Learning Goals:

- For an object made of some material, to calculate the changes in length or volume that material undergoes in response to changes in temperature and external forces (stress).
- To explain why the change of length of an object due to thermal expansion is proportional to its initial length.
- For systems consisting of two different materials, to quantitatively analyze effects resulting from the different expansion rates of different parts.
- To explain why the fractional change in volume of an object for a small change in temperature is three times the fractional change in length

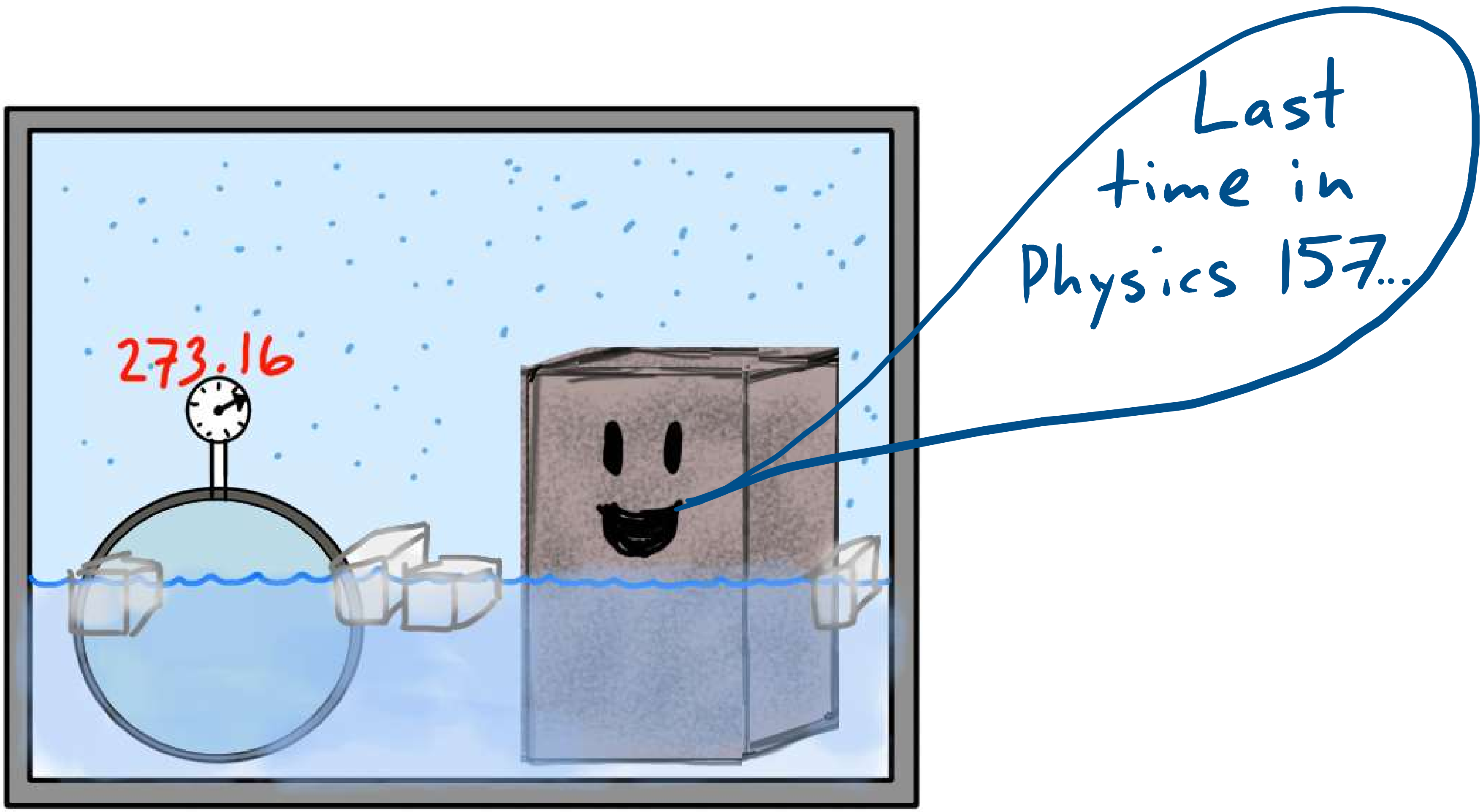
Office hours today: 3:30 - 5:30 Hennings 420

Clicker: A steel ball does not quite fit through a hole in a copper plate. If $\alpha_{steel} < \alpha_{copper}$, we could help the ball fit through the hole by

A. Heating the system
B. Cooling the system
C. Either A or B will work
D. Neither A nor B will work

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

EXTRA: does the hole get larger or smaller when we heat the system? Why?


273.16
Last time in Physics 157...

Define Kelvin scale by:

$$T = \text{const.} \times P$$

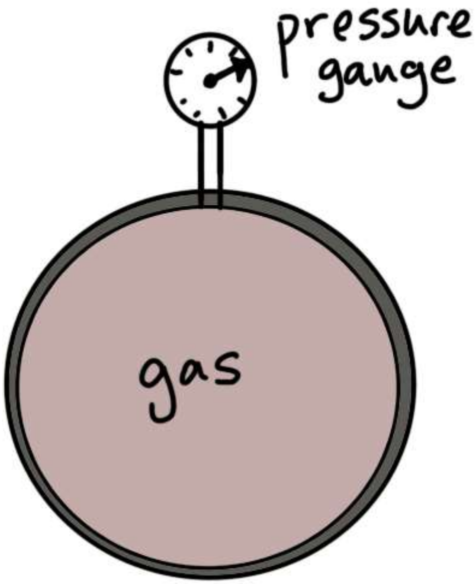
depends on particular thermometer

pressure

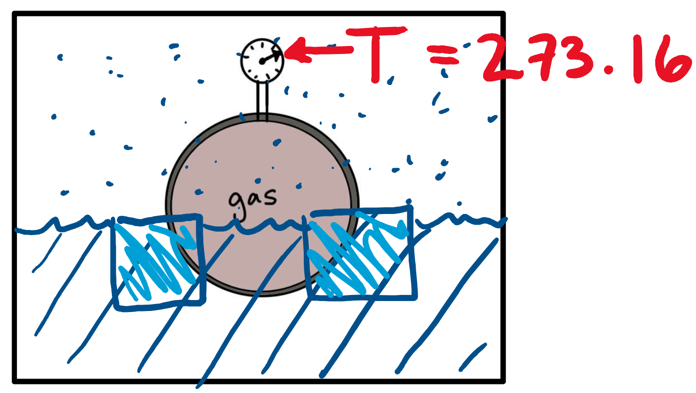
and

$$T = 273.16\,K$$

at triple point of water

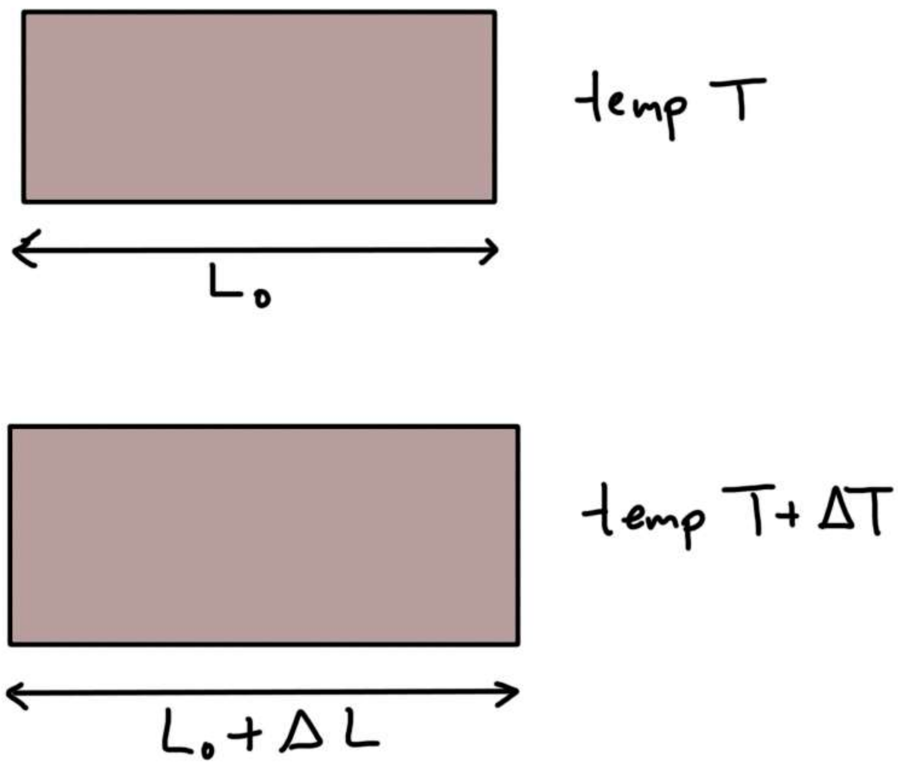


constant volume gas thermometer:



$$T_C = T_K - 273.15$$

Thermal expansion:



coefficient of linear expansion: a basic property of a material

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

- assumes $\frac{\Delta L}{L}$ is small
- α can depend on T

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Discussion question: why is the change in length of an object proportional to its initial length L_0 ? E.g. why does a steel rod that starts out twice as long expand twice as much?

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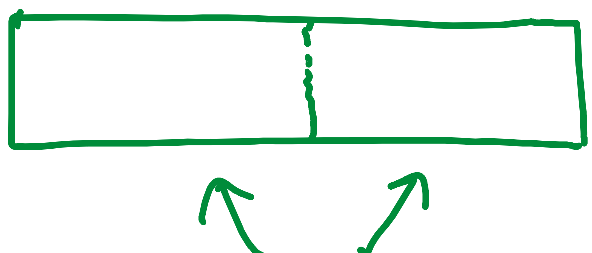
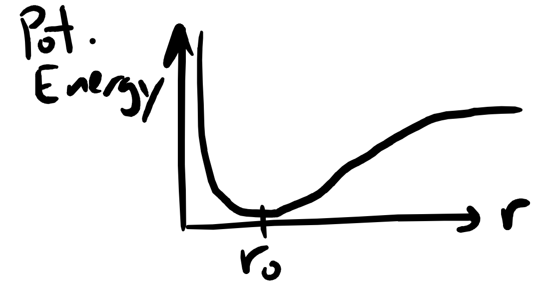


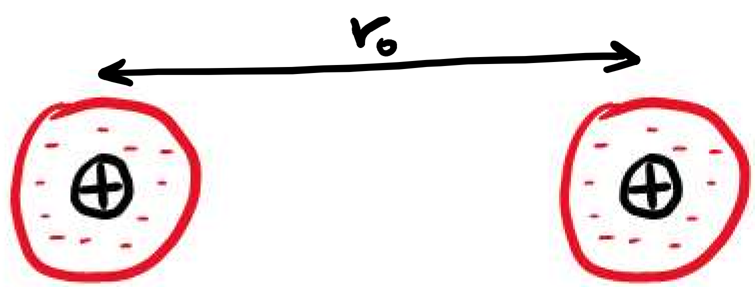
each half expands independently, same amount as original object

total expansion is double

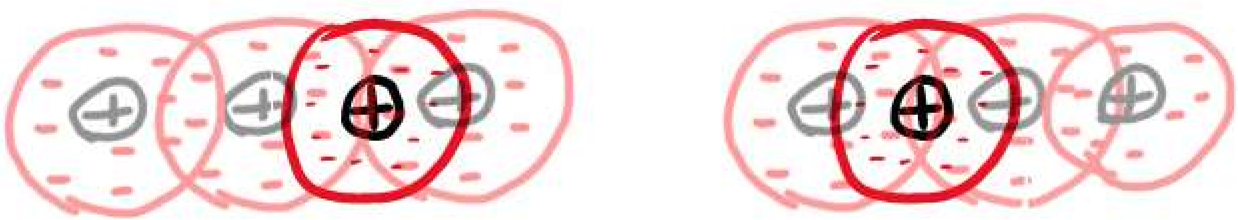
Why do materials usually expand when heated?



Nearby atoms in solid:



Lowest energy



Add energy

More higher energy configurations with $r > r_0$ than $r < r_0$.

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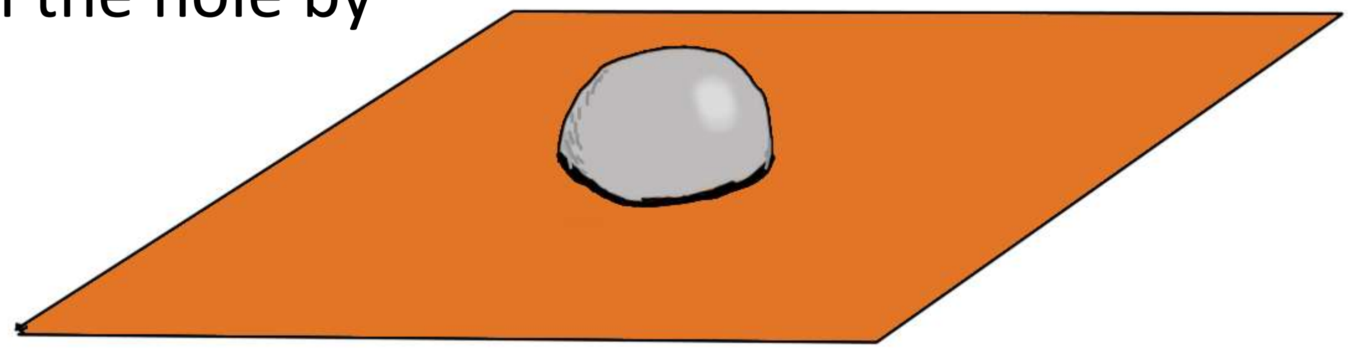

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ball + hole both expand, but hole expands more since $\alpha_{Cu} > \alpha_{steel}$

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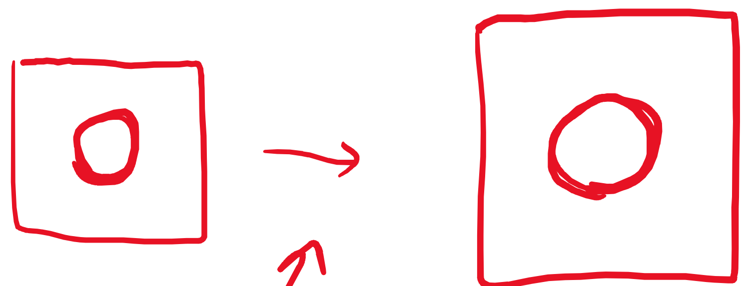


EXTRA: does the hole get larger or smaller when we heat the system? Why?

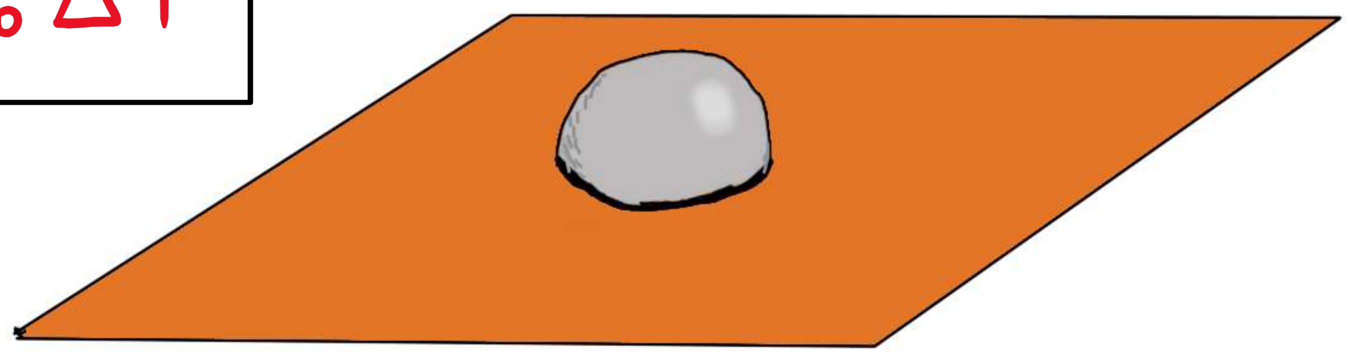
hole grows in proportion to plate (same as if hole were filled)

If the radius of the ball at T = 20°C is 1.001cm and the radius of the hole is 1.000cm, to what temperature must we heat the system before the ball falls through?

We have: $\alpha_s = 1.2 \times 10^{-5}\ K^{-1}$ *and* $\alpha_c = 8 \times 10^{-5}\ K^{-1}$

Discuss a strategy for solving this. What should be true about ΔL_{ball} relative to ΔL_{hole}?

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



Strategy: ① understand what happens to each part

② understand how the parts are related

①

hole expands: $\Delta L_{hole} = \alpha_{Cu} L_0^{Cu} \Delta T$ ← unknown

ball expands: $\Delta L_{ball} = \alpha_s L_0^{s} \Delta T$

② We need $\Delta L_{hole} = \Delta L_{ball} + 0.001\,cm$
in order for the ball to fall through

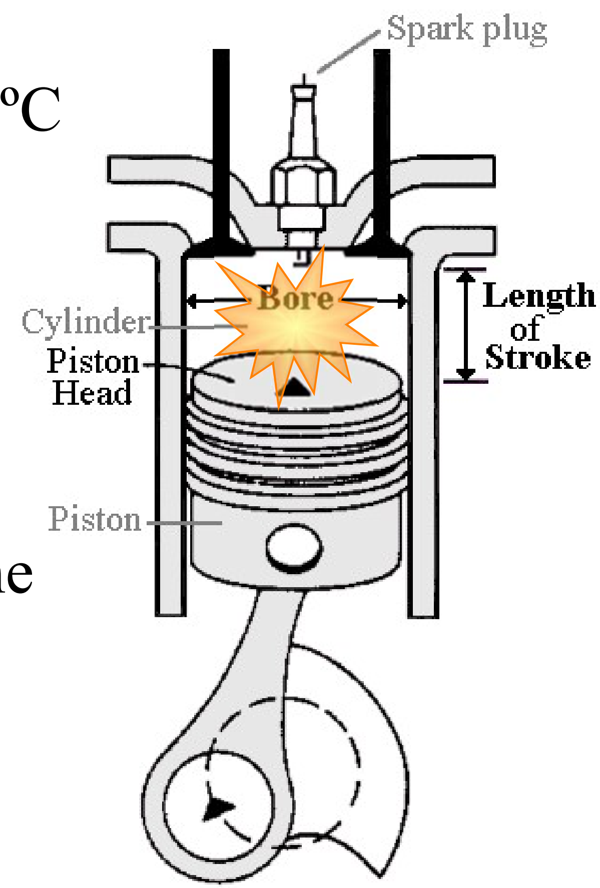
③ Rest is math: $\alpha_{Cu} L_0^{Cu} \Delta T = \alpha_s L_0^{s} \Delta T + 0.001\,cm$

solve for ΔT

Clicker: In some car engines, the piston is aluminum ($\alpha = 2.4 \times 10^{-5}$), while the cylinder is cast iron ($\alpha = 1.2 \times 10^{-5}$). If the engine needs to operator between 0ºC and 120ºC, which of these is **not** a good design:

A) The piston barely fits in the cylinder at 120ºC

B) The piston barely fits in the cylinder at 0ºC



EXTRA: what do we need to worry about if the engine gets too hot? Too cold?

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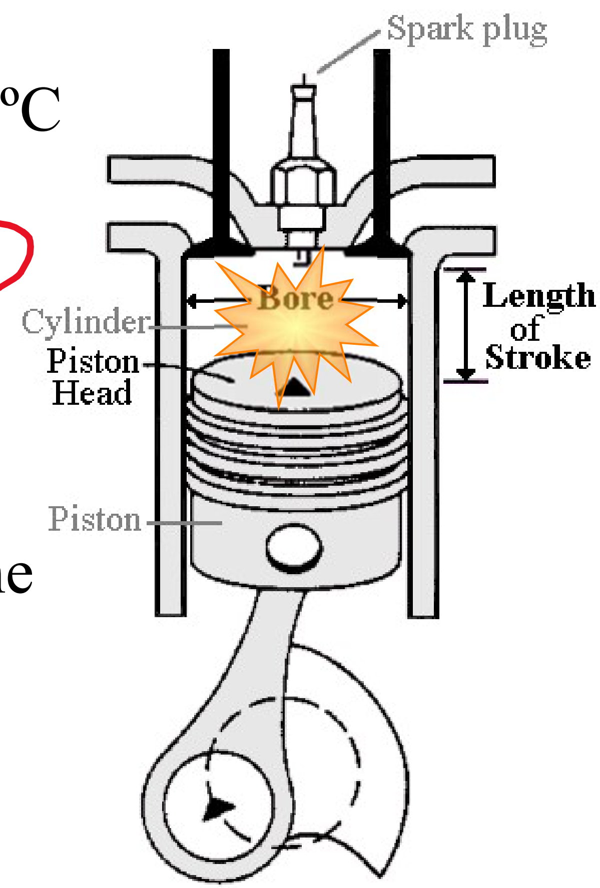
piston expands more than cylinder as engine heats up. Wouldn't be able to move at higher temperatures



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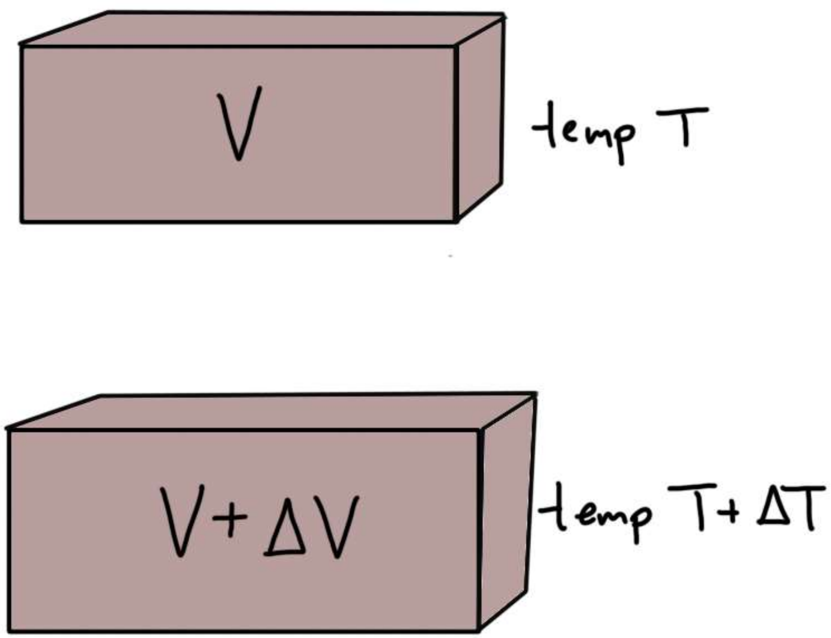
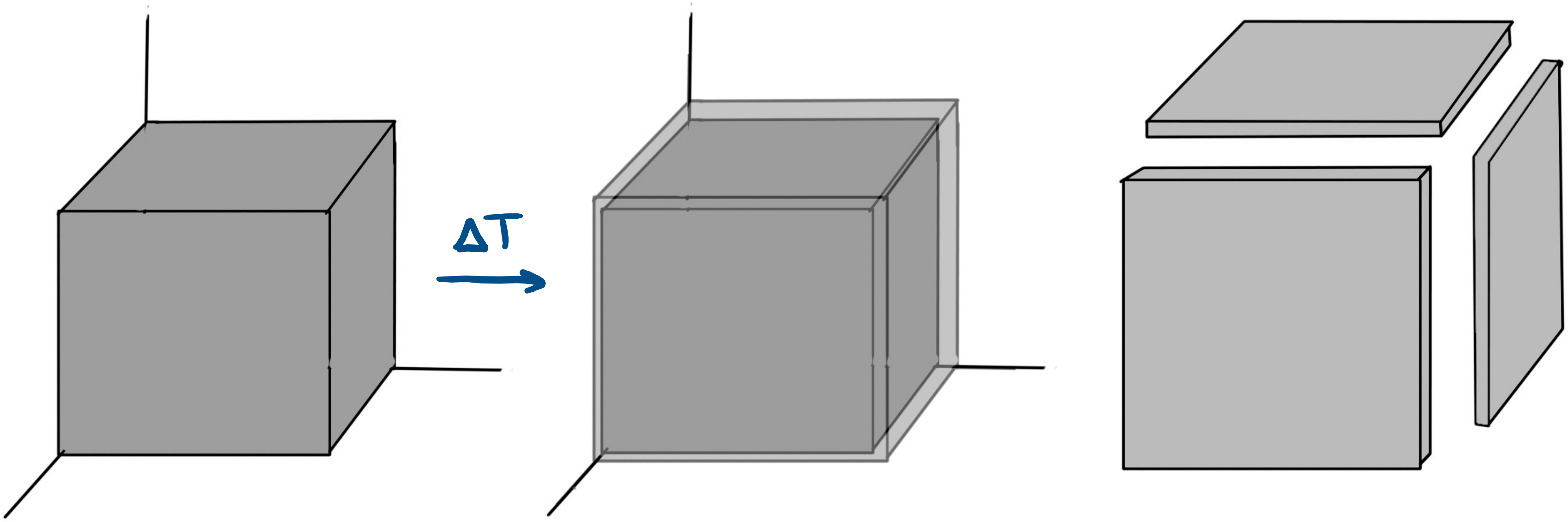
Volume expansion:



$$\boxed{\Delta V = \beta V_0 \Delta T}$$

also applies to liquids

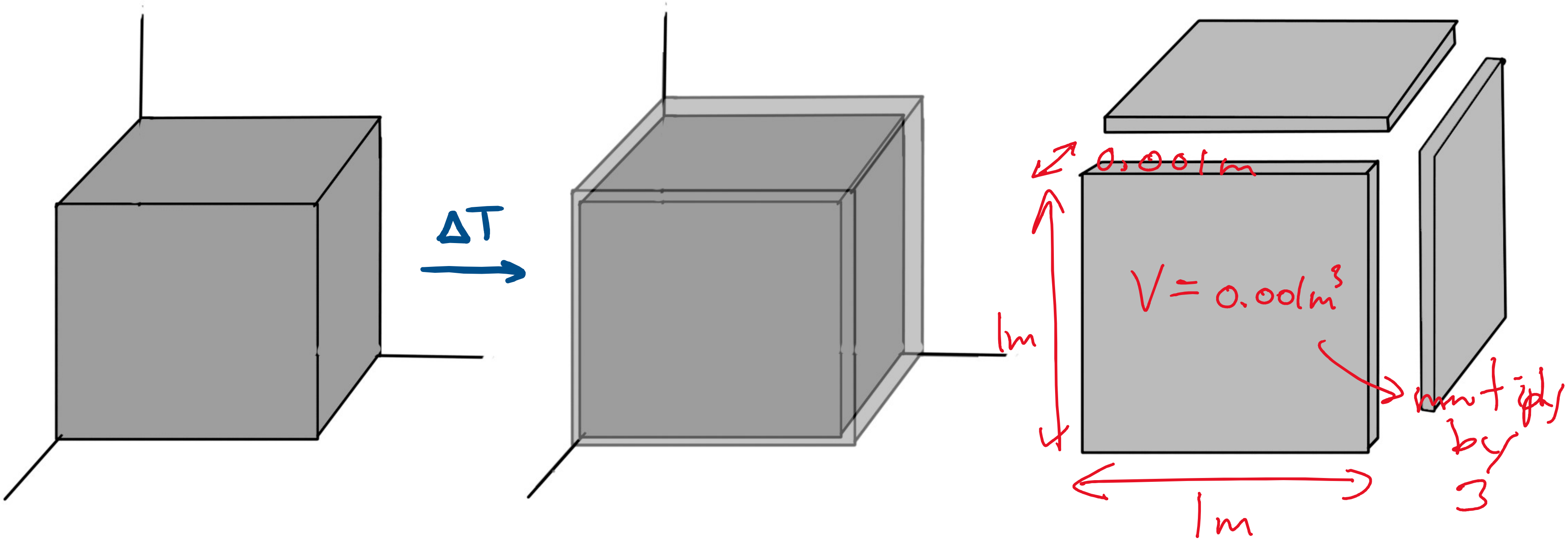


Clicker: When heated, each side of a 1m cube of material expands by 0.001m. The extra volume (shown in the third picture) after the expansion is approximately

A) $0.000000001m^3$ B) $0.00001m^3$ C) $0.001m^3$ D) $0.003m^3$

E) There is not enough information

look at the picture and use geometry to solve this!



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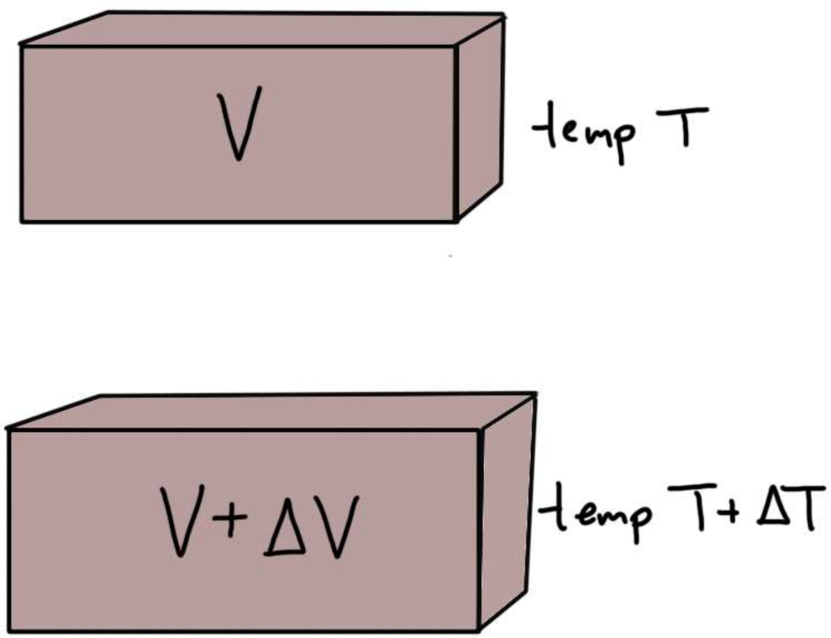

$$\boxed{\Delta V = \beta V_0 \Delta T}$$

$\beta = 3\alpha$ for solids

also applies to liquids

Mathematical derivation:

original volume: L^3

new volume $(1.001 \times L)^3 \approx 1.003\, L^3$

so 0.3% bigger

generally: $(L+\Delta L)^3 = \underset{V}{L^3} + \underbrace{3L^2\Delta L + 3L(\Delta L)^2 + (\Delta L)^3}_{\Delta V}$

$$\frac{\Delta V}{V} = 3 \cdot \frac{\Delta L}{L} + 3\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta L}{L}\right)^3$$

this means

$\beta = 3\alpha$

these are negligible compared to the first term if $\frac{\Delta L}{L}$ is small