Solid Expansion

OBJECTIVES

- Explain the expansion of solids in terms of molecular vibration
- Introduce linear expansion and define linear expansivity
- Obtain the relationship
- Introduce area expansion and define area expansivity
- Obtain the relationship
- Introduce volume expansion and define volume expansivity
- Obtain the relationship
- Explain apparent expansion and real expansion of liquid

- show that real expansion = apparent expansion + expansion of the container

- Derive the relationship
- Explain the anomalous expansion of water with the aid of a graph of volume vs. temperature for a fixed mass of water.
- Present the graph density of water vs. temperature.
- Explain that maximum density of water exists at 40C where its volume is minimum.
- Discuss the uses of expansion of solids and liquids

What is the relationship between temperature and kinetic energy? * Why do molecules move faster when they are heated?

- What happens to molecules when they are heated?

They move./vibrate

- What makes molecules move?

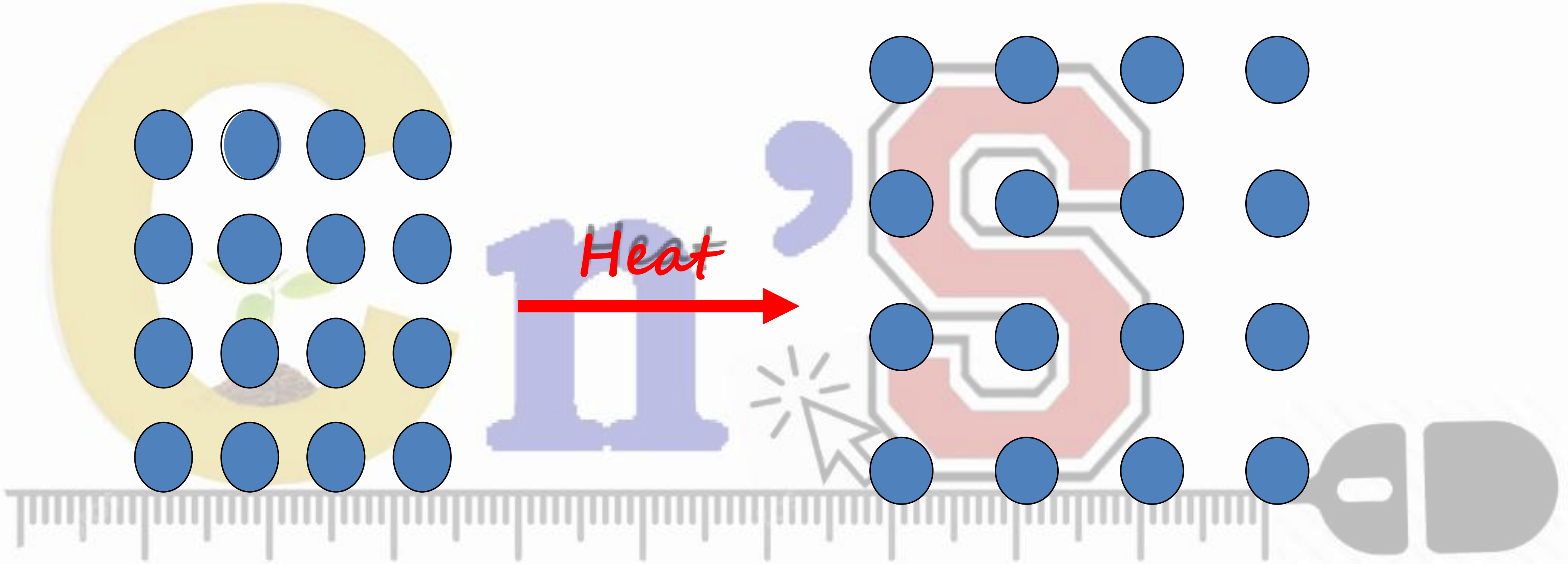
Energy (HEAT) makes molecules move

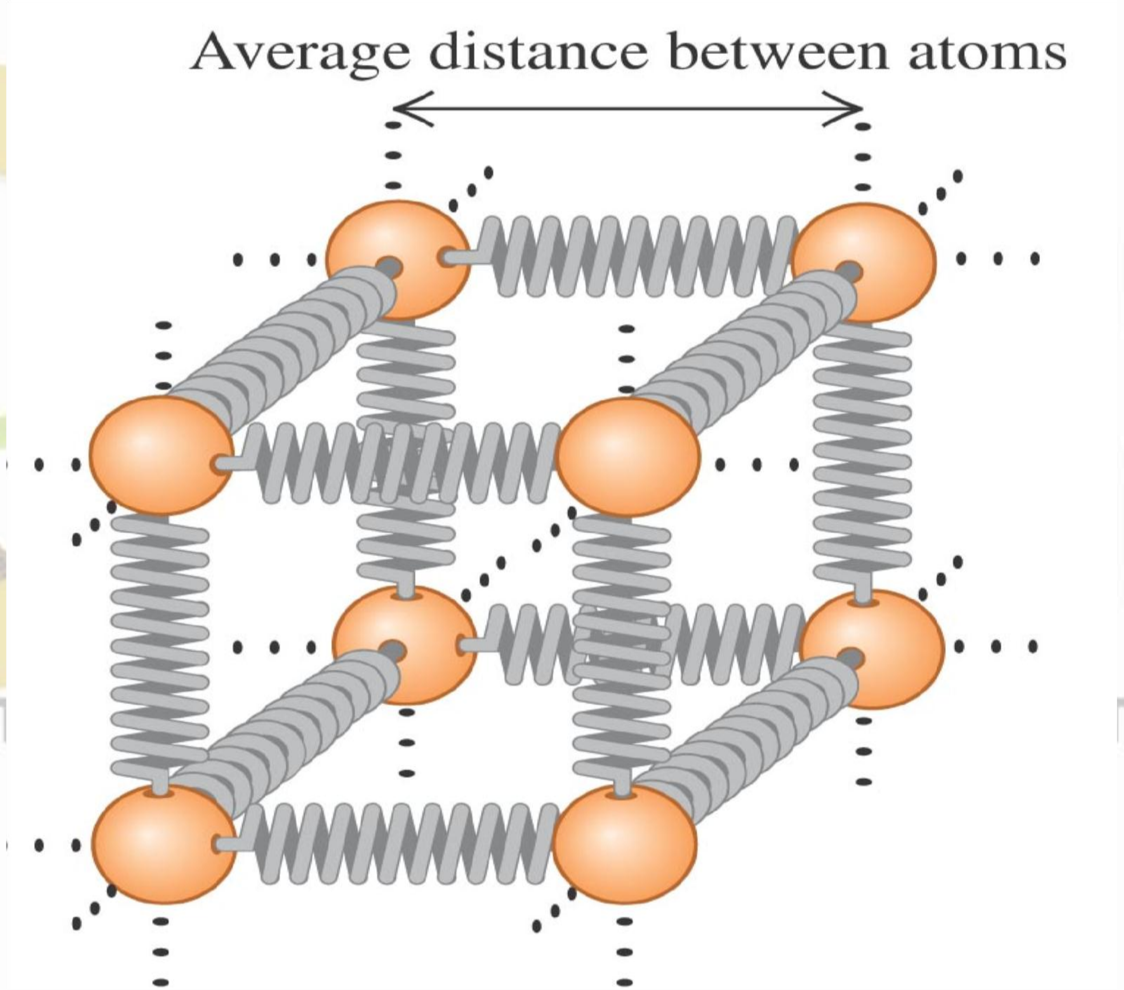
- What happens when molecules move apart?

The material expands.

more energy = expansion

less energy = contraction


Heat


Average distance between atoms

- Why do objects expand when they are heated?
- Why do objects contract when they cool down?

- Heat is energy. More energy makes molecules move more. When molecules move, they spread out, which makes the object expand.
- When objects cool down, they lose energy, which makes molecules slow down. When molecules move less, they get close together, which makes the object contract.

Thermal Expansion

- The thermal expansion of an object is a consequence of the change in the average separation between its constituent atoms or molecules
- At ordinary temperatures, molecules vibrate with a small amplitude
- As temperature increases, the amplitude increases
  - This causes the overall object as a whole to expand

How does a change in temperature affect the dimensions of a system?

FACTORS AFFECTING LINEAR EXPANSION

1. TEMPERATURE

- Higher change in temperature, the higher the expansion
- ΔT for the symbol

2. KIND OF MATERIAL (α)

- Quantified by a constant value for coefficient of thermal expansion for some materials
- The higher the coefficient, the higher the expansion

3. ORIGINAL DIMENSION

- Greater original dimension, greater the expansion.

Linear Expansion

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T$$

Change in dimension

Coefficient of expansion

Original length

Change in temperature

Linear expansion

$$\frac{\Delta L}{L_0} = \alpha \Delta T$$

This is the fractional change in length, which is a natural quantity to use. Since one would expect a 4m rod to expand twice as much as a 2m rod, the fractional change would be the same.

Different substances expand by different amounts. An experimental expansion coefficient is necessary to quantify expansion.

The change in temperature determines the fractional change in length. One would expect that a 2°C change in temperature would lead to twice as much expansion as a 1°C change. This relationship shows that.

Linear Expansion

$$\Delta L = \alpha L_0 \Delta T$$

$$L - L_0 = \alpha L_0 \Delta T$$

$$L = L_0 \left[1 + \alpha \Delta T \right]$$

Linear expansion

$$\frac{\Delta L}{L_0} = \alpha \Delta T$$

Table 17.1 Coefficients of Linear Expansion

Material	α [K^{-1} or $(C°)^{-1}$]
Aluminum	2.4×10^{-5}
Brass	2.0×10^{-5}
Copper	1.7×10^{-5}
Glass	$0.4\text{–}0.9 \times 10^{-5}$
Invar (nickel–iron alloy)	0.09×10^{-5}
Quartz (fused)	0.04×10^{-5}
Steel	1.2×10^{-5}

Applications of Thermal Expansion

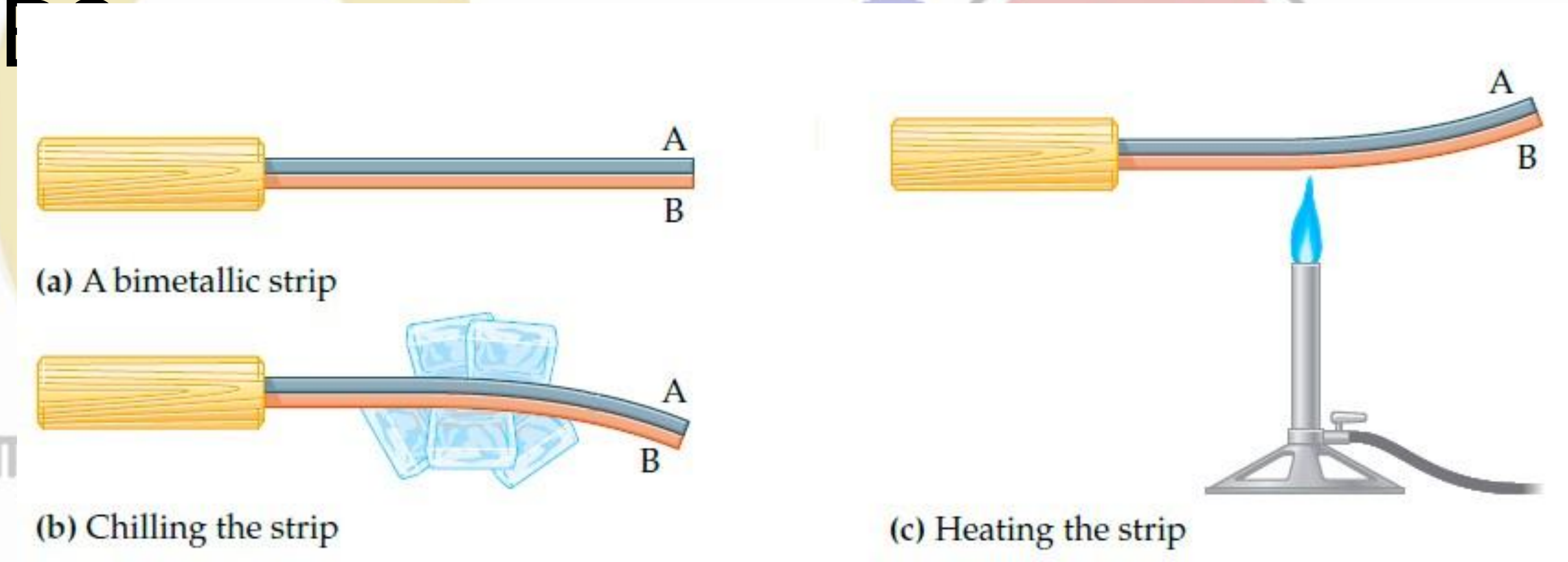
- Thermometers
  - In thermometers, thermal expansion is used in temperature measurements.
- Removing tight lids
  - To open the cap of a bottle that is tight enough, immerse in it hot water for a minute or so. Metal cap expands and becomes loose. It would now be easy to turn it to open.
- Riveting
  - To join steel plates tightly together, red hot rivets are forced through holes in the plates. The end of hot rivets is then hammered. On cooling, the rivets contract and bring the plates tightly gripped.
- Fixing metal tires on wooden wheels
  - Iron rims are fixed on wooden wheels of carts. Iron rims are heated. Thermal expansion allows them to slip over the wooden wheel. Water is poured on it to cool. The rim contracts and becomes tight over the wheel.

- The transmission cable are not tightly fixed to the poles.
- Pendulum of wall clock and balance wheel of wrist watch are made of invar (an alloy which have very low value of coefficient of expansion).
- Test tubes, beakers and crucibles are made of pyrex-glass or silica because they have very low value of coefficient of linear expansion.

Question

When a bimetallic strip is heated and cooled, it behaves as in the following diagram. Which substance has the larger coefficient of expansion?

A or B?

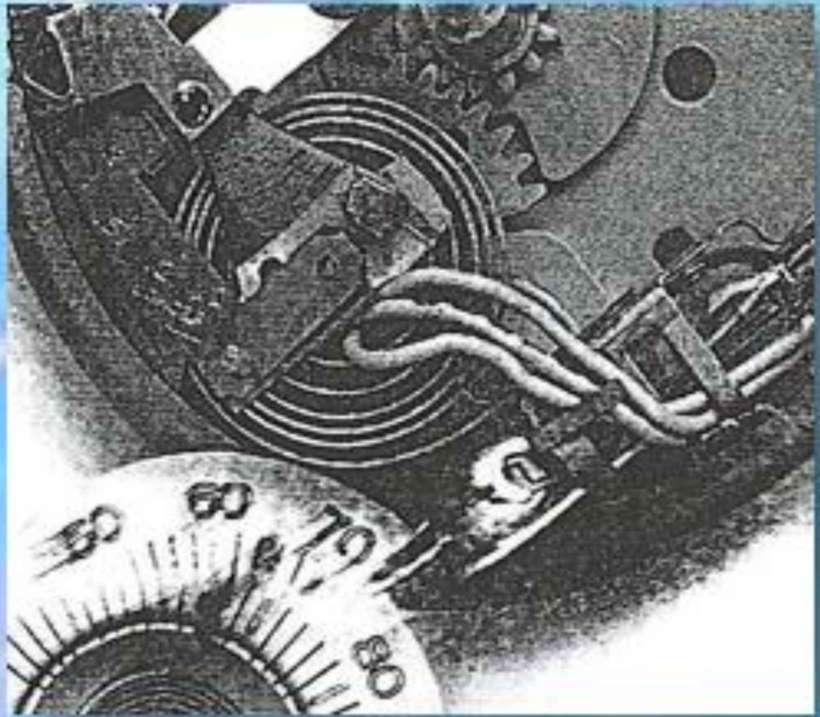


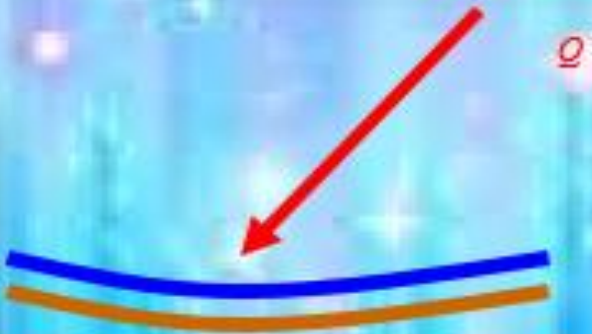
Bimetallic Strip

- A bimetal strip consists of two thin strips of different metals such as brass and iron joined together. On heating the strip, brass expands more than iron. This unequal expansion causes bending of the strip.
- bimetal strips are used for various purposes. Bimetal thermometers are used to the measure temperature especially in furnaces and ovens. Bimetal strips are used in thermostats. Bimetal thermostat is used to control the temperature of heater coil in an electric iron.
- Thermostats
  Use a bimetallic strip
  Two metals expand differently
  Since they have different coefficients of expansion
  Thermostat is a heat regulating device which work on the principle of thermal expansion.

Two strips of different metals welded together at one temperature become more or less curved at other temperatures because the metals have different values for their coefficient of linear expansion □.

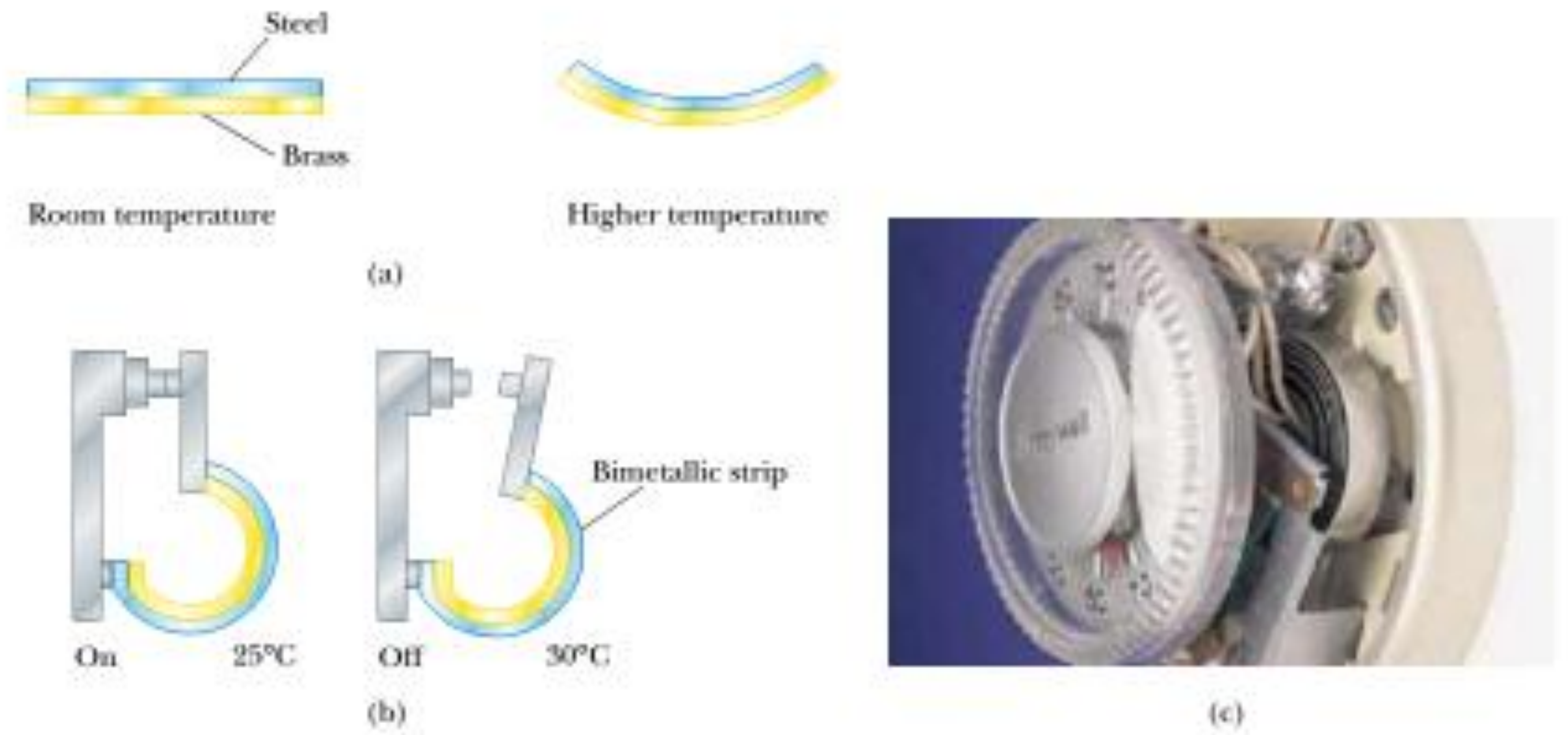
They are often used as thermometers and thermostats





Applications of Thermal Expansion

Bridges are built with ‘joints’ so they don’t crack when the temperature changes.



There is a space left between the two rail tracks so they can expand freely and fill the space

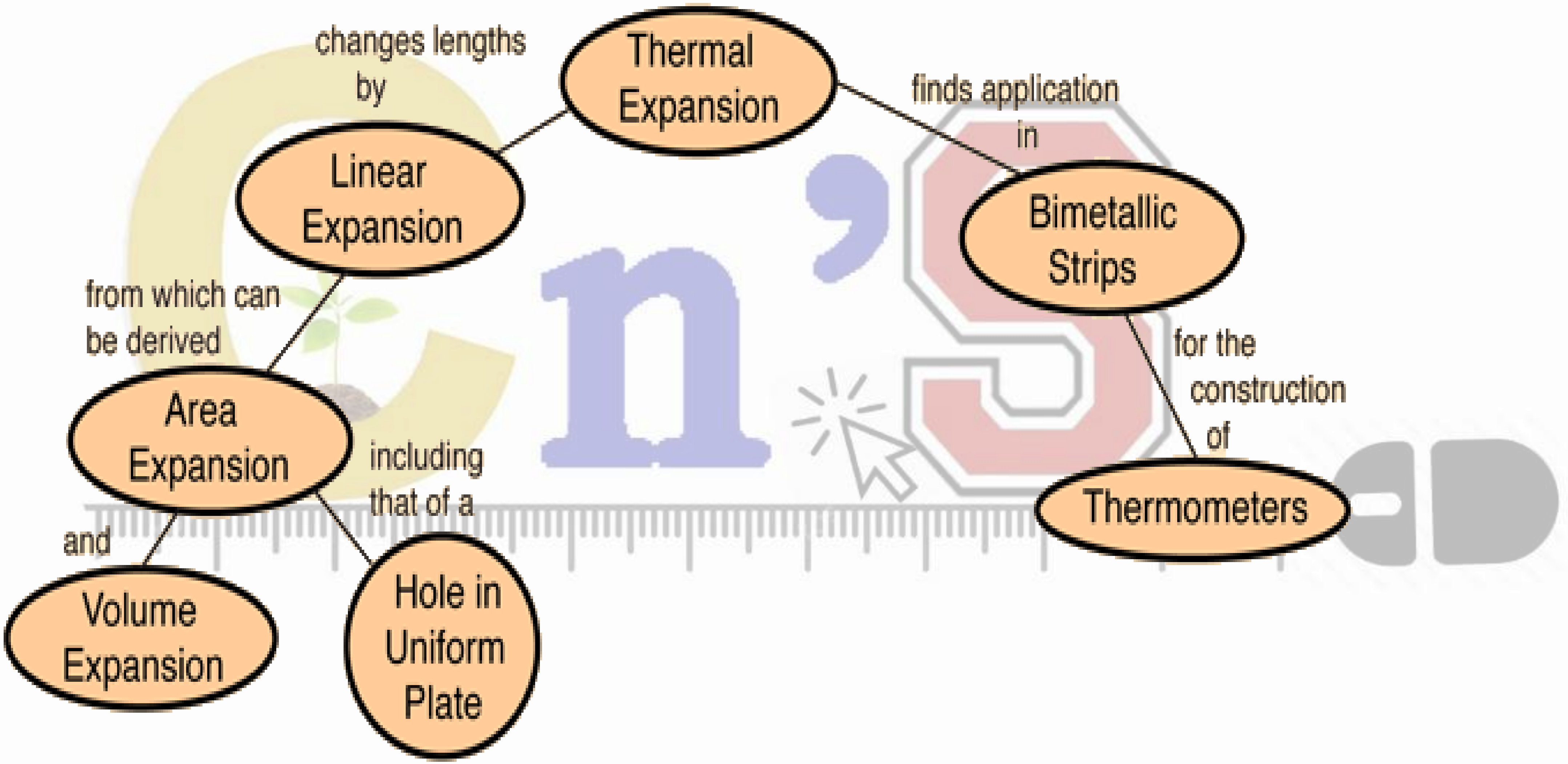
The iron railings which are present on the road of the over bridge the gap is present so as they can expand freely in hot weather

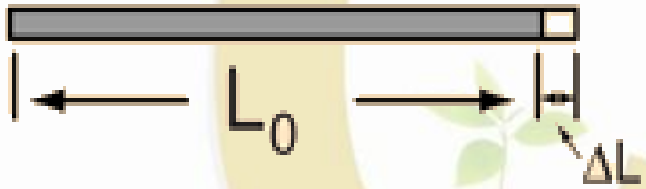
BECAUSE STEEL HAS A RELATIVELY HIGH COEFICIENT OF

THERMALEXPANSION, STANDARD RAILROAD TRACKS ARE CONSTRUCTED SO THAT THEY CAN SAFELY EXPAND ON A HOT DAY WITHOUT DERAILING THE TRAINS TRAVELING

OVER THEM

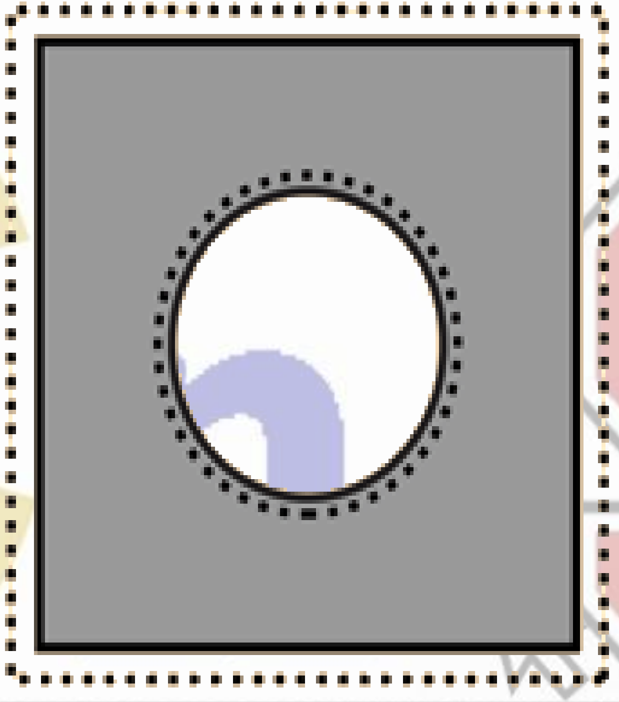
Expansion Concepts





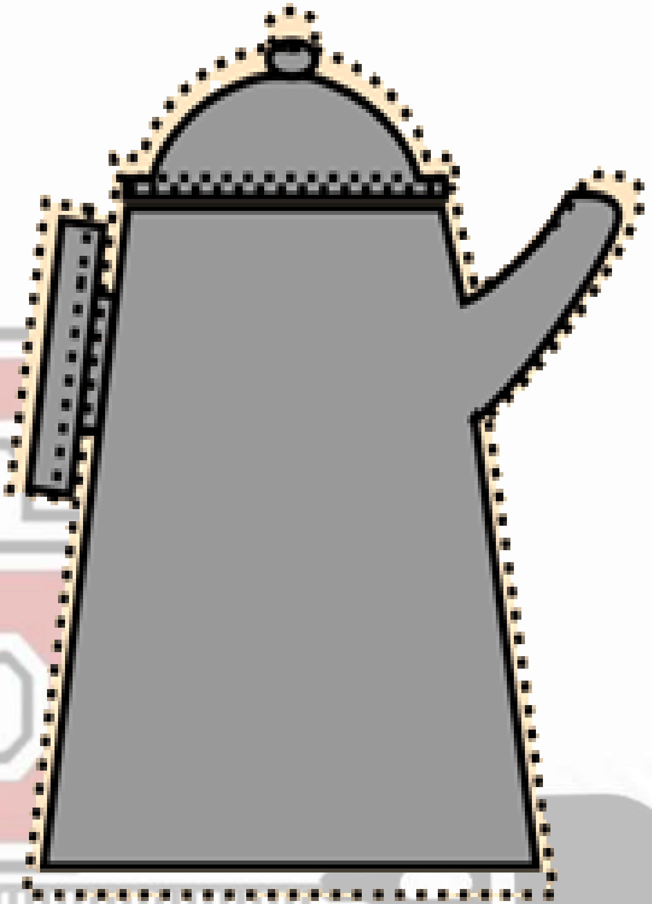
Linear expansion

$$\frac{\Delta L}{L_0} = \alpha \Delta T$$



Area expansion

$$\frac{\Delta A}{A_0} = 2\alpha \Delta T$$

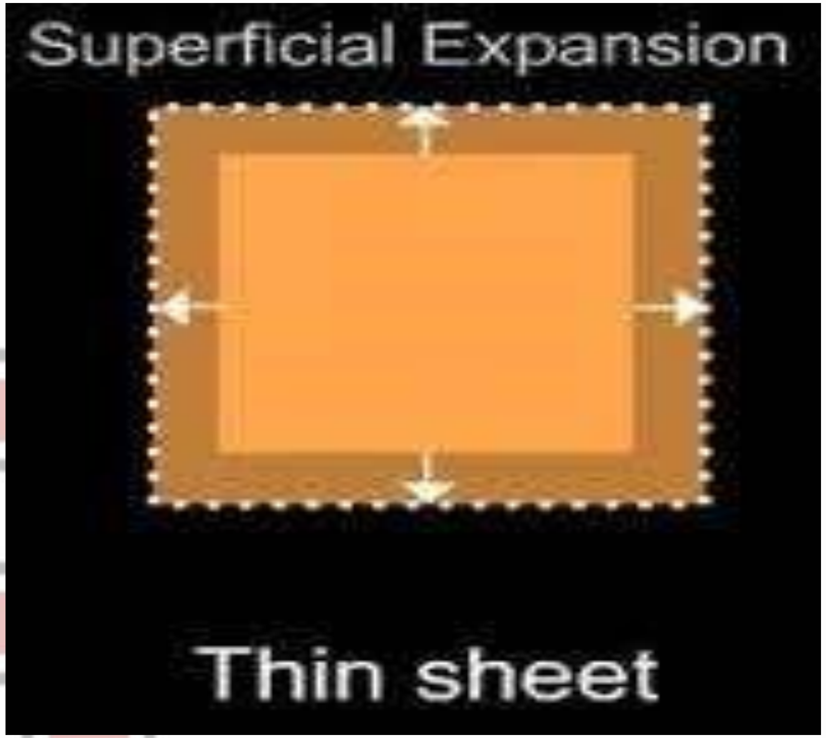


Volume expansion

$$\frac{\Delta V}{V_0} = 3\alpha \Delta T$$

Superficial Expansion

: Increase in area on heating is called superficial expansion.A_0-Is the original area .



Area expansion

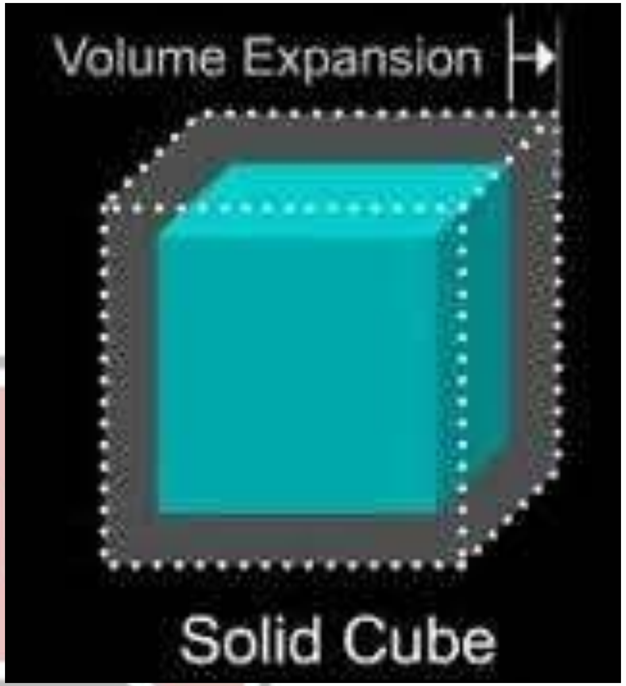
$$\frac{\Delta A}{A_0} = 2\alpha\Delta T$$

ΔA- Is the change in the area.

Δ t = change in temperature.

α = coefficient of superficial expansion.

Cubical Expansion



$$\Delta V = \beta V_0 \Delta T$$

$$for\ solids, \beta = 3\alpha$$

Volume expansion

$$\frac{\Delta V}{V_0} = 3\alpha\Delta T$$

Increase in volume on heating is called cubical expansion.

V_0 = real volume. ΔV=change in volume.

Δt = change in temperature.

α = coefficient of cubical expansion.

Expansion of a railroad Track

(a) A steel railroad track has a length of 30.000 m when the temperature is 0°C. What is its length on a hot day when the temperature is 40.0°C? (The coefficient of linear expansion =11 x 10-6 C-1)   Ans=   L =30.013 m

Q1

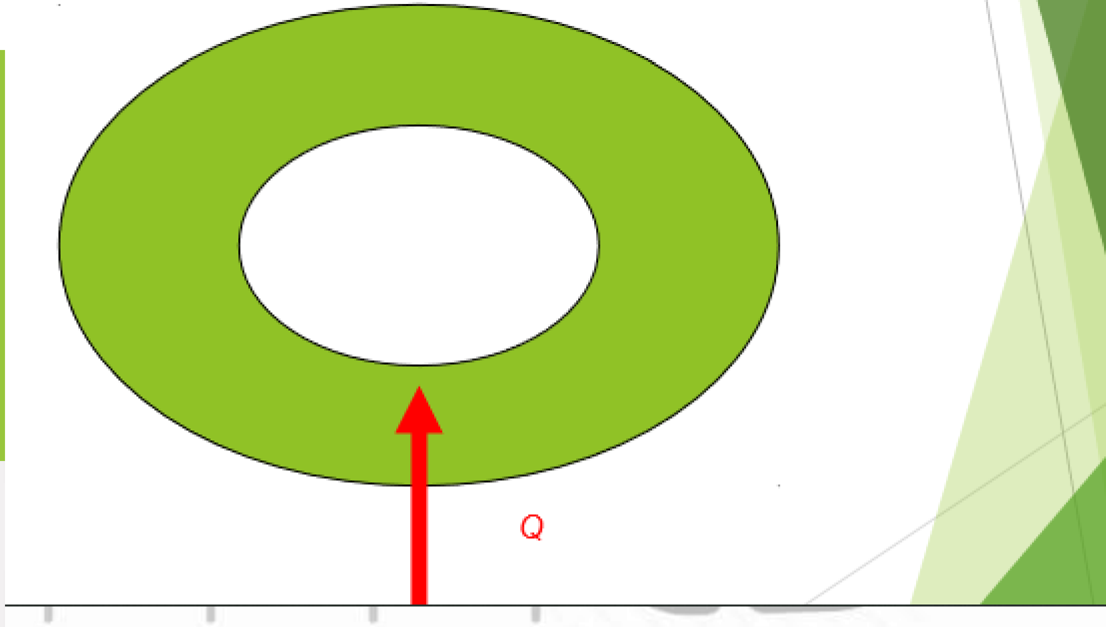
A nut is very tight on a screw. Which of the following is most likely to free it?

(a) Cooling the nut
(b) Heating the nut
(c) Heating the screw
(d) None of these

Q2

A iron disc with a hole in it is heated.

Will the diameter of the hole (a) increase, (b) decrease or (c) not change?



- Circle Expansion
- The coefficient of linear expansion of aluminum is 23 x 10-6/C°. A circular hole in an aluminum plate is 2.725 cm in diameter at 0°C. What is the diameter of the hole if the temperature of the plate is raised to 100°C? (2.731 cm)

1.Calculate the increase in length of brass rod, which measures 220 cm at 10 °C, such that it is heated to 950 °C. [α for brass = 0.000018 /°C]. Also calculate the overall length at 950° C ?

sol: Given L_0 =220 m, $\alpha = 0.000018$ /°C and $t = 950 - 10 = 940$ °C

Increase in length $(L_t - L_0) = L_0 \times \alpha \times t$

$= 220 \times 0.000018 \times 940$

$= 3.72$ cm

$\therefore$ Length at 950 °C $= 220 + 3.72$

$= 223.72$ cm

2. A brass rod 2 m long, when heated through 80 °C, increases in length by 3.2 mm. Calculate the coefficient of linear expansion for brass?

Sol: Given, original length=2 m.

Rise in temperature=80 °C

Increase in length=3.2 mm = 3.2×10^{-3} m.

- α=increase in length/original length × rise in temperature

  =$(3.2 \times 10^{-3})/(2 \times 80)$ =0.00002 per °C.

- The steel bed (12 x 10^{-6} □C^{-1}) of a suspension bridge is 200 m long at 20 □C.

- If the temperature goes from -30 □C to +20 □C, what contraction and expansion is possible?

➢ First in winter,

DL = (12 x 10^{-6} □C^{-1})(200 m)(-50 □C)

DL = -0.12 m

➢ Then in summer,

DL = (12 x 10^{-6} □C^{-1})(200 m)(20 □C)

DL = 0.048 m

A surveyor uses a steel measuring tape that is exactly 50.000 m at a temperature of 20 ºC. What is the length on a hot summer day when the temperature is 35 ºC?

$$\alpha_{steel} = 1.2 \times 10^{-5}\ K^{-1}$$

Given:

$L_0 = 50.000\ \text{m}$

$\Delta T = 15\ ^{o}\text{C}$

$\alpha = 1.2 \times 10^{-5}\ \text{K}^{-1}$

Solution:

$\Delta L = L_0\, \alpha\, \Delta T$

$\Delta L = 50.000m(1.2 \times 10^{-5}\ \text{K}^{-1})(15\ ^{o}\text{C})$

$= 50.009\ \text{m}$

Gas Tank

- A 72 L steel gas tank is open and filled to the top with gasoline, $b = 950 \times 10^{-6}$ □C^{-1}, at 18 □C. The car sits in the sun and reaches a temperature of 32 □C.

- How much gasoline overflows from the tank?

➢The gasoline expands with temperature. Solve for $DV = bV_0\ DT$.

Solution:

$DV = (950 \times 10^{-6}\ □C^{-1})(72\ L)(14\ □C)$

$DV = 0.96\ L$

You get more gas if you fill it when it's cool!

Question

You have enough money to buy 10 L of petrol. When should you buy it?

2 pm

2 am

Problem

A surveyor uses a steel measuring tape that is exactly 50.000 m at a temperature of 20 °C.

a) What is the length on a hot summer day when the temperature is 35 °C? ($\alpha_{steel} = 1.2\times10^{-5}\ K^{-1}$)

b) On this day, when the tape reads 35.794 m, what is the true distance?

Problem

A petrol tanker loads 40,000 L of fuel in Darwin and drives it to Sydney, where the temperature is 25° lower. How many litres of petrol does he deliver? $\beta_{petrol} = 9.5\times10^{-4}\ K^{-1}$ and $\alpha_{steel} = 1.2\times10^{-5}\ K^{-1}$

Example 12.3 Buckling of a sidewalk

A concrete sidewalk is constructed between two buildings on a day when the temperature is 25°C. The sidewalk consists of two slabs, each three meters in length and of negligible thickness. As the temperature rises to 38 °C, the slabs expand, but no space is provided for thermal expansion. The buildings do not move, so the slabs

Determine

the vertical distance y in part b of

the drawing.