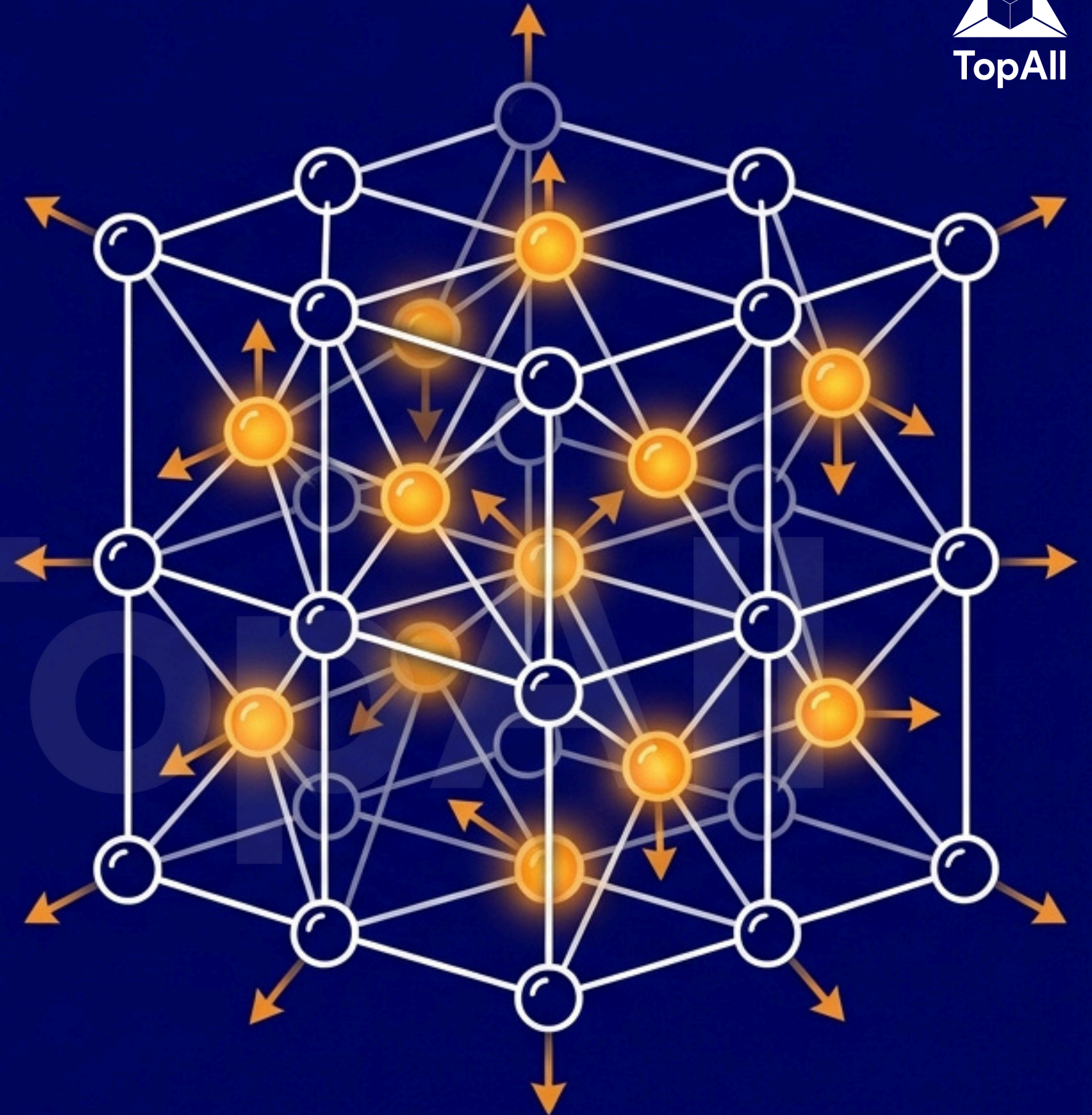


Why Materials Expand When Heated

Decoding the physics behind dimensional changes in solids, liquids, and gases.

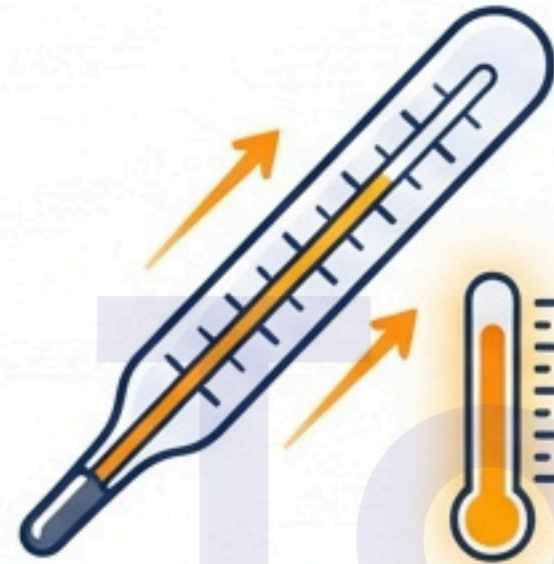


You Already Know How This Works



Solid Expansion

A tightly screwed metal lid expands when placed in hot water, loosening its grip on a glass jar.



Liquid Expansion

Mercury expands rapidly in warm water, rising up the capillary tube. It contracts and falls in cold water.



Gas Expansion

A partially inflated balloon expands to full size in a warm room, but shrinks in cold water due to air contraction.

The 3 Dimensions of Expansion

1D

Linear Expansion

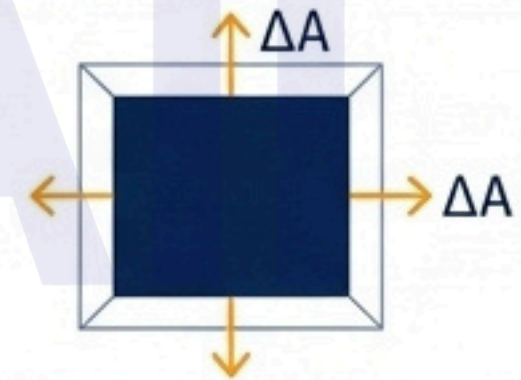
Expansion in length. Formula preview: $\Delta l/l \propto \Delta T$



2D

Area Expansion

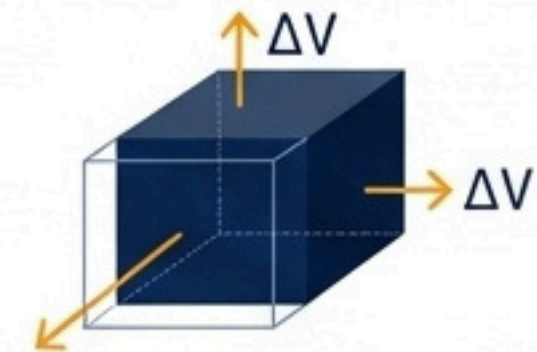
Expansion in area. Formula preview: $\Delta A/A \propto \Delta T$



3D

Volume Expansion

Expansion in volume. Formula preview: $\Delta V/V \propto \Delta T$





The Mathematics of Expansion

Linear Coefficient (α_l) →

$$\frac{\Delta l}{l} = \alpha_l \Delta T$$

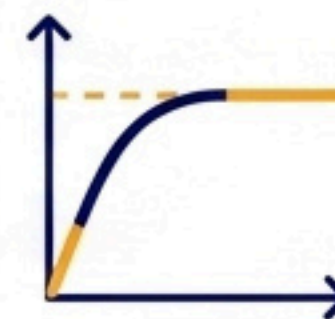
Note: Copper expands ~5x more than glass. in Inter

Volume Coefficient (α_v) →

$$\frac{\Delta V}{V} = \alpha_v \Delta T$$

Exam Trap

α_v is not strictly constant. It varies at lower temperatures and plateaus only at high temperatures.



The Golden Rule for Isotropic Solids →

$$\alpha_v = 3\alpha_l$$

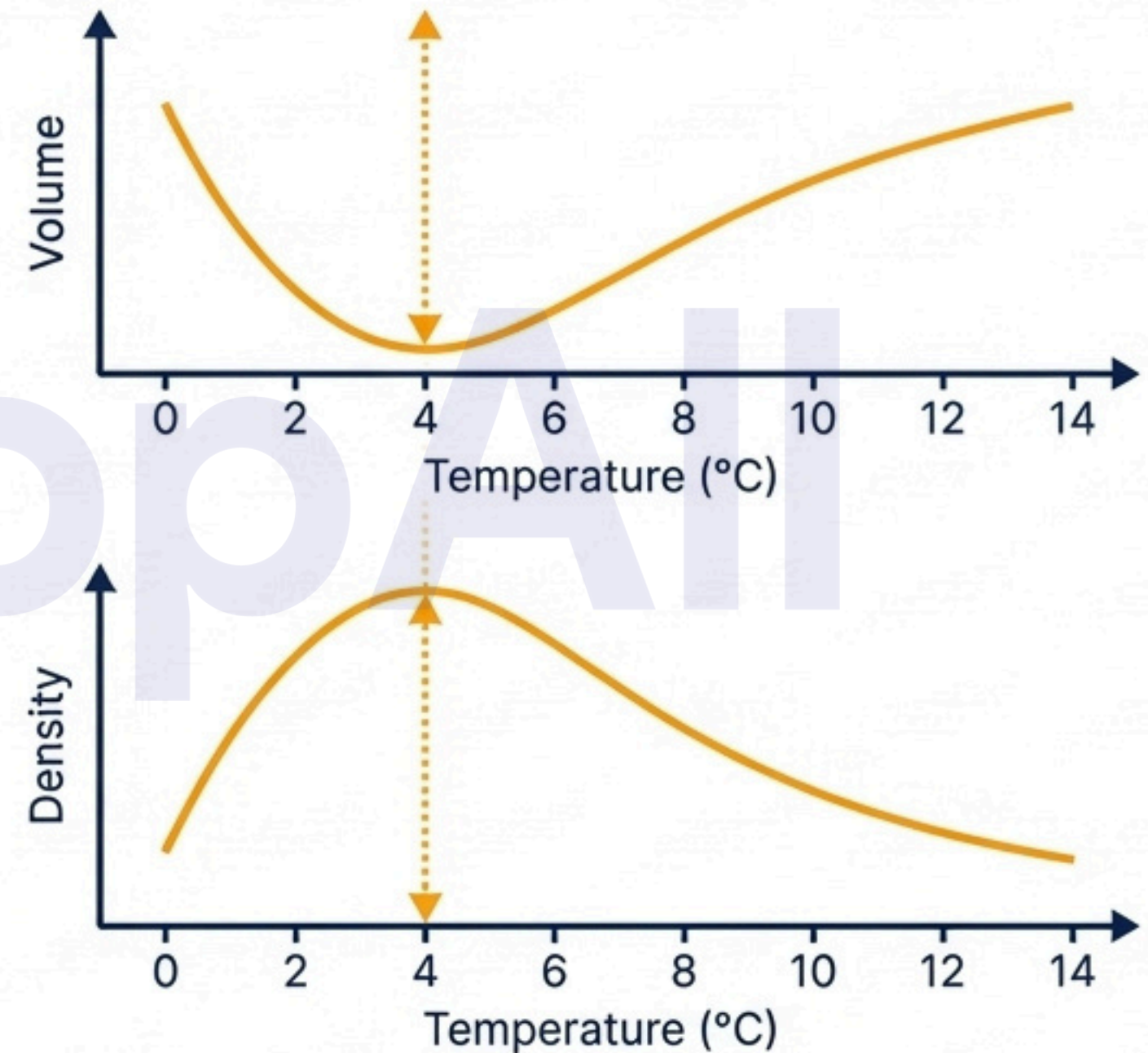
Proof insight: Derived by neglecting infinitesimally small terms like $(\Delta l)^2$ and $(\Delta l)^3$ during expansion.

The Water Anomaly (0°C to 4°C) High-Yield Concept

The Rule Breaker: Unlike almost all other substances, water contracts when heated from 0°C to 4°C.

The Density Peak: Volume reaches an absolute minimum, and Density is MAXIMUM exactly at 4°C.

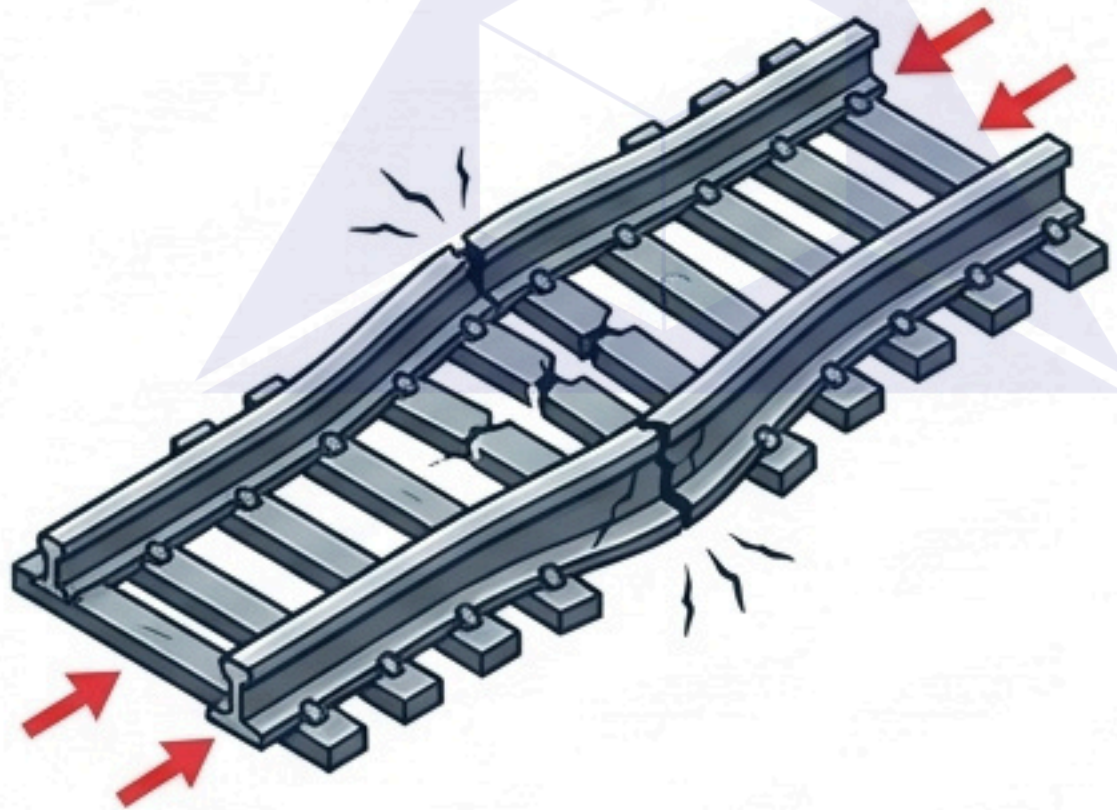
Environmental Impact: Bodies of water freeze top-down. Dense 4°C water sinks, while colder, less dense water (and ice) floats to the surface, protecting aquatic life below.



Thermal Stress & The Blacksmith's Ring

Thermal Stress

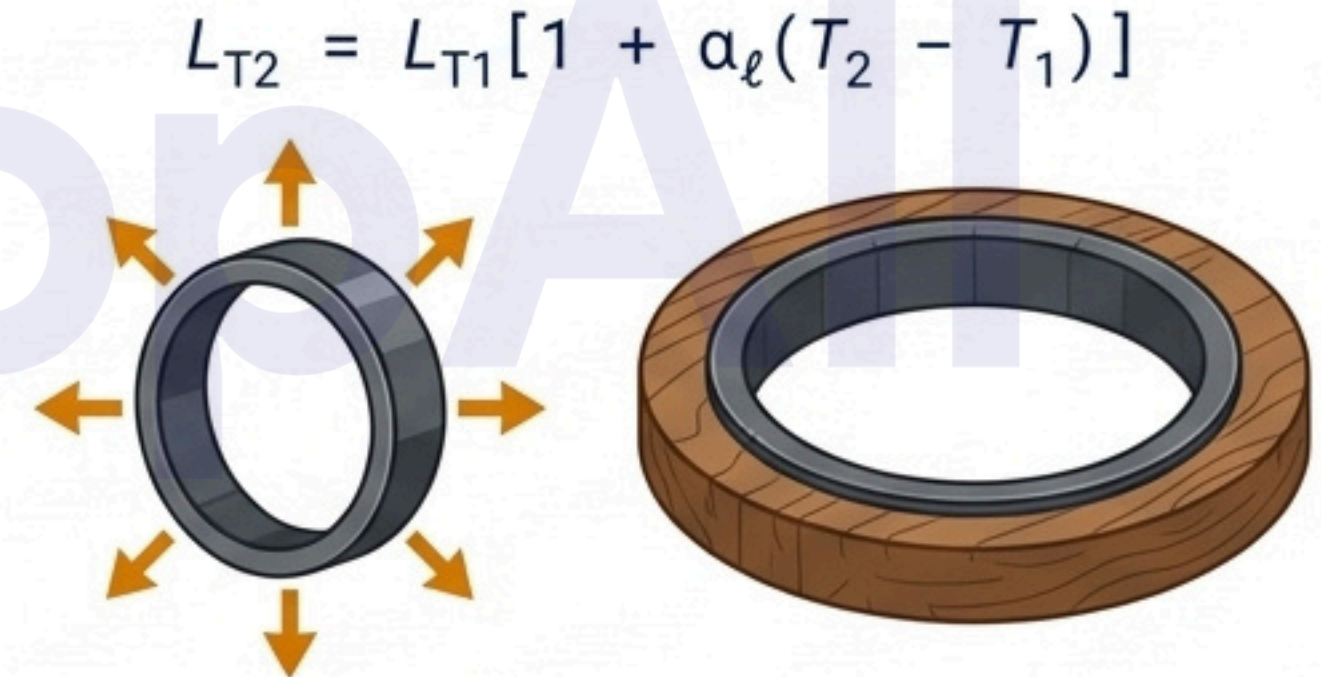
If you rigidly fix the ends of a rod and heat it, it cannot expand. This constrained expansion creates massive compressive strain and thermal stress.



Example 10.2

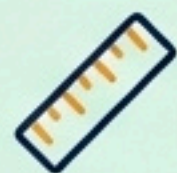
Harnessing Expansion

Problem: Fitting an iron ring ($D = 5.231\text{m}$) onto a larger wooden wheel rim ($D = 5.243\text{m}$) at 27°C .



Result: Heat to **218°C** . It slides on, then shrinks as it cools for a perfect, tight grip.

Key Takeaways (H1: 32px)



1. Dimensions Change: Heating causes linear (α_l), area, and volume (α_v) expansion matching the object's geometry.



2. The 3x Rule: For isotropic materials, the volume coefficient is three times the linear coefficient ($\alpha_v = 3\alpha_l$).



3. Temperature Dependence: α_v is not perfectly constant; it varies at lower temperatures before plateauing.



4. Water's Anomaly: Water contracts from 0°C to 4°C , reaching its maximum density exactly at 4°C .



5. Thermal Stress: Preventing thermal expansion generates immense compressive stress.