AIGMF celebrating International Women's Day 2025

Role of Science in Glass Manufacturing

By

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8th March, 2025

CSIR-Central Glass and Ceramic Research Institute
(Established in 1950)

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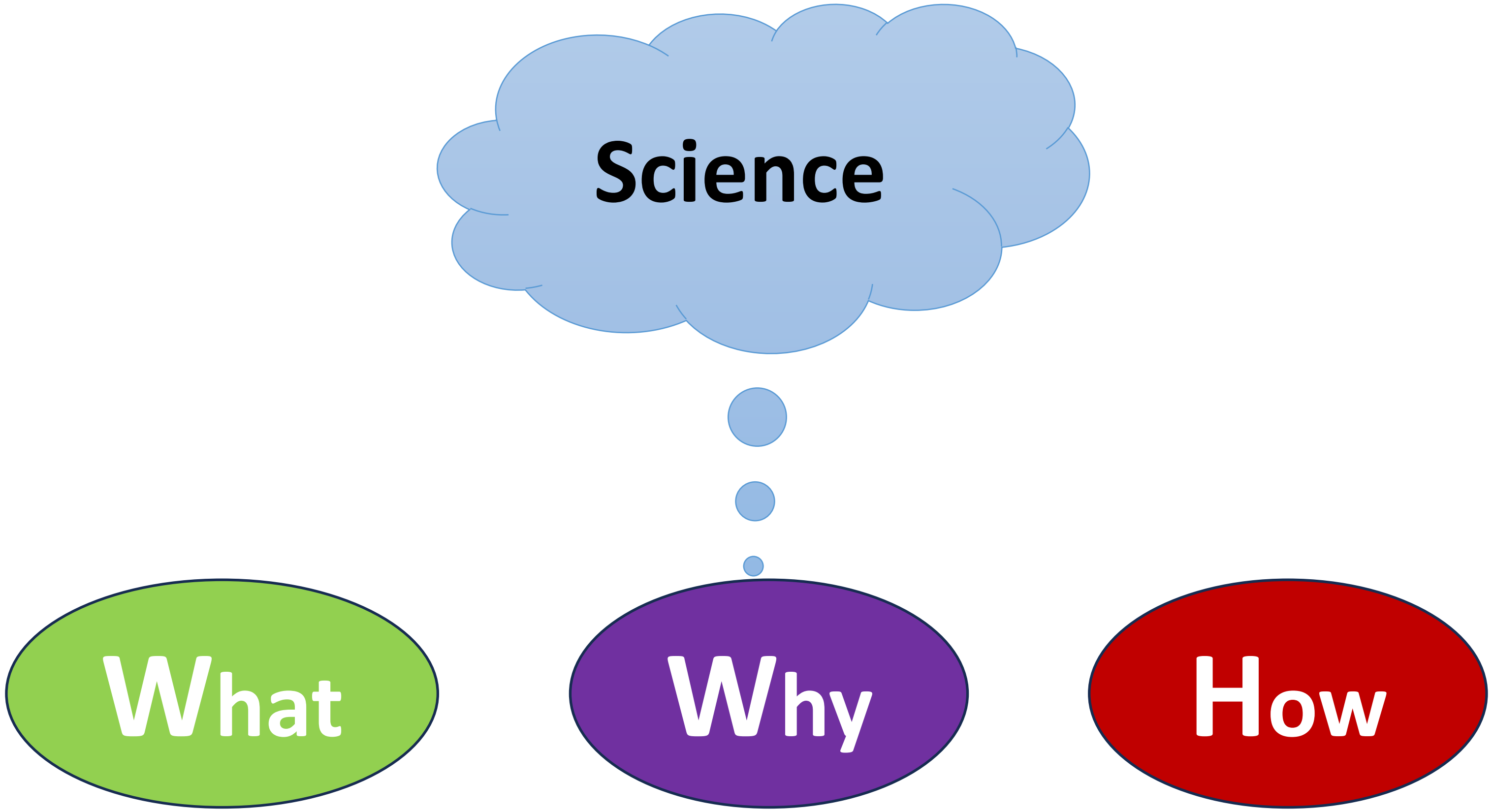
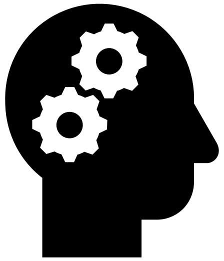
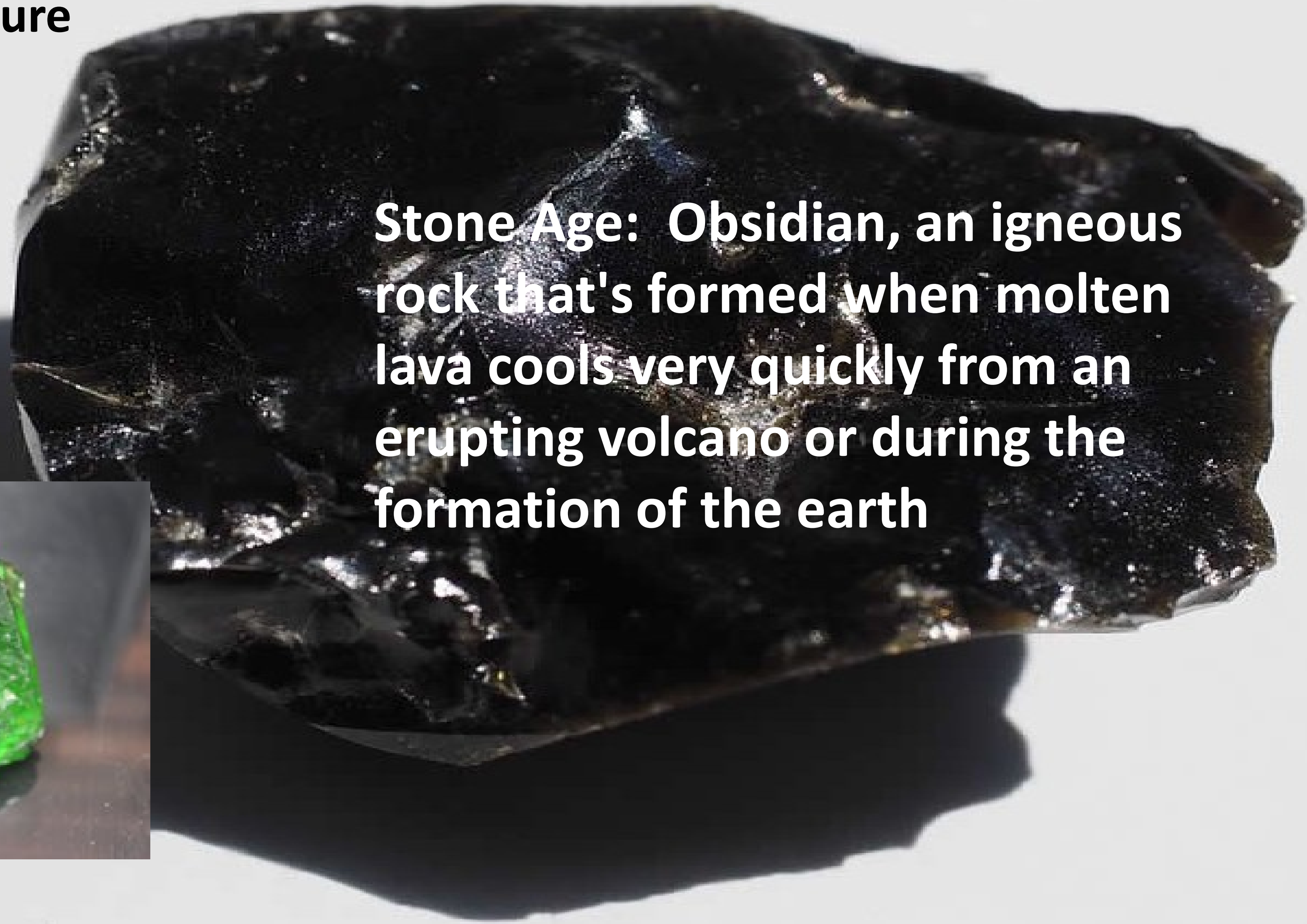


The Study of Nature



Glass: A Gift from Nature



Stone Age: Obsidian, an igneous rock that's formed when molten lava cools very quickly from an erupting volcano or during the formation of the earth

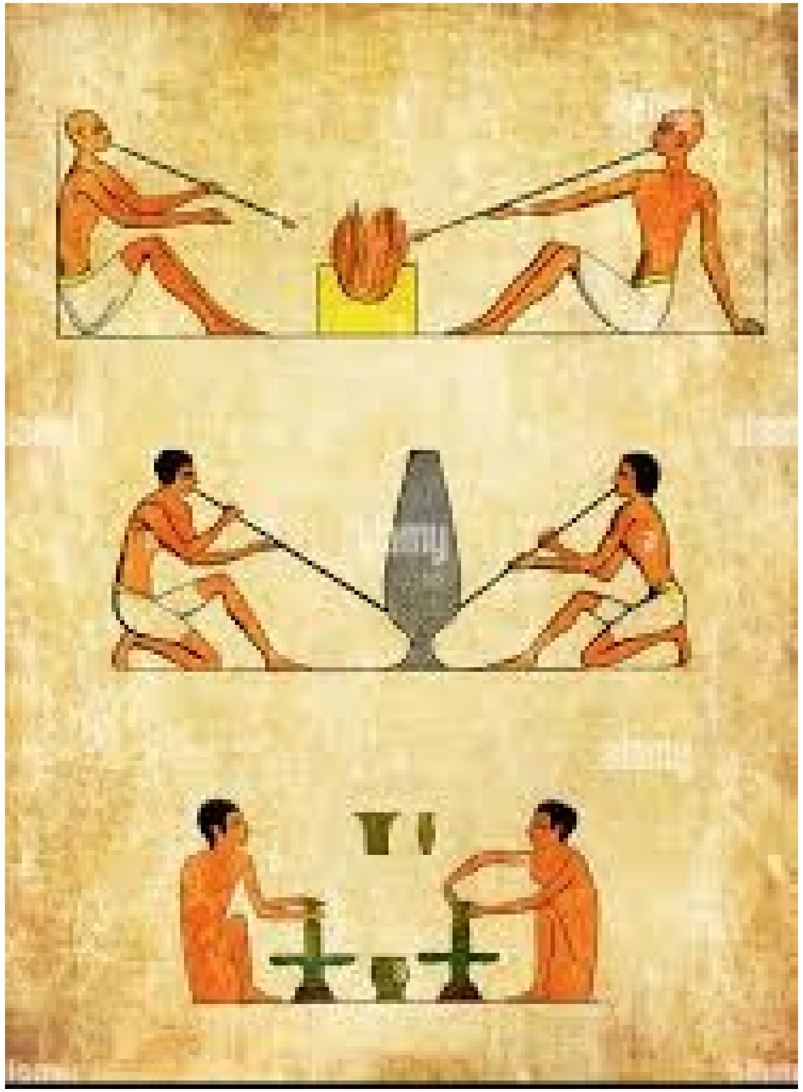
Natural glass on Earth: Meteorites and lightning. Glass that is made as a result of the collision of a meteorite with the Earth's surface is called meteoritic glass or tektite. Glass that is made as a result of a cloud-to-ground lightning discharge is called a fulgurite

Meteoritic glass : Libyan Desert Glass

Fulgurite

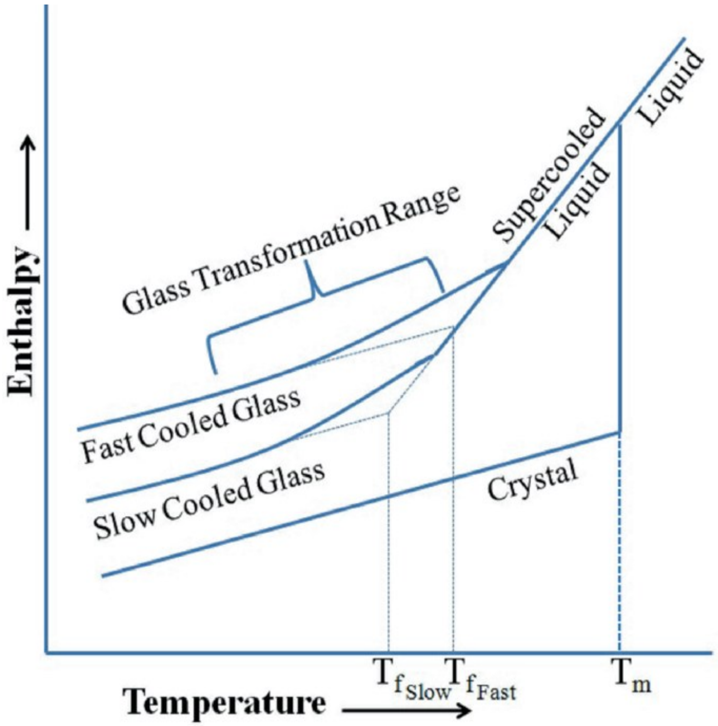
Sea Glass

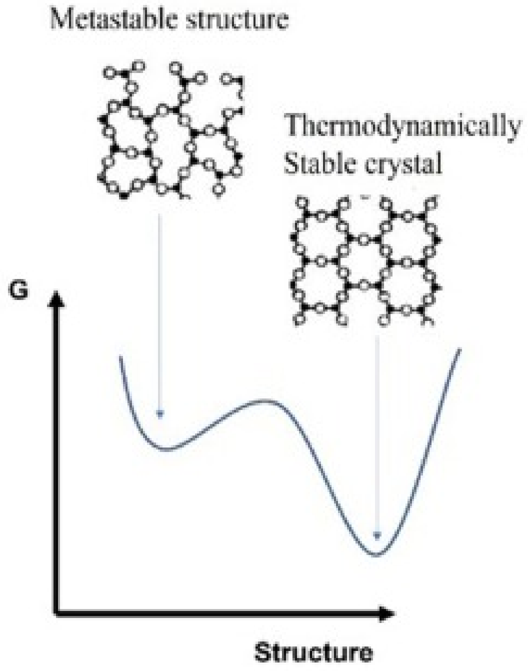
Glass making in the ancient age



How to reproduce Glass: The Science of Glass

Quenching of high temperature molten sand

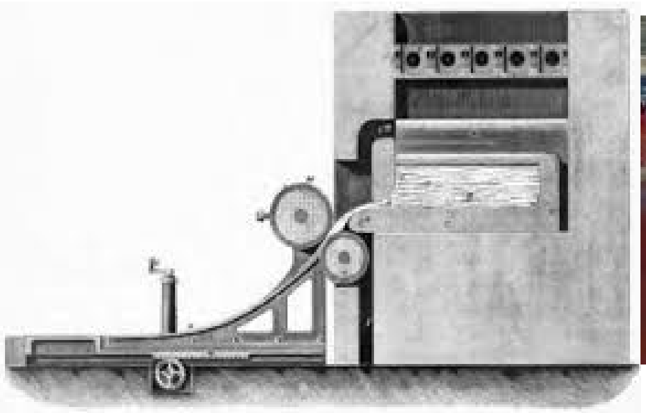


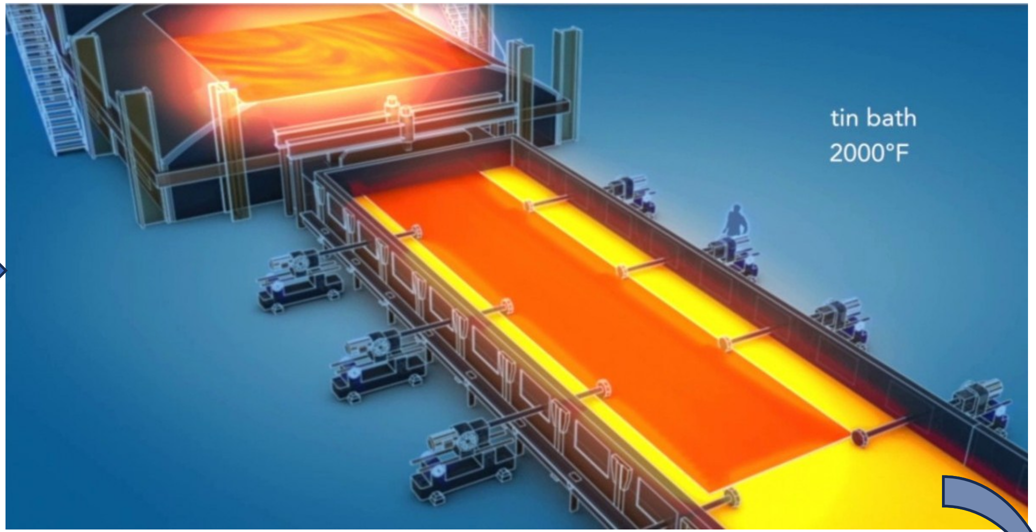


- ✓ Zachariasen theory of glass
- ✓ Dietzel model for glass
- ✓ Sun's theory of glass

Window glasses using old technologies

Development of Science → Development of technology





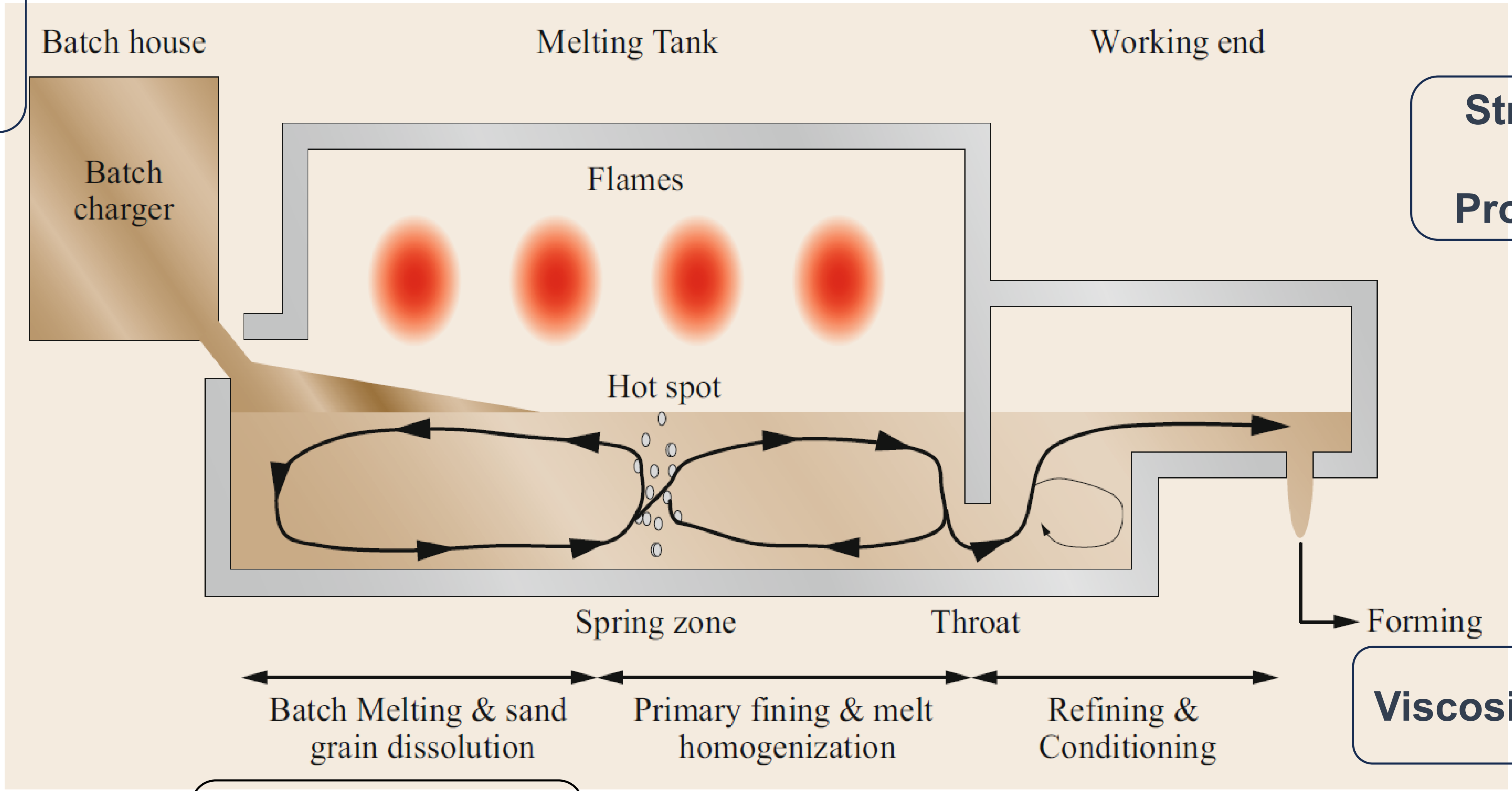
Glasses with non-uniform thickness and homogeneity

Highly uniform thickness and homogeneity, and ultra-transparency

Science behind Glass Manufacturing

Chemistry of raw materials

Structure and Properties



Viscosity

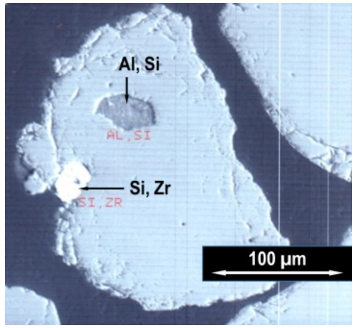
Thermodynamics and Energetics

Flow and fluid dynamics

Batch Calculation

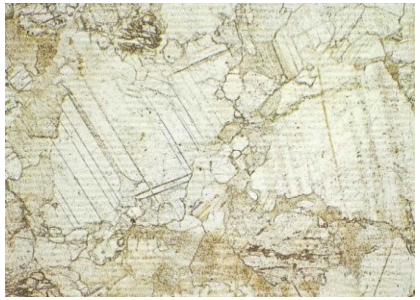
1. Chemical composition
   - ➢ To achieve desired properties
2. Selection of raw materials
   - ➢ Combination of a suitable glass former, modifier, and intermediate
   - ➢ Raw material melting point
   - ➢ Cationic field strength
   - ➢ Raw material purity and particle size
3. Selection of Eutectic composition
   - ➢ Best Glass forming ability (Obeying Zachariasen's and field strength rule)
   - ➢ Minimum melting temperature

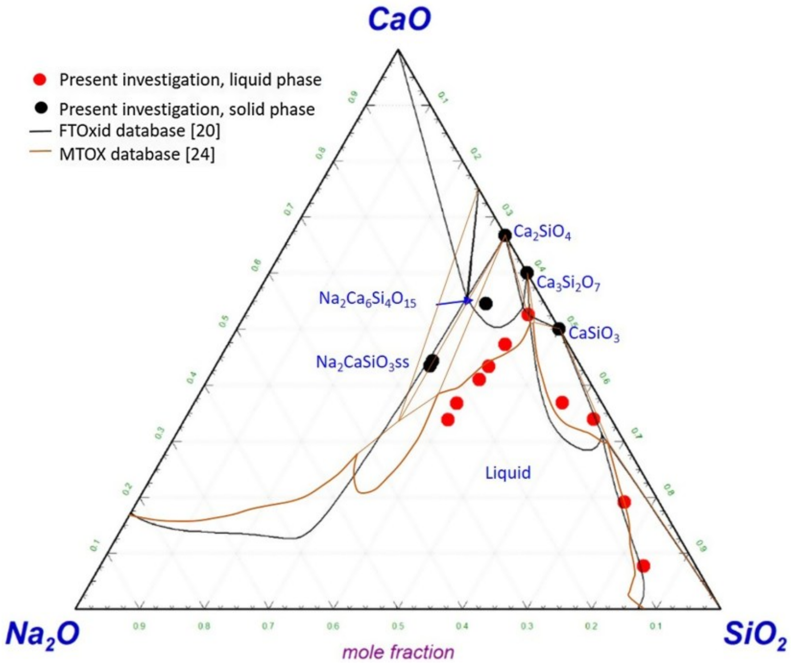
Sand

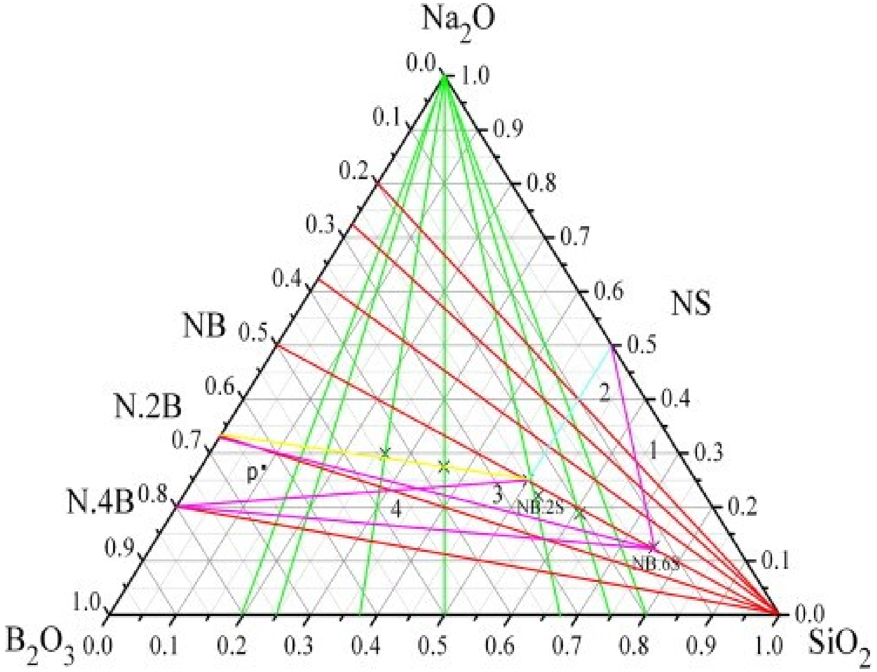


Soda Ash

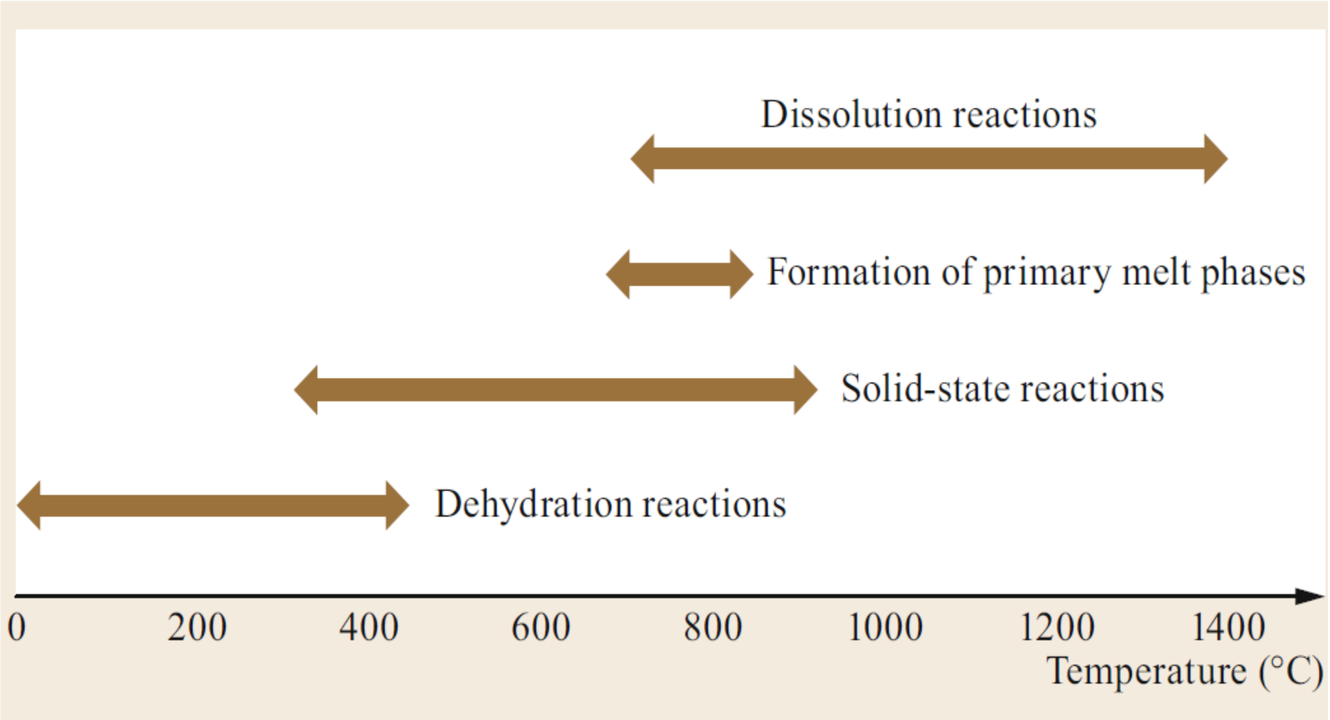
Limestone





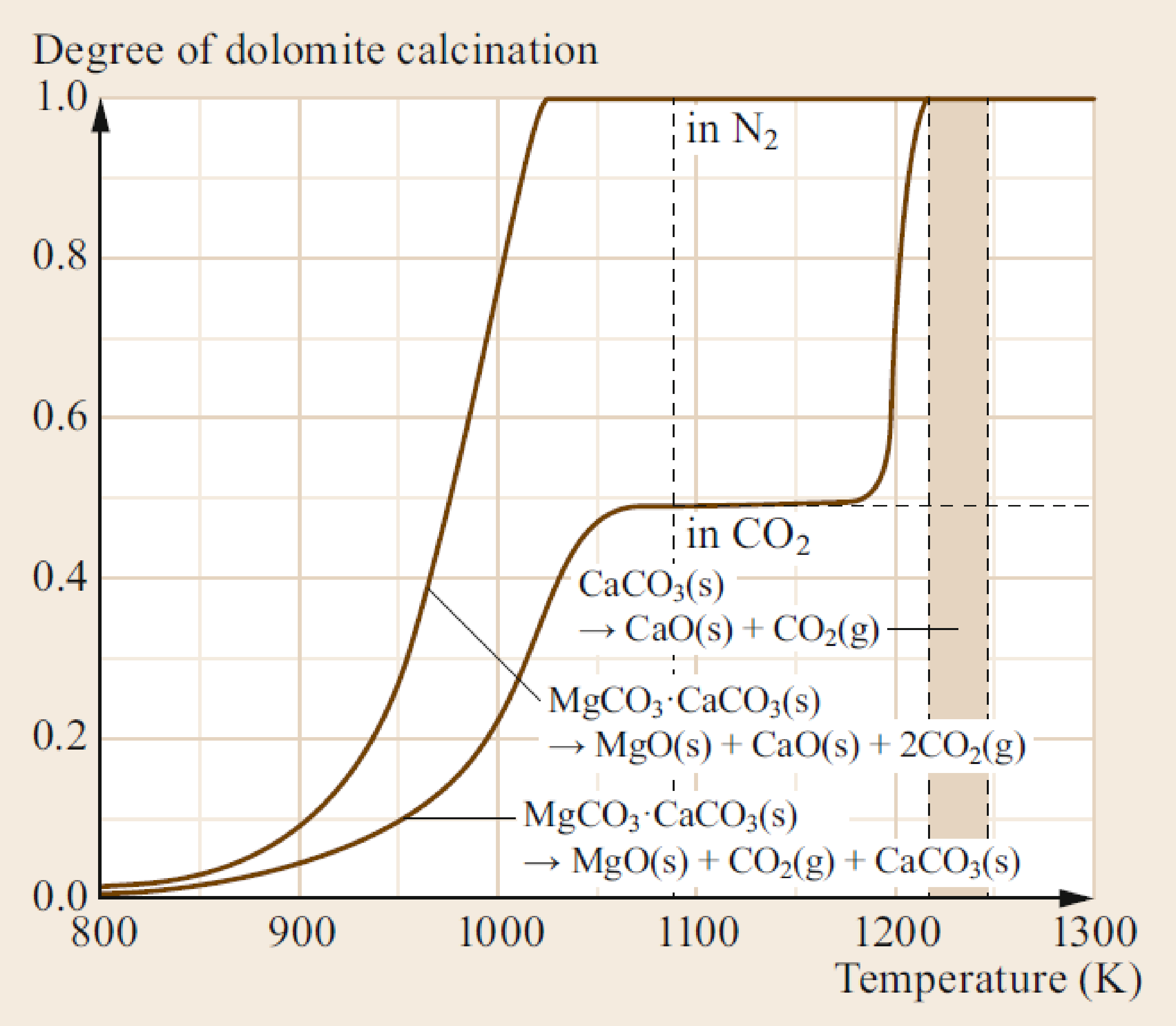


Chemical reaction of raw materials at different temperatures



$$Na_2CO_3(s) + MgCO_3(s) \rightarrow Na_2Mg(CO_3)_2 \quad [300\text{–}550\,°C]$$

$$Na_2CO_3(s) + CaCO_3(s) \rightarrow Na_2Ca(CO_3)_2 \quad [550\text{–}850\,°C]$$



Thermodynamics and Energetics

$$H_{heat} = \sum_{\phi} n_{\phi} \cdot H_{\phi}^{\bullet}$$

raw material i	kg/t		oxide j	kg/t		phase k	kg/t
sand	740.0		SiO_2	740.0		SiO_2	286.9
limestone	178.5		CaO	100.0		$Na_2O\cdot 3CaO\cdot 6SiO_2$	351.1
soda ash	273.6		Na_2O	160.0		$Na_2O\cdot 2SiO_2$	362.0
			gases g				
			CO_2	192.1			
sum	1192.1			1192.1			1000.00

$$2Na_2CO_3(l) + SiO_2(s) \rightarrow 2Na_2O\cdot SiO_2(l) + 2CO_2(g)$$

$$Na_2CO_3(l) + SiO_2(s) \rightarrow Na_2O\cdot SiO_2(l) + CO_2(g)$$

$$Na_2CO_3(l) + 2SiO_2(s) \rightarrow Na_2O\cdot 2SiO_2(l) + CO_2(g)$$

Raw Materials (25 °C) $\xrightarrow{\Delta H^{\circ}_{chem}}$ glass (25 °C) + batch gases

Glass (25 °C) $\xrightarrow{\Delta H(T_{ex})}$ melt (T_{ex})

Thermodynamics and Energetics

$$\Delta H^{\circ}_{chem} = H^{\circ}_{glass} + H^{\circ}_{gas} - H^{\circ}_{batch}$$

$$H^{\circ}_{glass} = \sum_{k} n_k \left(H^{\circ}_{k} + H^{vit}_{k}\right)$$

$$H^{\circ}_{gas} = \sum_{b} n_g \cdot H^{\circ}_{g}$$

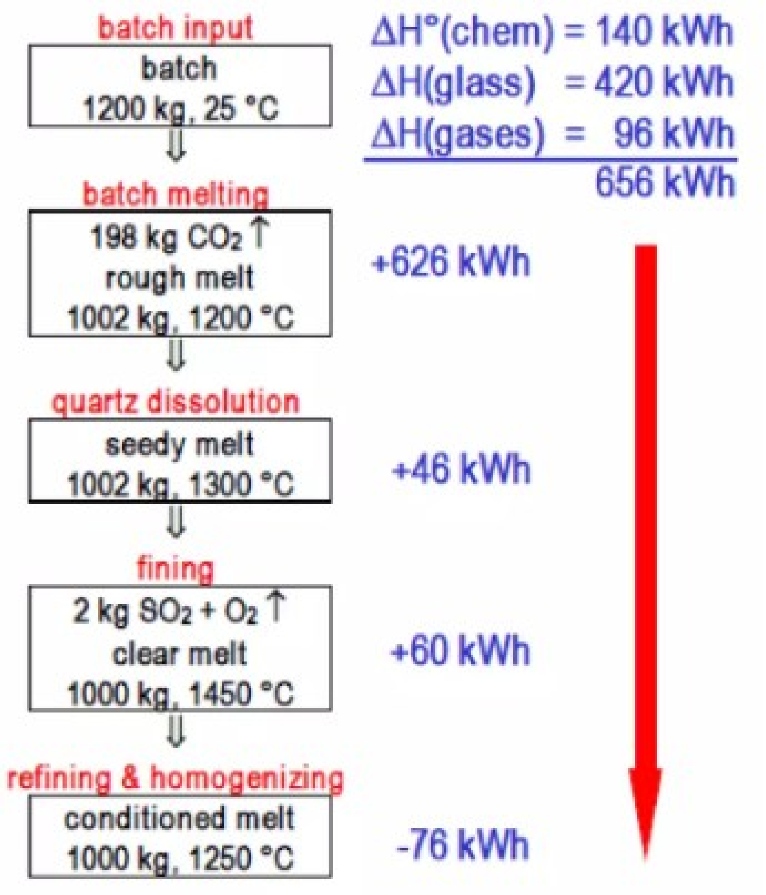
$$H^{\circ}_{batch} = \sum_{b} n_b \cdot H^{\circ}_{b}$$

$$Na_2CO_3(s) \rightarrow 2Na(s) + \frac{1}{2}O_2(g) + CO_2(g)$$

$$Na_2CO_3(s) + H_2O(g) \rightarrow 2NaOH(g) + CO_2(g)$$

$$SiO_2 + 2Na(s) + \frac{1}{2}O_2(g) \rightarrow Na_2O \cdot SiO_2(s)$$

$$SiO_2 + 2NaOH(g) \rightarrow Na_2O \cdot SiO_2(s) + H_2O(g)$$



Flow and Fluid Dynamics

$(P_{Vapour}$ of Gas$)_{melt}$ > $(P_{Vapour}$ Pressure of Gas$)_{bubble}$

diffusion of gases from the melt into a bubble

$$p_{\text{bubble}} = p_0 + \rho g H + \frac{2\sigma}{r}$$

P_0= furnace pressure
ρ = density of melt (g/cc)
σ= Surface tension of melt near bubble
r= Bubble radius

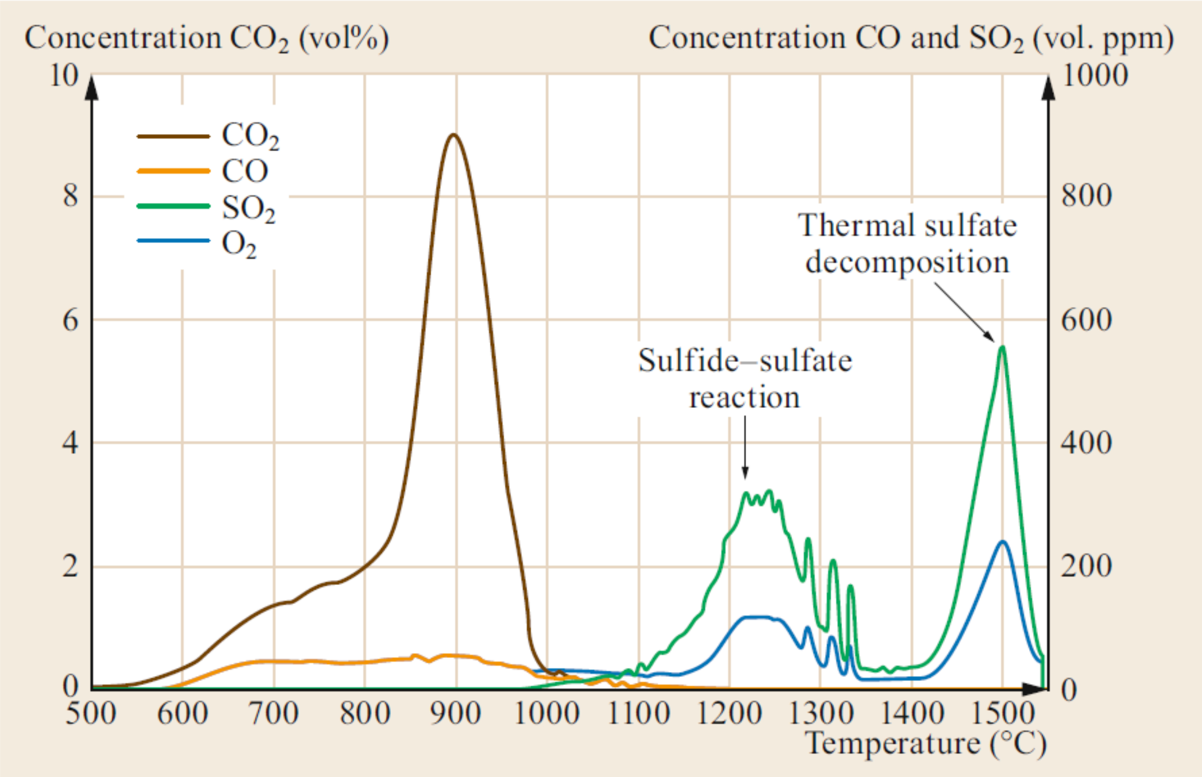
ascension rate of the bubbles

Stokes Law

$$v = \frac{cg\rho r^2}{\eta}$$

V = ascension rate
ρ = density of melt (g/cc)
r= Bubble radius
η= Viscosity
C= constant

Gas evolution from soda-lime-silicate glass using fining agent



$$Na_2SO_4 + nSiO_2(s) \rightarrow Na_2O \cdot (SiO_2)_n + SO_2(g) + \frac{1}{2}O_2(g)$$

$$2C + Na_2SO_4 \rightarrow 2CO + Na_2S$$

$$4CO + Na_2SO_4 \rightarrow 4CO_2 + Na_2S$$

$$4C + Na_2SO_4 \rightarrow 4CO + Na_2S$$

$$Na_2S + 3Na_2SO_4 + xSiO_2 \rightarrow (Na_2O)_4 \cdot (SiO_2)_x + 4SO_2(g)$$

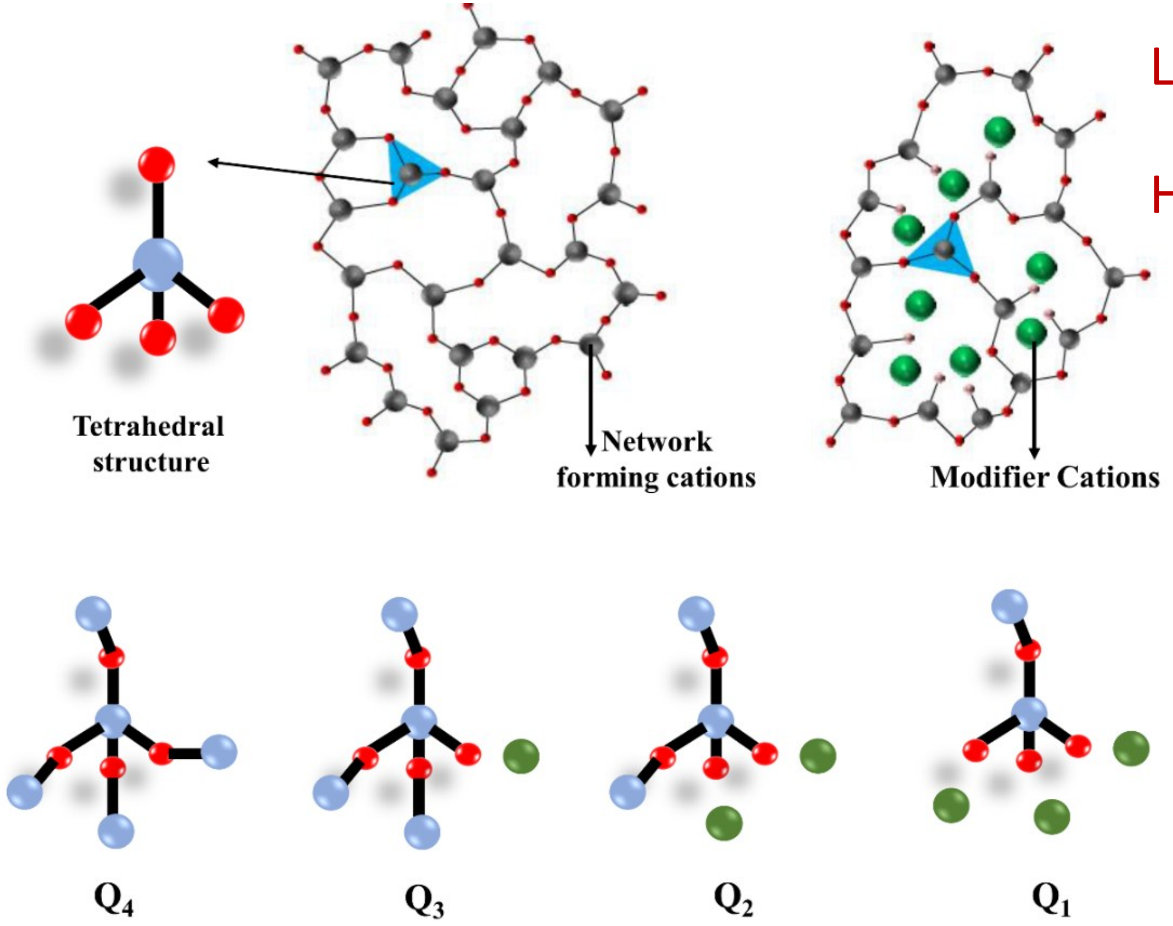
Oxygen fining

$$Sb_2O_5 \rightarrow Sb_2O_3 + O_2(g)$$

$$SnO_2 \rightarrow SnO + \frac{1}{2}O_2(g)$$

$$2\,CeO_2 \rightarrow Ce_2O_3 + \frac{1}{2}O_2(g)$$

Glass Structure and Chemical Homogeneity



Low Field Strength Cations- High Chemical Homogeneity

High Field Strength Cations- Less Chemical Homogeneity

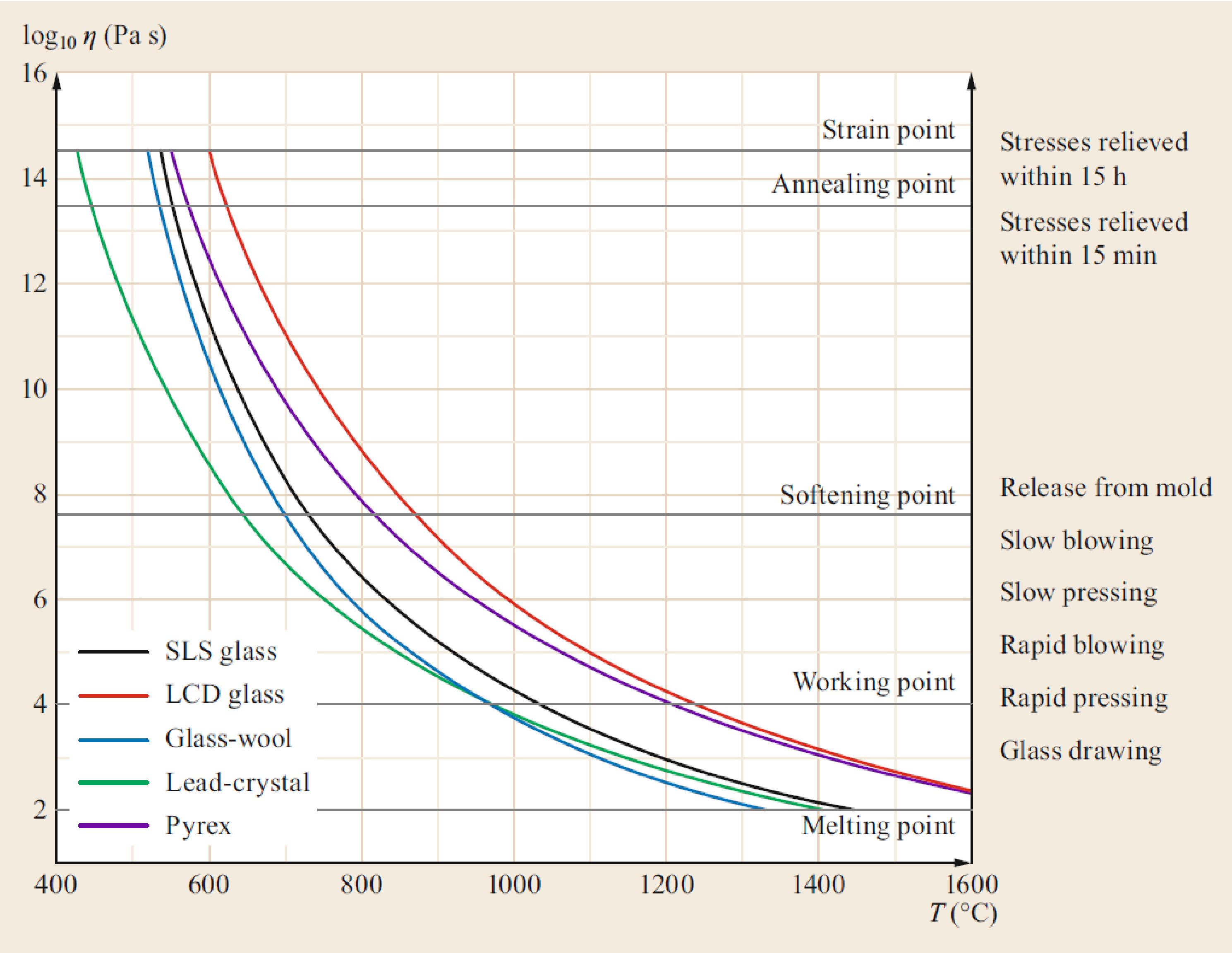
$$Q_4 + Na^+ \rightarrow Q_3 + NBO$$

Homogeneous distribution of Q_3

$$2Q_4 + Ca^{2+}/Mg^{2+} \rightarrow Q_2 + Q_4$$

Formation of separate Q_2 and Q_4 rich regions

Viscosity of the melt



$$\log \eta(T) = \log \eta_\infty + (12 - \log \eta_\infty)\frac{T_g}{T} \times \exp\left[\left(\frac{m}{12 - \log \eta_\infty} - 1\right)\left(\frac{T_g}{T} - 1\right)\right],$$

Viscosity of the melt

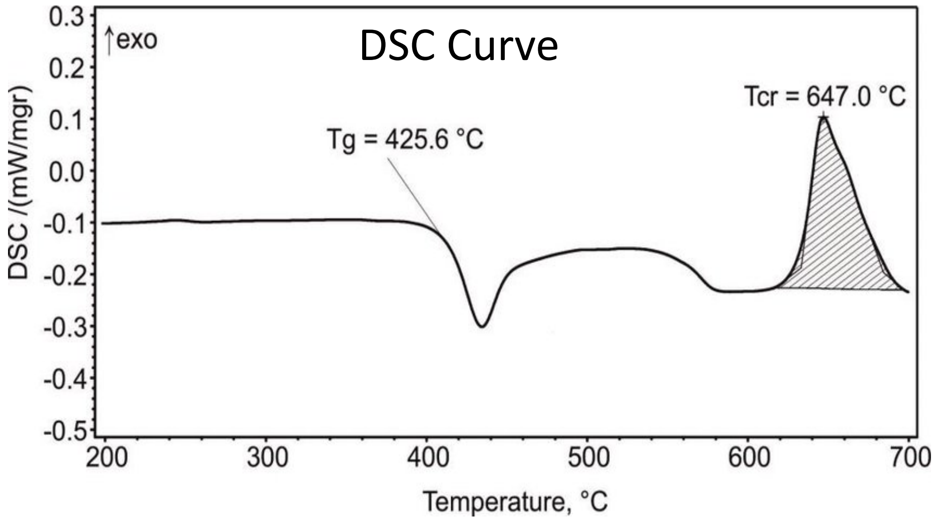
- ***Melt Flow***: Viscosity determines the glass forming and shaping into desired forms such as bottles, windows, fiber optics, etc.
- ***Bubble removal*****:** During the melting process, proper viscosity facilitates the removal of trapped air bubbles, leading to a clear and defect-free glass.
- ***Stress relief*****:** To relieve internal stresses, Annealing relies on controlled viscosity for gradual structural relaxation in the glass.
- ***Composition dependence*****:** The chemical composition of a glass significantly impacts its viscosity, allowing manufacturers to tailor the glass for specific applications by adjusting the ingredients.
- ***Crystallization Temperature***: Higher viscosity can delay the onset of crystallization, while lower viscosity can promote it

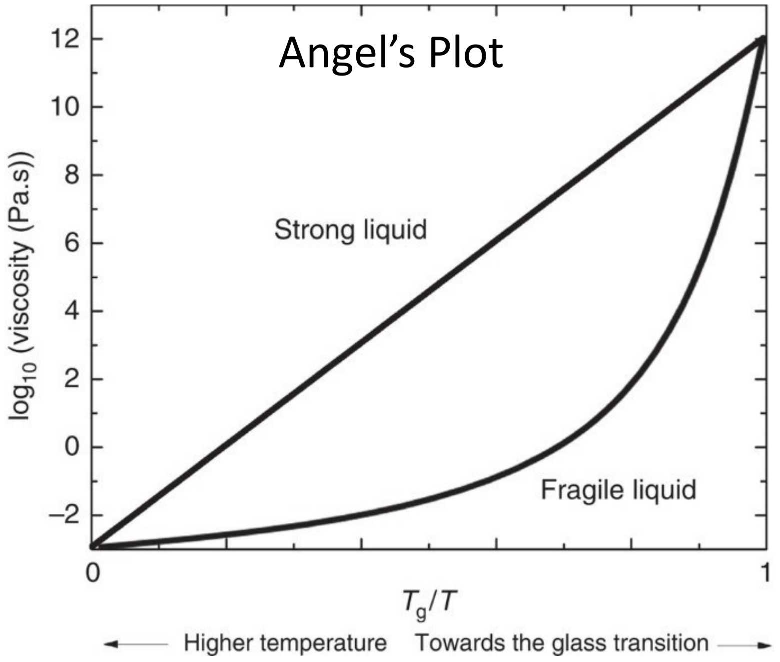
Impact of Viscosity to Control Glass-Ceramics

Crystallization Control: Viscosity determines the rate of crystallization and the size and distribution of crystals in glass ceramics.

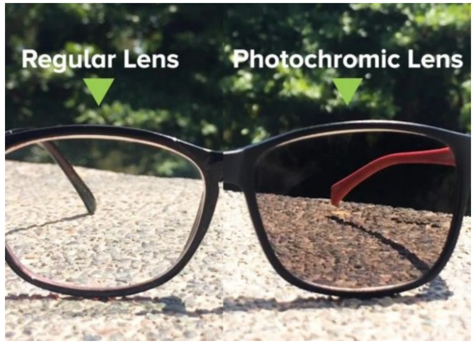
- Lower viscosity allows for easier atomic movement, facilitating controlled nucleation and growth of crystals and vice versa. This results in a more uniform and desirable microstructure.

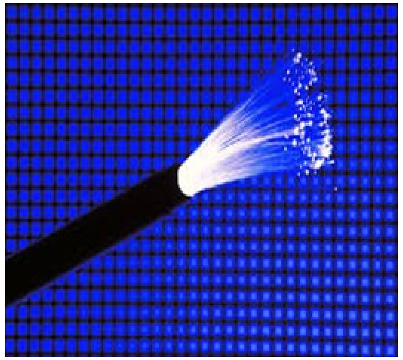
- Higher viscosity restricts the atomic movement and retains the amorphous phase.





Development of Glass Science: Advancement of Technology for emerging applications





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