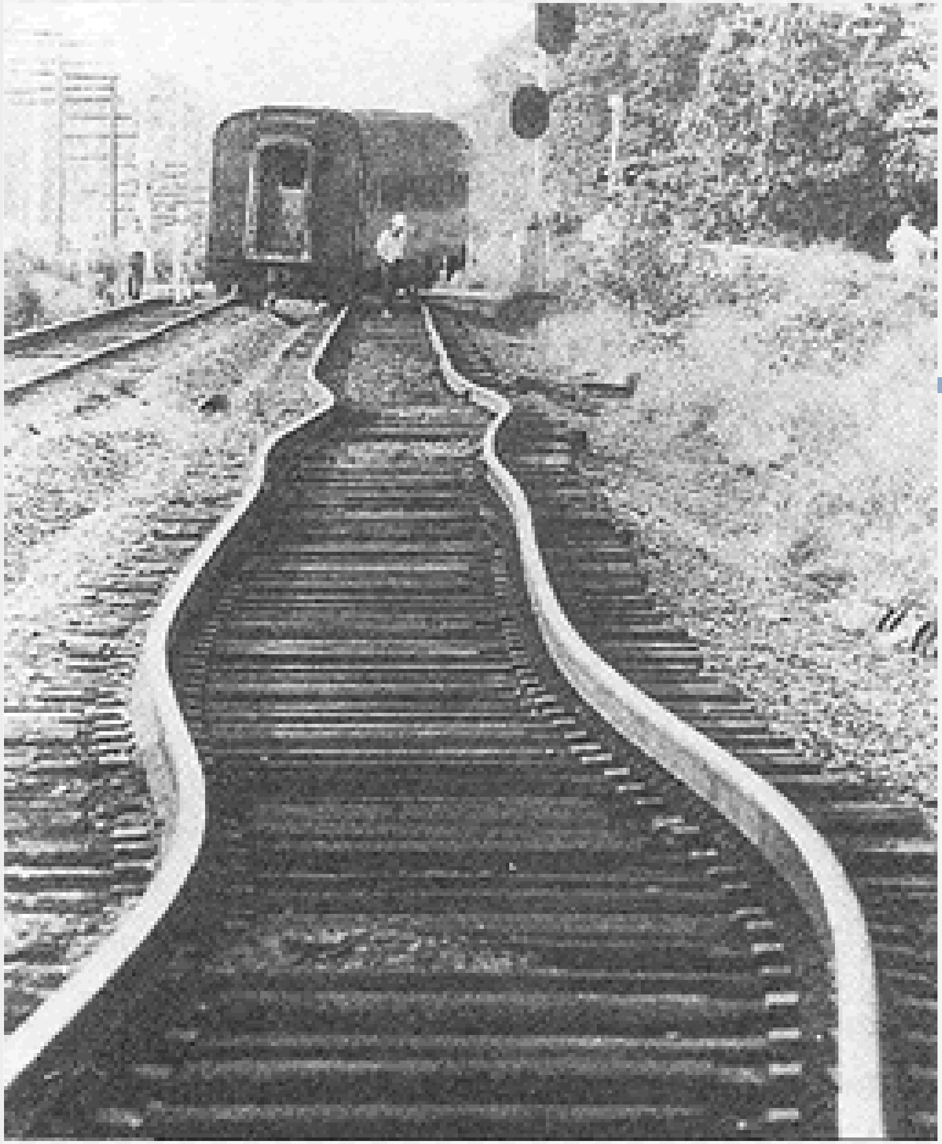
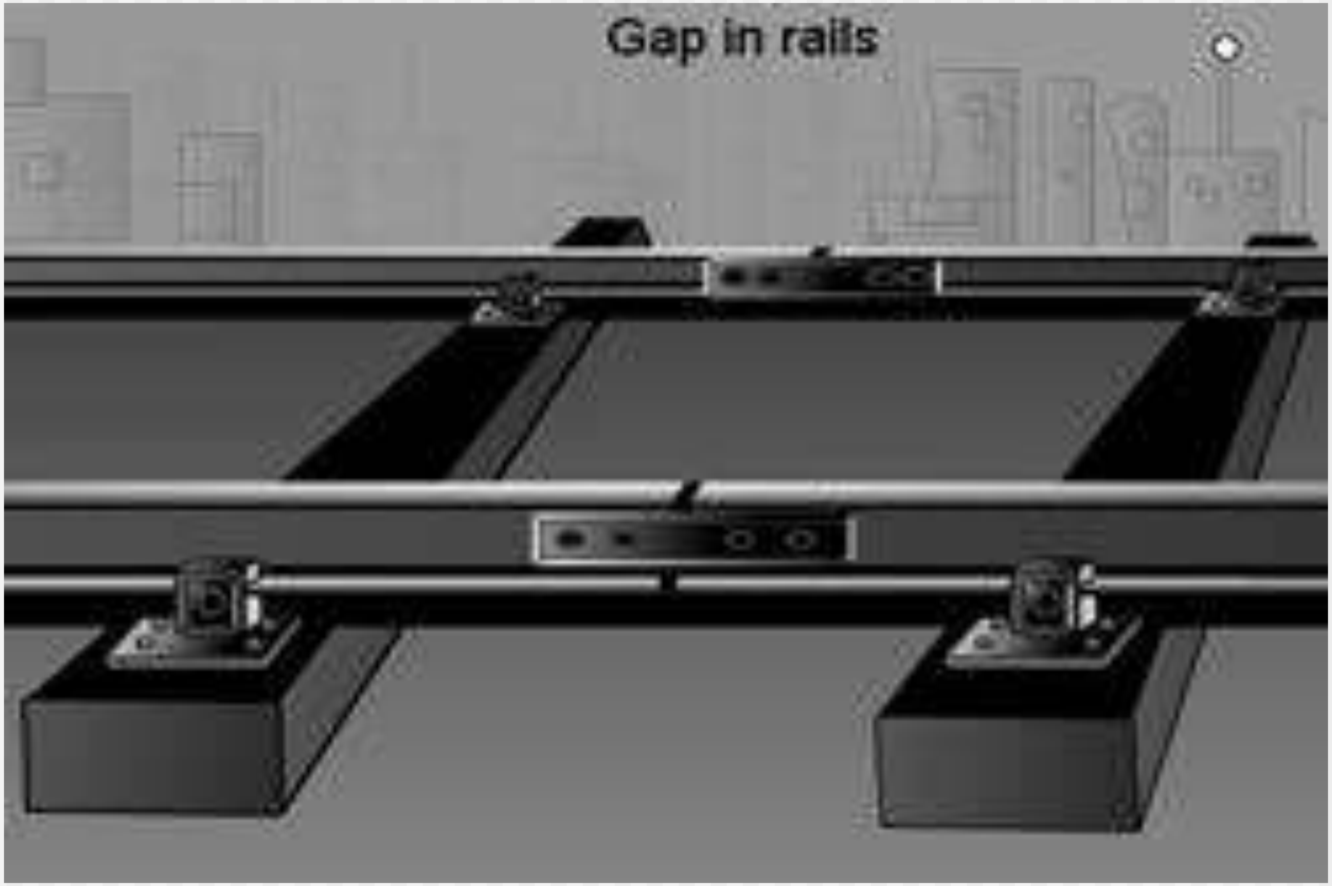
Physics: Section 12.5
Linear Expansion / Volumetric Expansion

Thermal Expansion

- Most solids and liquids expand when heated and contract when cooled.
- In most solids and liquids, when temperature rises, their molecules vibrate more and have more kinetic energy.
- At these higher levels of vibration, the particles aren't bound to each other as tightly, so the object expands.




Gap in rails

Thermal Expansion

- The amount an object expands can be calculated for both one-dimensional (linear) and three-dimensional (volumetric) expansion.
- The amount a material expands is characterized by the material's coefficient of expansion. Each substance has a constant for which describes its ability to expand.
- Linear constants are denoted by the Greek letter alpha(α)
- Volumetric constants are denoted by the Greek letter beta (β)

Thermal Expansion

Linear Expansion

Amount of linear expansion (ΔL) depends on the following:

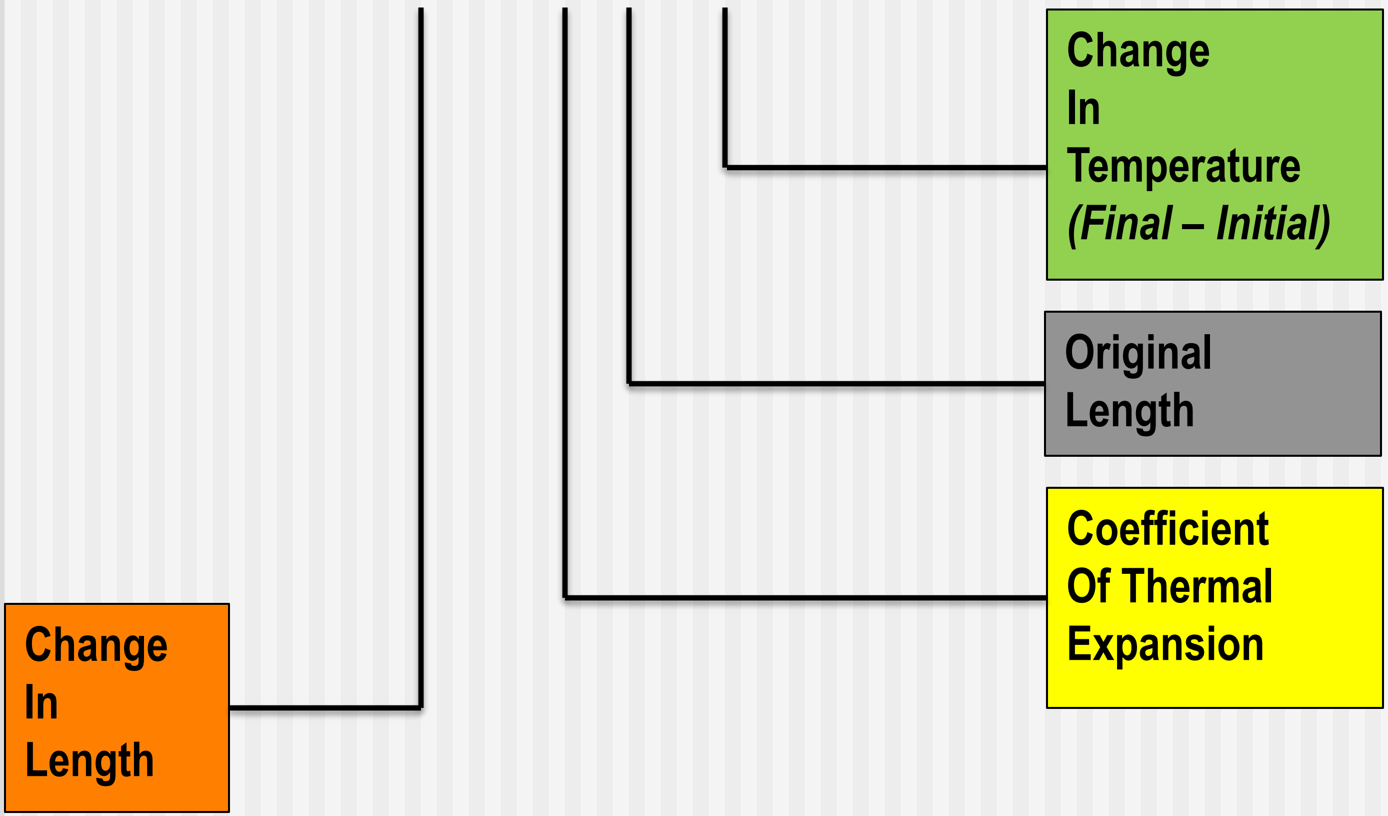
1. ΔT ($T_{final} - T_{initial}$) : Change in temperature (ºC)
2. L_i : Original length
3. α (alpha) : Coefficient of thermal expansion

Units for Coefficient of Thermal Expansion

α units: 1/ºC

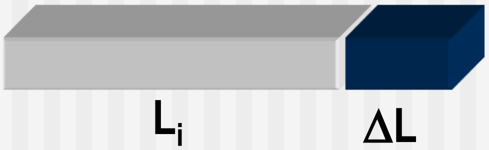
Linear Expansion Formula

$$\Delta L = \alpha L_i \Delta T$$



Linear Expansion Formula

$$\Delta L = \alpha L_i \Delta T$$



Linear Expansion - FYI

- Alpha (α) is material dependent, i.e. it’s different for steel, aluminum, concrete, etc.
- Since the coefficient of linear expansion is different for different materials, therefore each substance has its own rate of expansion.
- Reference Sheet

Linear Expansion Example #1

A Brass strip is 3 cm long at 0ºC. How long will it be at 100ºC if the coefficient of linear expansion for Brass is 1.8 x 10^{-5}/ºC?

$\Delta L = (\alpha)(L_i)(\Delta t)$

$\Delta L = (1.8 \times 10^{-5}/^{o}C)(3\ cm)(100^{o}C - 0^{o}C)$

$\Delta L = 0.0054\ cm$

$L_f = \Delta L + L_i$

$L_f = 0.0054\ cm + 3\ cm$

$L_f = 3.0054\ cm$

Linear Expansion Example #2

Metric rulers are calibrated at 20ºC. What is the error in a measurement of 500 mm if made at 45ºC. (α = 1.2 x 10^{-5}/ºC)

$\Delta L = (\alpha)(L_i)(\Delta t)$
ΔL = (1.2 x 10^{-5}/ºC)(500 m)(45ºC - 20ºC)
ΔL = 0.15 mm

Linear Expansion Example #3

A glass jar ($\alpha = 0.3 \times 10^{-5}/^{o}C$) has a metal lid ($\alpha = 1.6 \times 10^{-5}/^{o}C$) which is stuck. If you heat them by placing them in hot water, the lid will be:

(A) Easier to open

(B) Harder to open

(C) Same

Linear Expansion Example #4

A brass rod is 0.70 m long at 40ºC. Find the length of this rod at 50ºC.

Linear Expansion Example #5

Compute the increase in length of 50 m of copper wire when its temperature changes from 12 to 32ºC.

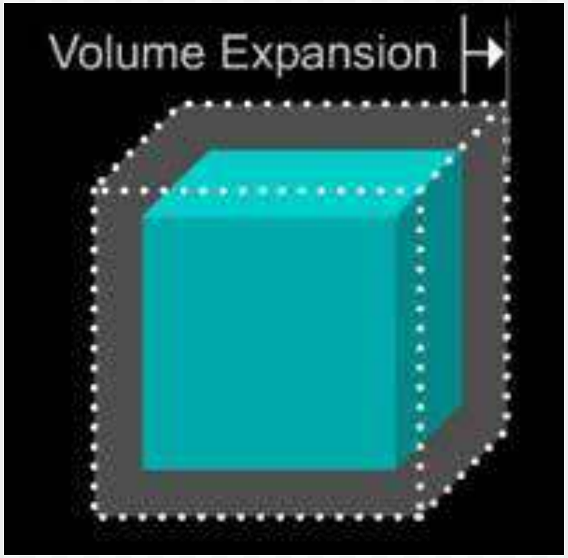
Linear Expansion Example #6

The diameter of a hole drilled though a piece of brass is 1.5 cm at 20.0ºC. What is the diameter at 15.0ºC?

J.S. Miller Video – Thermal Expansion

http://www.youtube.com/watch?v=fZaAqRS6uOM

Volumetric Expansion



Volumetric Expansion

Volumetric Expansion

Amount of volume expansion (ΔV) depends on the following:

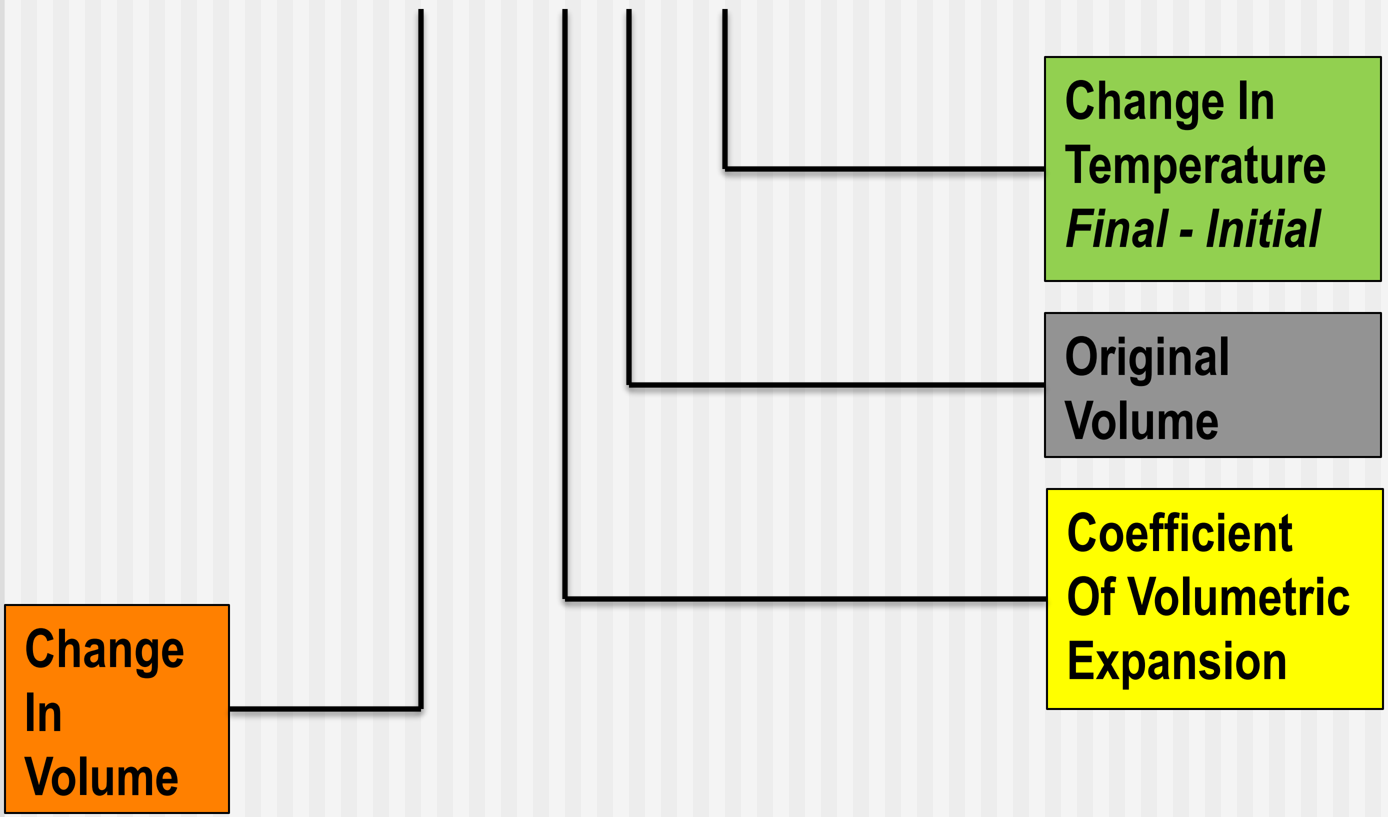
1. ΔT ($T_{final} - T_{initial}$) : Change in temperature (ºC)
2. V_i : Original volume
3. Beta (β): Coefficient of volumetric expansion

Units for Coefficient of Volumetric Expansion:

β units: 1/ºC

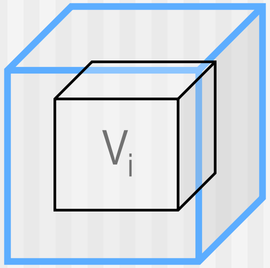
Volumetric Expansion Formula

$$\Delta V = \beta V_i \Delta T$$



Volumetric Expansion Formula

$$\Delta V = \beta V_i \Delta T$$



$V_i + \Delta V$

Volumetric Thermal Expansion Example #1

The coefficient of volumetric expansion of mercury is 1.8×10^{-4} /ºC. If the temperature of 10 L of mercury increases by 30 ºC, how much volume will the mercury increase by?

$\Delta V = (\beta)(V_i)(\Delta t)$

$\Delta V = (1.8 \times 10^{-4})(10\ L)(30\ ^\circ C)$

$\Delta V = 0.054\ L$

Volumetric Thermal Expansion Example #2

Suppose that the gas tank in your car is completely filled when the temperature is 17ºC. How many gallons will spill out of the 20 gallon steel tank when the temperature rises to 35ºC?

$\beta_{gas} = 9.5 \times 10^{-4} /^{\circ}C$

$\beta_{steel} = 0.36 \times 10^{-4} /^{\circ}C$

Volumetric Thermal Expansion Example #2

We need to find the difference from the expansion of the gas and the expansion of the steel:

$\Delta V_{gas} = (\beta)(V_i)(\Delta t)$
$\Delta V_{gas} = (9.5 \times 10^{-4}/^{o}C)(20\ gal)(18^{o}C)$
$\Delta V_{gas} = 0.342\ gallons$

$\Delta V_{steel} = (\beta)(V_i)(\Delta t)$
$\Delta V_{steel} = (0.36 \times 10^{-4}/^{o}C)(20\ gal)(18^{o}C)$
$\Delta V_{steel} = 0.01296\ gallons$

$\Delta V_{final} = \Delta v_{gas} - \Delta V_{steel}$
$\Delta V_{final} = 0.342\ gal – 0.01296\ gal$
$\Delta V_{final} = 0.32904\ gal$

Volumetric Thermal Expansion Example #3

The hot water heating system of a building contains 60.0 ft^3 of water in steel pipes. How much water will overflow into the expansion tank if the system is filled at 40ºC and then is heated to 80ºC?

(β_{steel} = 0.36 x 10^{-4} /ºC)

Volumetric Thermal Expansion Example #3:

We need to find the difference from the expansion of the water and the expansion of the steel:

$\Delta V_{water} = (\beta)(V_i)(\Delta t)$
$\Delta V_{water} = (2.1 \times 10^{-4}/^{o}C)(60\ ft^3)(40^{\circ}\ C)$
$\Delta V_{water} = 0.504\ ft^3$

$\Delta V_{steel} = (\beta)(V_i)(\Delta t)$
$\Delta V_{steel} = (0.36 \times 10^{-4}/^{o}C)(60\ ft^3)(40^{o}C)$
$\Delta V_{steel} = 0.0864\ ft^3$

$\Delta V_{final} = \Delta v_{water} - \Delta V_{steel}$
$\Delta V_{final} = 0.504\ ft^3 – 0.0864\ ft^3$
$\Delta V_{final} = 0.4176\ ft^3$

Volumetric Thermal Expansion Example #4

A thermometer contains 0.50 cm^3 of alcohol at room temperature (20ºC) when Stanley takes it into the physics lab for an experiment. By how much does the volume of alcohol in the thermometer change after it sits in an 80ºC Pyrex glass beaker?

($\beta_{alcohol} = 11.2 \times 10^{-4}$/ºC)

Volumetric Thermal Expansion Example #4:

We need to find the difference from the expansion of the alcohol and the expansion of the glass:

$\Delta V_{alcohol} = (\beta)(V_i)(\Delta t)$
$\Delta V_{alcohol} = (11.2 \times 10^{-4}/^oC)(.50\ cm^3)(60^oC)$
$\Delta V_{alcohol} = 0.0336\ cm^3$

$\Delta V_{glass} = (\beta)(V_i)(\Delta t)$
$\Delta V_{glass} = (0.09 \times 10^{-4}/^oC)(.50\ cm^3)(60^oC)$
$\Delta V_{glass} = 0.00027\ cm^3$

$\Delta V_{final} = \Delta v_{alcohol} - \Delta V_{glass}$
$\Delta V_{final} = 0.0336\ cm^3 – 0.00027\ cm^3$
$\Delta V_{final} = 0.0333\ cm^3$

Volumetric Thermal Expansion Example #5

A Pyrex glass of water with volume 1 liter is completely filled at 5ºC. How much water will spill out of the Pyrex glass when the temperature is raised to 85ºC?

Volumetric Thermal Expansion Example #5:

We need to find the difference from the expansion of the water and the expansion of the glass:

$\Delta V_{water} = (\beta)(V_i)(\Delta t)$
$\Delta V_{water} = (2.1 \times 10^{-4}/^{o}C)(1\ L)(80^{o}C)$
$\Delta V_{water} = 0.0168\ L$

$\Delta V_{glass} = (\beta)(V_i)(\Delta t)$
$\Delta V_{glass} = (0.09 \times 10^{-4}/^{o}C)(1\ L)(80^{o}C)$
$\Delta V_{glass} = 0.00072\ L$

$\Delta V_{final} = \Delta v_{water} - \Delta V_{glass}$
$\Delta V_{final} = 0.0168\ L – 0.00072\ L$
$\Delta V_{final} = 0.01608\ L$