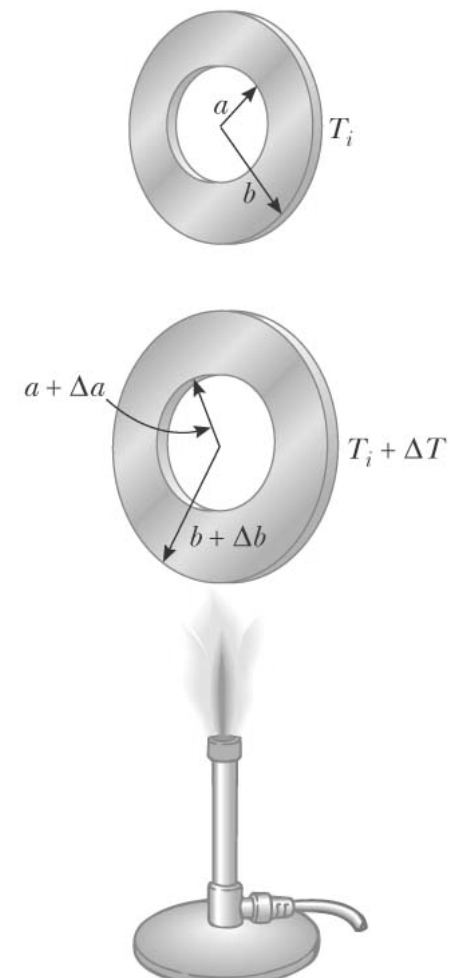
Thermal Expansion

- Thermal expansion is the increase in the size of an object with an increase in its temperature
- Thermal expansion is a consequence of the change in the average separation between the atoms in an object
- If the expansion is small relative to the original dimensions of the object, the change in any dimension is, to a good approximation, proportional to the first power of the change in temperature

Thermal Expansion, example

- As the washer shown at right is heated, all the dimensions will increase
- A cavity in a piece of material expands in the same way as if the cavity were filled with the material
- The expansion is exaggerated in this figure



Linear Expansion

- Assume an object has an initial length L
- That length increases by ΔL as the temperature changes by ΔT
- We define the **coefficient of linear expansion** as

$$\alpha = \frac{\Delta L / L_i}{\Delta T}$$

- A convenient form is $\mathrm{D}\boldsymbol{L} = a\boldsymbol{L_i}\,\mathrm{D}\boldsymbol{T}$

Linear Expansion

- This equation can also be written in terms of the initial and final conditions of the object:

$$L_f - L_i = a\, L_i (T_f - T_i)$$

- The coefficient of linear expansion, a, has units of $(^oC)^{-1}$

Linear Expansion

- Some materials expand along one dimension, but contract along another as the temperature increases

- Since the linear dimensions change, it follows that the surface area and volume also change with a change in temperature

Table 19.1

Average Expansion Coefficients for Some Materials Near Room Temperature

Material	Average Linear Expansion Coefficient $(\alpha)(^\circ\text{C})^{-1}$	Material	Average Volume Expansion Coefficient $(\beta)(^\circ\text{C})^{-1}$
Aluminum	24×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Brass and bronze	19×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Acetone	1.5×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Lead	29×10^{-6}	Turpentine	9.0×10^{-4}
Steel	11×10^{-6}	Gasoline	9.6×10^{-4}
Invar (Ni–Fe alloy)	0.9×10^{-6}	Air[a] at 0°C	3.67×10^{-3}
Concrete	12×10^{-6}	Helium[a]	3.665×10^{-3}

[a] Gases do not have a specific value for the volume expansion coefficient because the amount of expansion depends on the type of process through which the gas is taken. The values given here assume that the gas undergoes an expansion at constant pressure.

Volume Expansion

The change in volume is proportional to the origina
volume and to the change in temperature

$$\mathrm{D}\boldsymbol{V} = b\boldsymbol{V_i}\,\mathrm{D}\boldsymbol{T}$$

b - is the **coefficient of volume expansion**

– For a solid, $b = \mathbf{3}a$

– This assumes the material is isotropic, the same in all directions

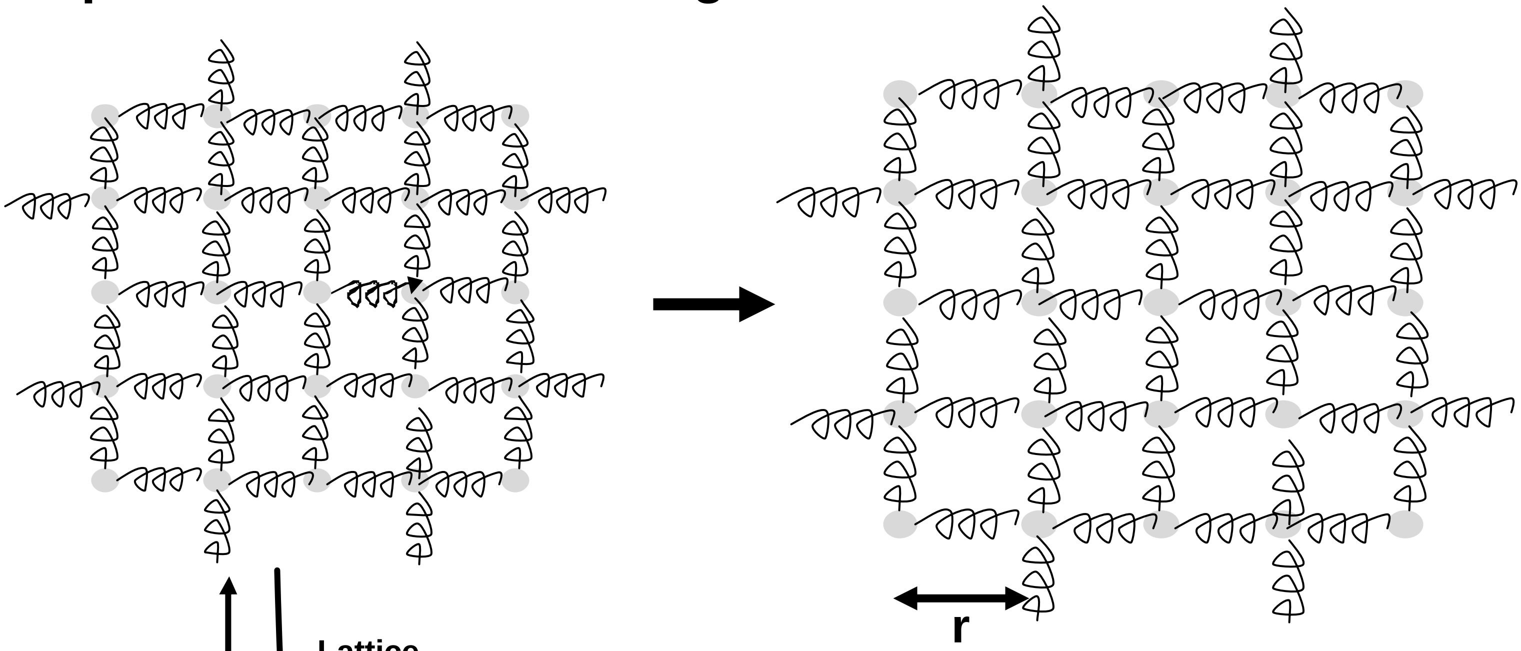
Area Expansion

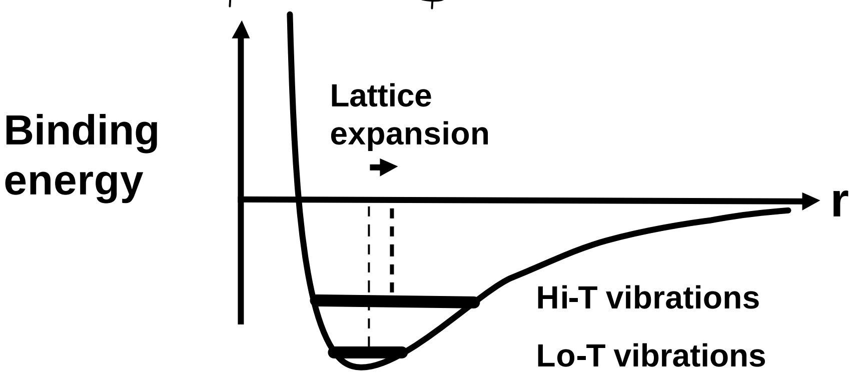
- The change in area is proportional to the original area and to the change in temperature:

$$\mathrm{D}\boldsymbol{A} = \mathbf{2}a\boldsymbol{A}_i\mathrm{D}\boldsymbol{T}$$

Thermal Expansion of solids (and liquids)

Equilibrium distance change due to excitation of vibrations





Result:

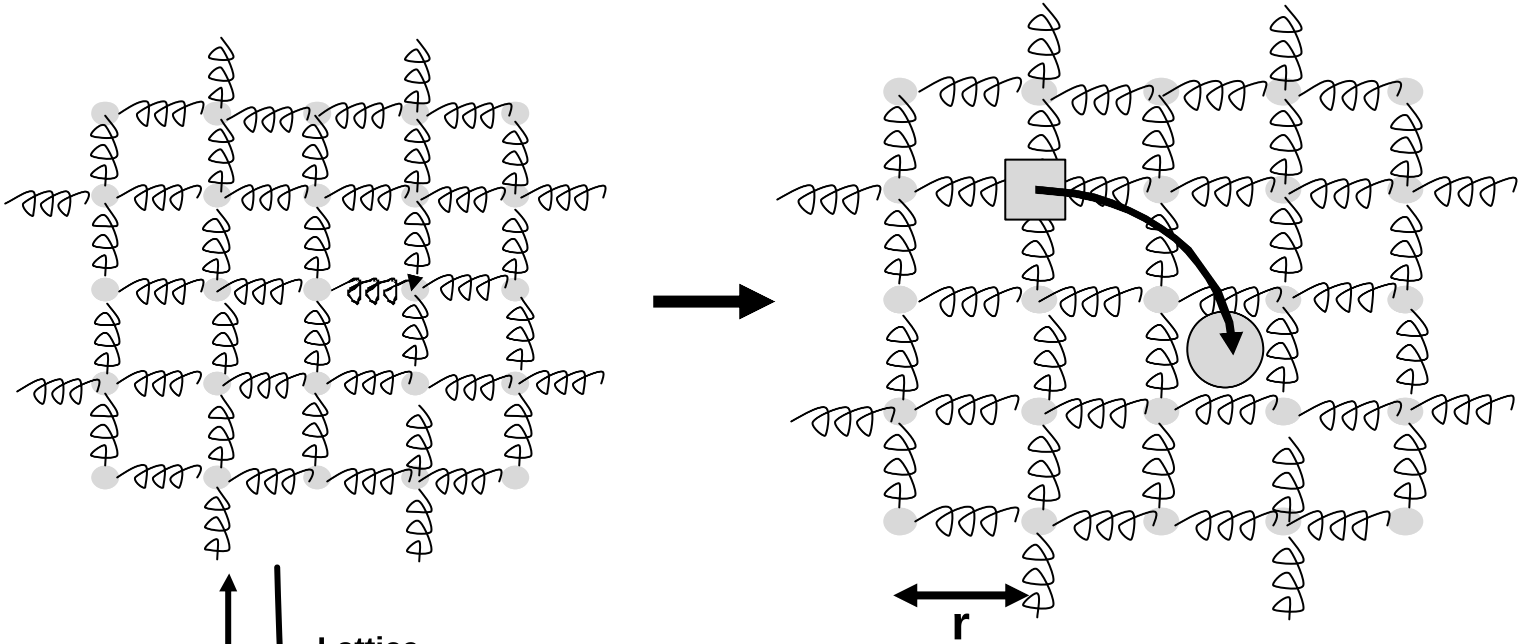
$$\frac{\Delta L}{L} = \Delta T a$$

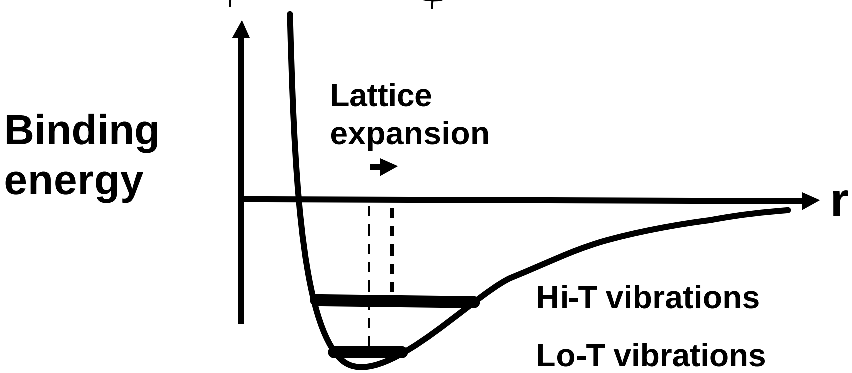
Electrostatic binding forces get weaker as atoms get further apart.

Note: a **itself usually increases with T**

Thermal Expansion of solids (and liquids)

Formation of defects





Result:

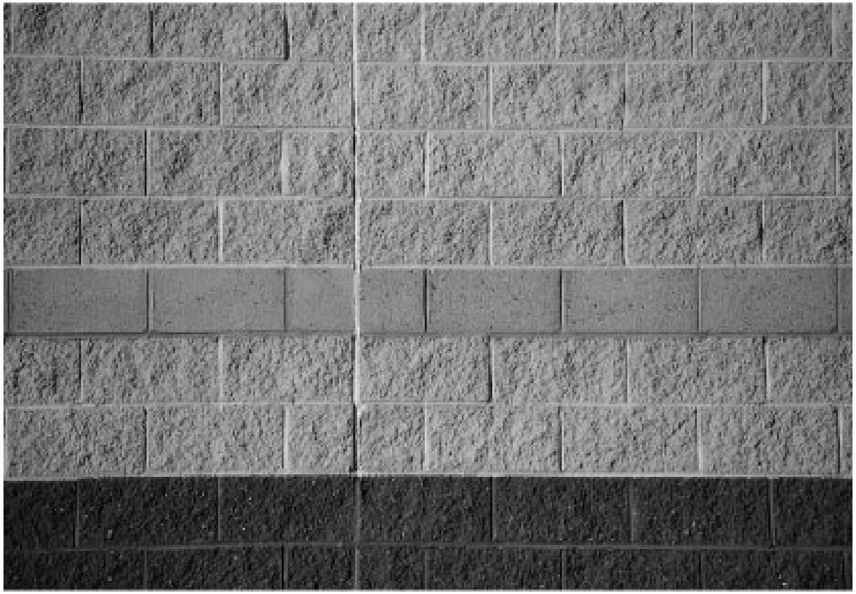
$$\frac{\Delta L}{L} = \Delta T a$$

Electrostatic binding forces get weaker as atoms get further apart.

Note: a **itself usually increases with T**

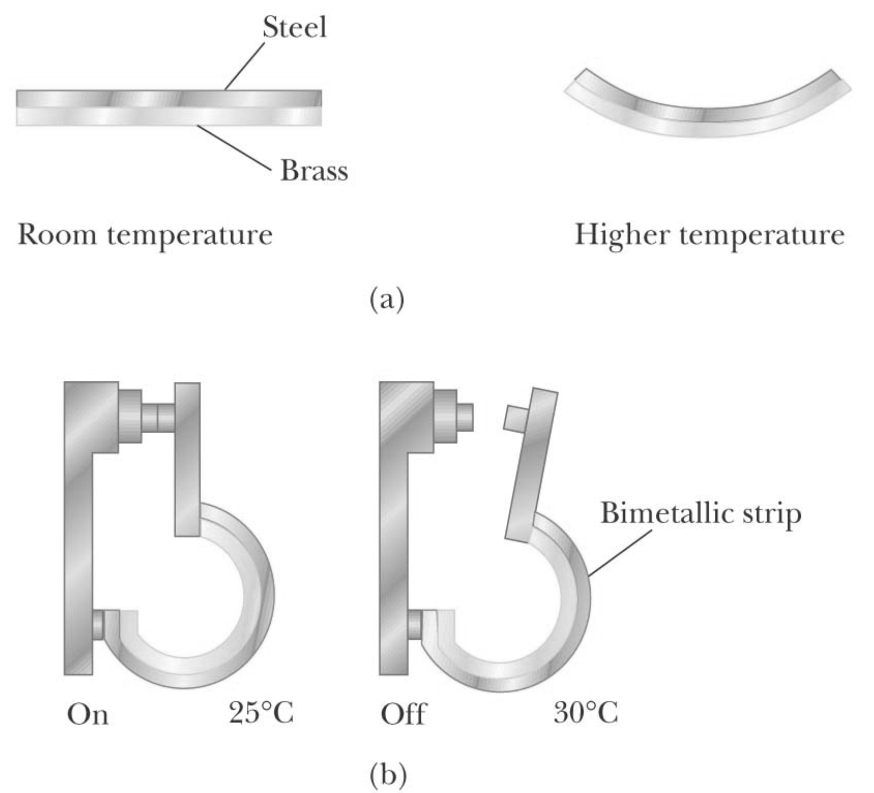
Thermal Expansion, Example

- In many situations, joints are used to allow room for thermal expansion
- The long, vertical joint is filled with a soft material that allows the wall to expand and contract as the temperature of the bricks changes



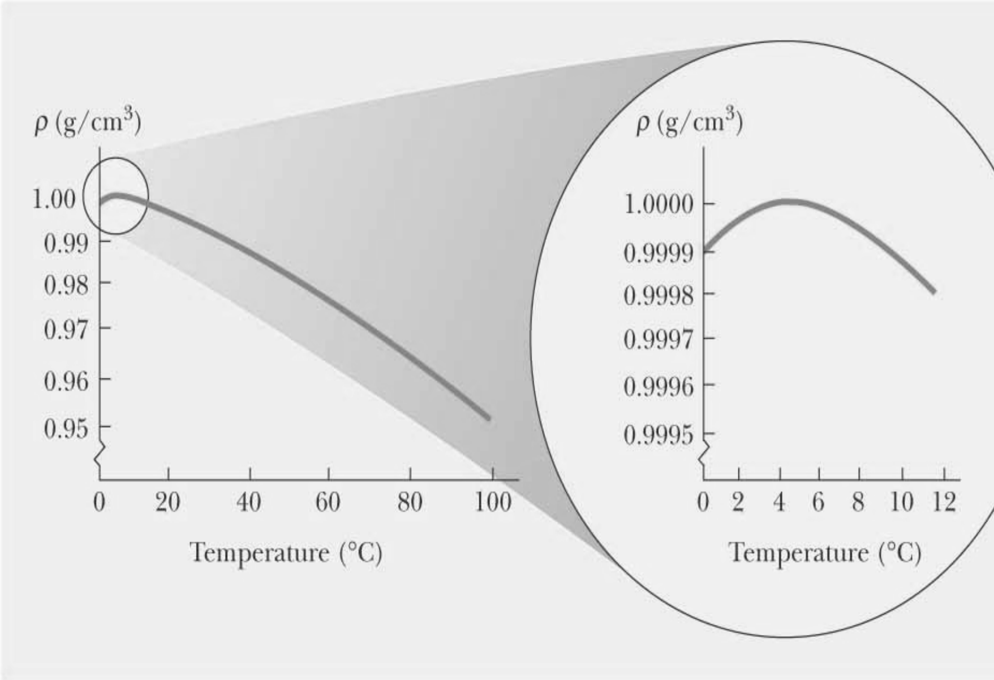
Bimetallic Strip

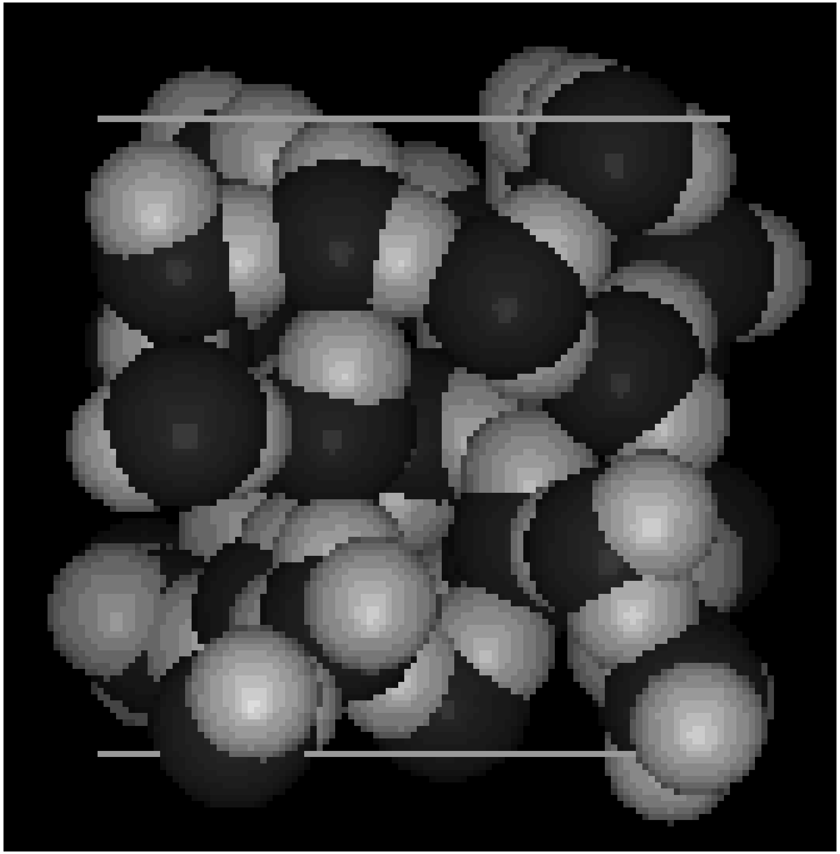
- Each substance has its own characteristic average coefficient of expansion
- This can be made use of in the device shown, called a bimetallic strip
- It can be used in a thermostat



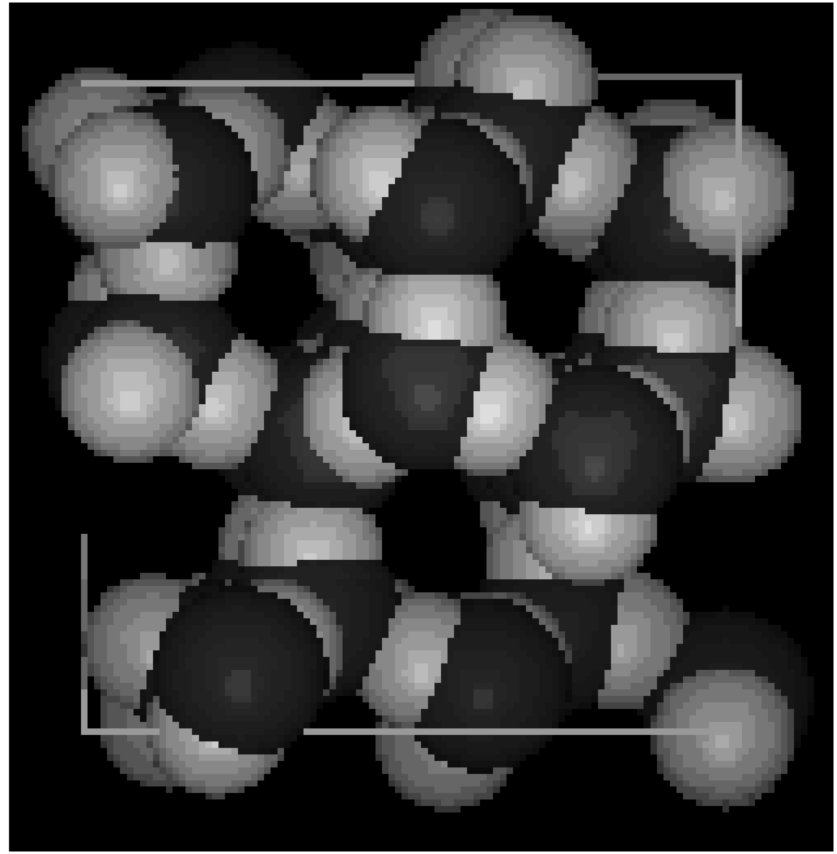
Water's Unusual Behavior

- As the temperature increases from 0ºC to 4ºC, water contracts
  - Its density increases
- Above 4ºC, water expands with increasing temperature
  - Its density decreases
- The maximum density of water (1.000 g/cm^3) occurs at 4ºC





Water



Ice