THERMAL EXPANSION

MOST MATERIALS - GASSES, LIQUIDS, SOLIDS expand when they are heated. The thermometer, of course, is based upon this principle and the need for devices to measure temperature lead to detailed studies:

CONSIDER <u>COOKING</u> - how could the Royal Chef make a proper souffle w/o regulating T

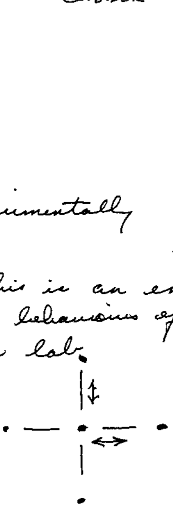
INDUSTRIAL PROCESSES - Annealing a proper Claymore . . .

etc

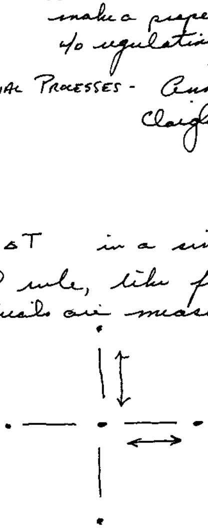
Experimentally

$\Delta L \propto \Delta T$ in a single dimension

This is an empirical rule, like friction, where the behaviours of materials are measured in the lab.



at low T atom vibrates a little around equilibrium



Higher T atom vibrates more, bonds are stretched, equilibrium positions are further apart.

In one dimension for object of length L_0

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

where α is the coefficient of linear expansion

Like friction, we do not have an exact theory of thermal expansion but we have a basic understanding of how it works:

At a given T (Energy) materials with weak interatomic bonds have greater vibration than objects w/ strong bonds

HIGH α	LOW α
WEAK BONDS	STRONG BONDS
LOW YOUNG'S MODULUS	HIGH YOUNG'S MODULUS
SOFT	HARD
LOW MELTING POINT	HIGH MELTING POINT
METALLIC BONDS	COVALENT BONDS

SIMILARLY

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

where $\beta \approx 3\alpha$ for isotropic solid

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

α: coeff't of linear expansion

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

β = T coeff't of volume expansion

MATERIAL	α	β
LEAD	29×10^{-6}	87×10^{-6}
IRON	9-12	36
STEEL	12	36
INVAR	1.5	2.7
ASPHALT		600
CONCRETE	10-14	36
GRANITE	8	
GLASS	9-12	26
PYREX	3	9
DIAMOND	1	
QUARTZ	0.5	1.2
CERAMIC GLASS	0.08×10^{-6}	
GASOLINE		950×10^{-6}
MERCURY		182
WATER		207

e.g. 1 GOLDEN GATE BRIDGE is 0.8 mi long on a typical day T= 72°F. How long on a hot day T= 100°F.

$\Delta T = 28°F$

$= \frac{5}{9}\, 28 = 15.6\,°C = 15.6\,K$

GG is built upon steel structure

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

$= 0.8\,mi\; 12\times10^{-6}\,K^{-1} \cdot 15.6$

$= 1.5\times10^{-4}\,mi$ (Expands by about $9\frac{1}{2}$")

In 1937 BB contracted by 4'5" ! on v. cold day

- Need expansion joints in sidewalks, bridges, etc.

- Run hot water on recalcitrant jar lid (n.b. α, β greater for tin than for glass

e.g. 2 Fill up your 10 gallon tank to the brim at 72F. Drive home 1 mile w/ fuel efficiency 25 miles per gallon use up 0.04 gal. Tank heats up to 100F ($\Delta T = 15.6K$)

$\Delta V = 950\times10^{-6} \cdot 15.6 \cdot 9.96$ GAL

$= 0.15$ gal

Oops !

We can see that:

$$\frac{dL}{dT} = \alpha L$$

$$V \sim L^3$$

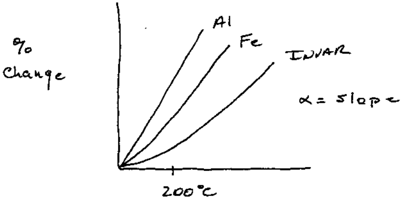
$$\frac{dV}{dT} = \frac{d}{dT}\left(L^3\right) = 3L^2\frac{dL}{dT}$$

$$= 3L^2 \alpha L$$

$$= 3\alpha L^3$$

$$= 3\alpha V$$

$\beta = 3\alpha$ for "well behaved" material n.b. This is idealized behaviour



α is not strictly constant for iron + esp. not for invar.

WATER has a maximum density at 4°C (minimum volume). H_2O molecules speeds decrease as T decreases for liquid, molecules get closer together, but as water freezes + crystallizes the regular crystalline with open spaces causes volume to increase

See Hecht fig 14.8