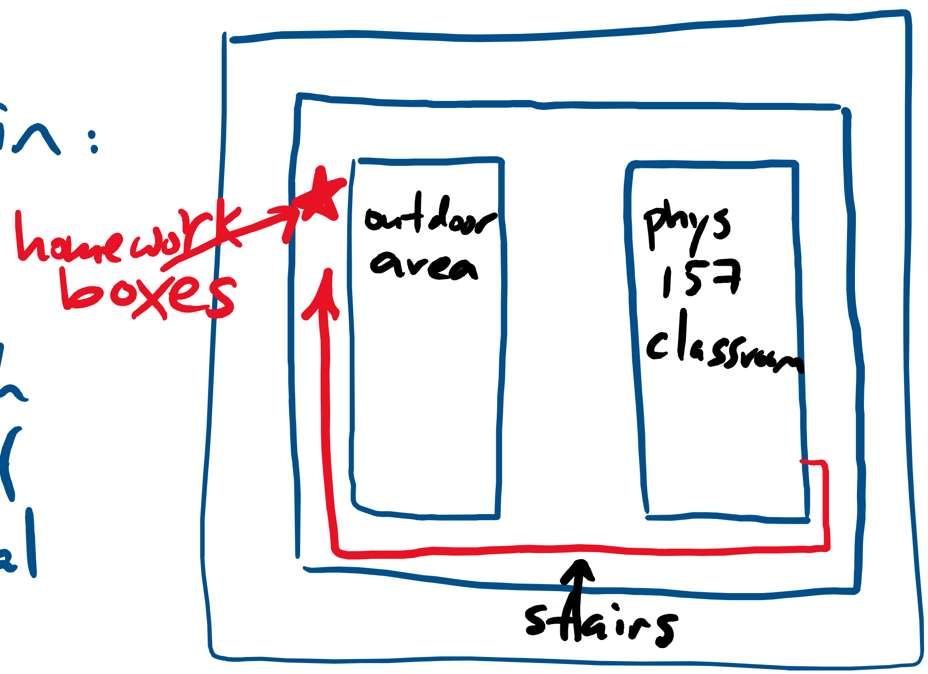
Homework sessions with TAs:

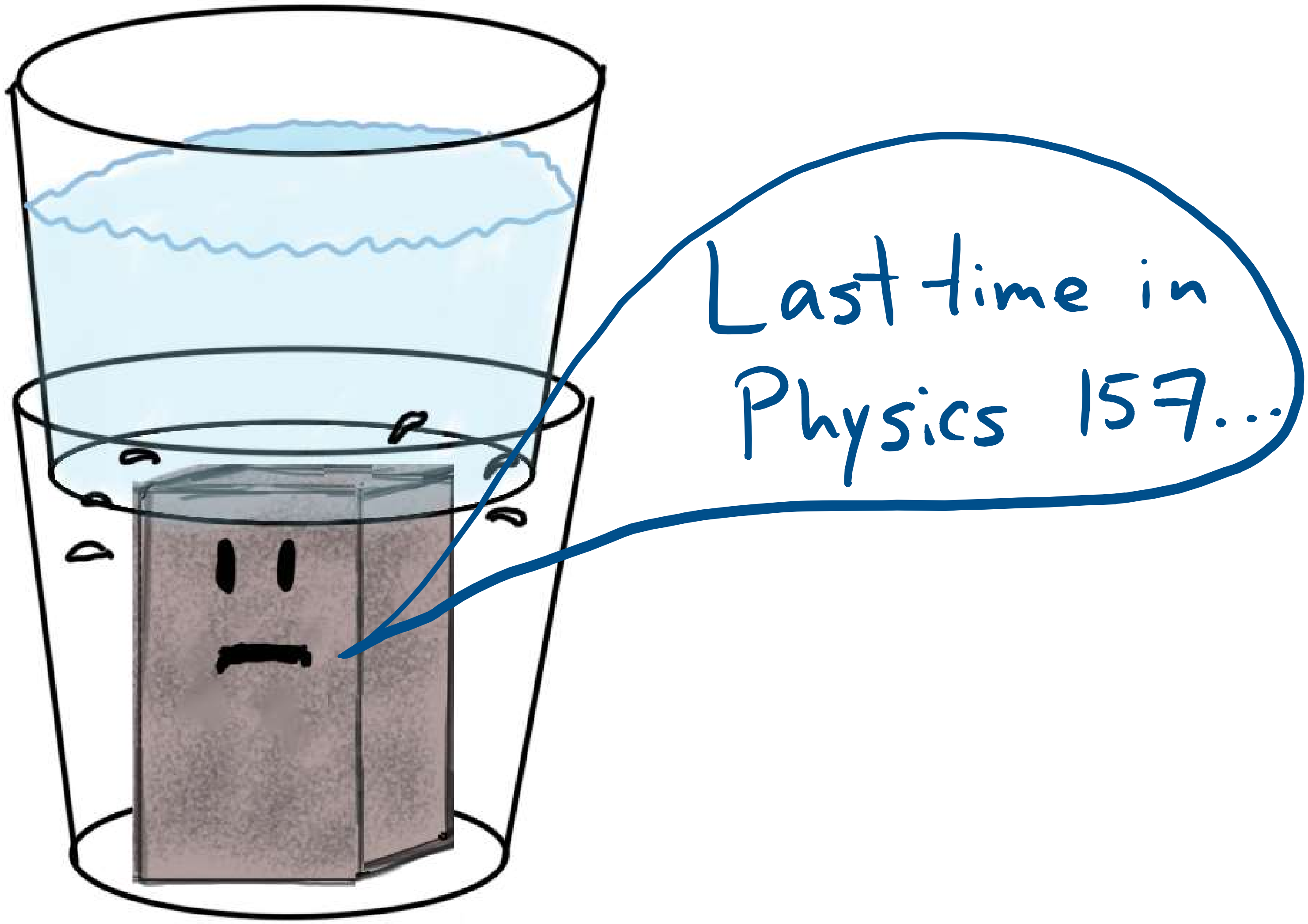
Monday 5-7pm in Hennings 200

Tuesday 5-7pm room will be announced by lunchtime Tuesday on Canvas + Physics 157 website.

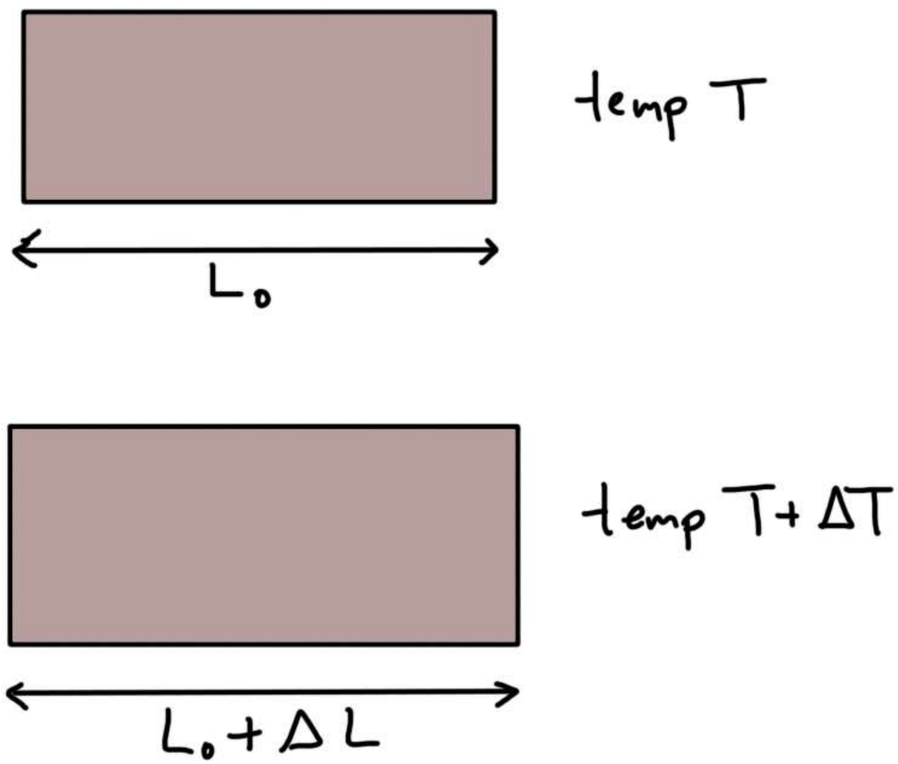
Homework hand-in:

- hand in at the box with the letter of your tutorial section




Last time in Physics 157...

Thermal expansion:

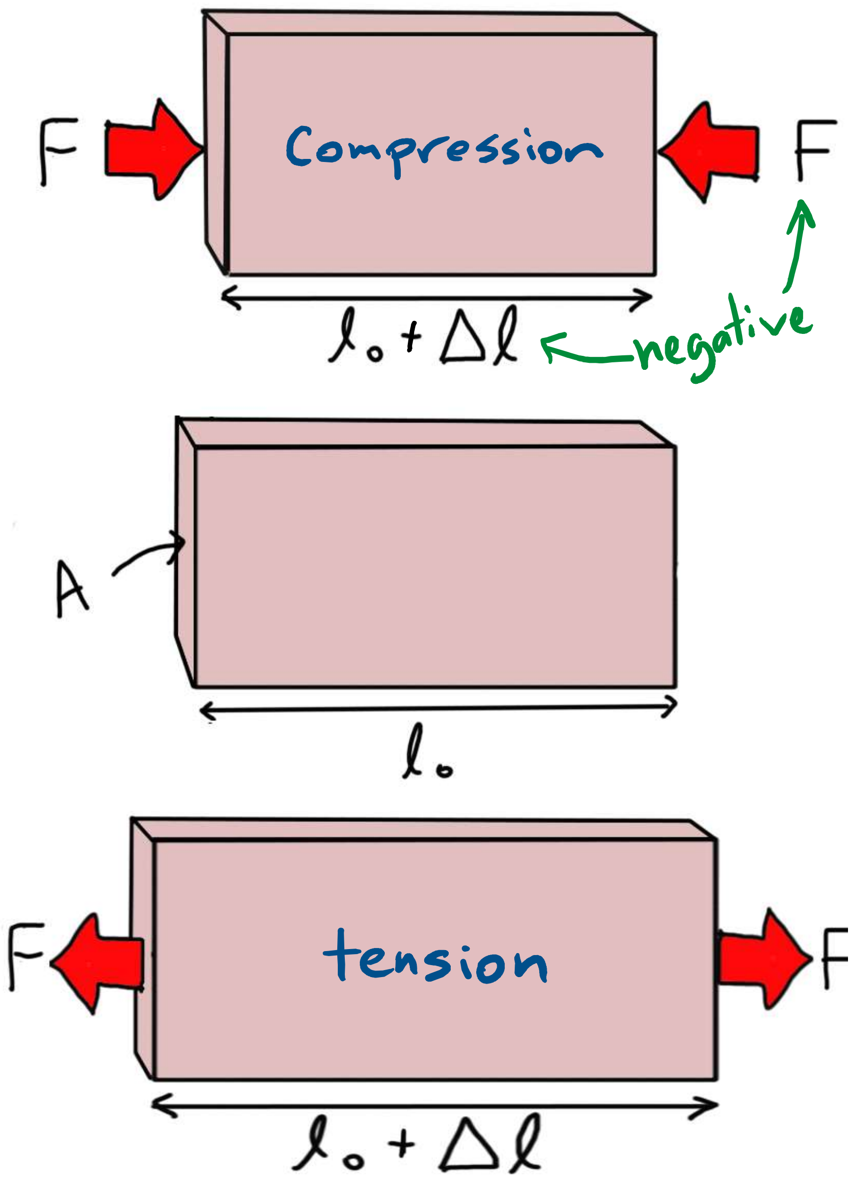


$$\boxed{\Delta L = \alpha L_0 \Delta T}$$

coefficient of linear expansion

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

Stress & Strain



$$\frac{F}{A} = Y \frac{\Delta l}{l_0}$$

stress (units of pressure)

Young's modulus

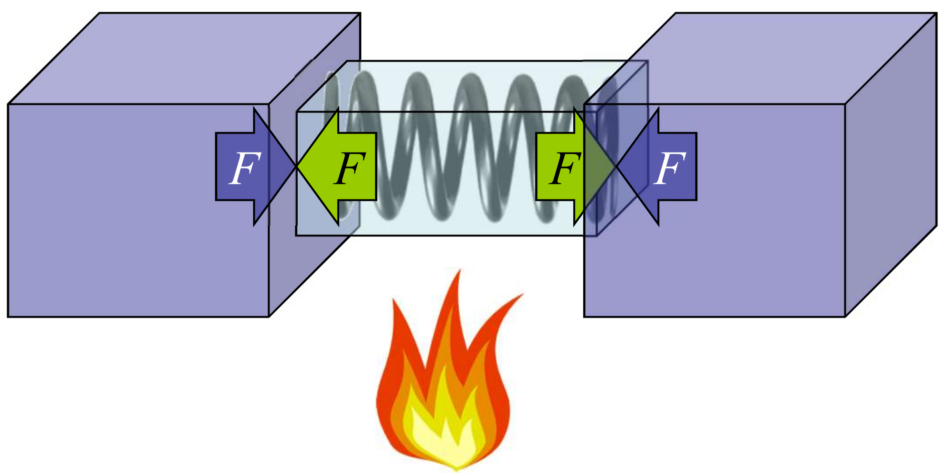
strain

Young's modulus = a basic property of a material (resistance to squishing)

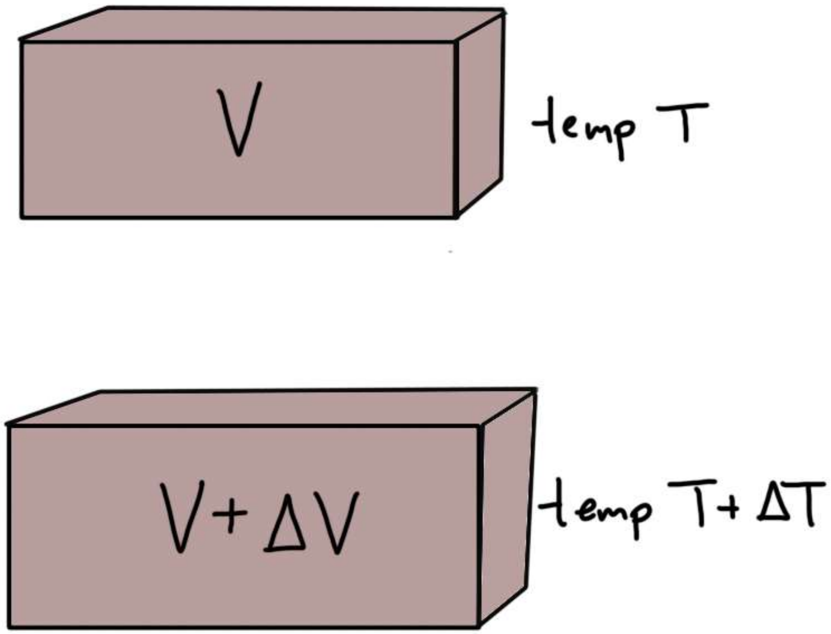
like $F = k\Delta x$ for spring

TODAY:

- a little more about thermal expansion
- more on stress and strain
- combined effects of thermal expansion and external forces

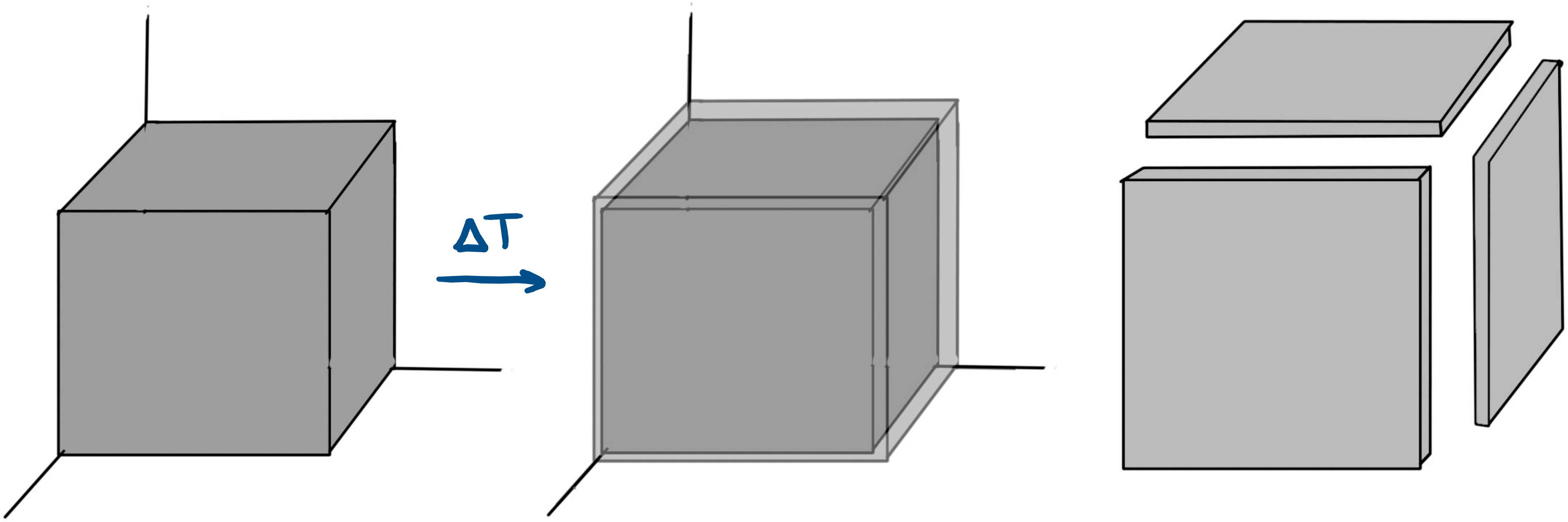


Volume expansion:



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

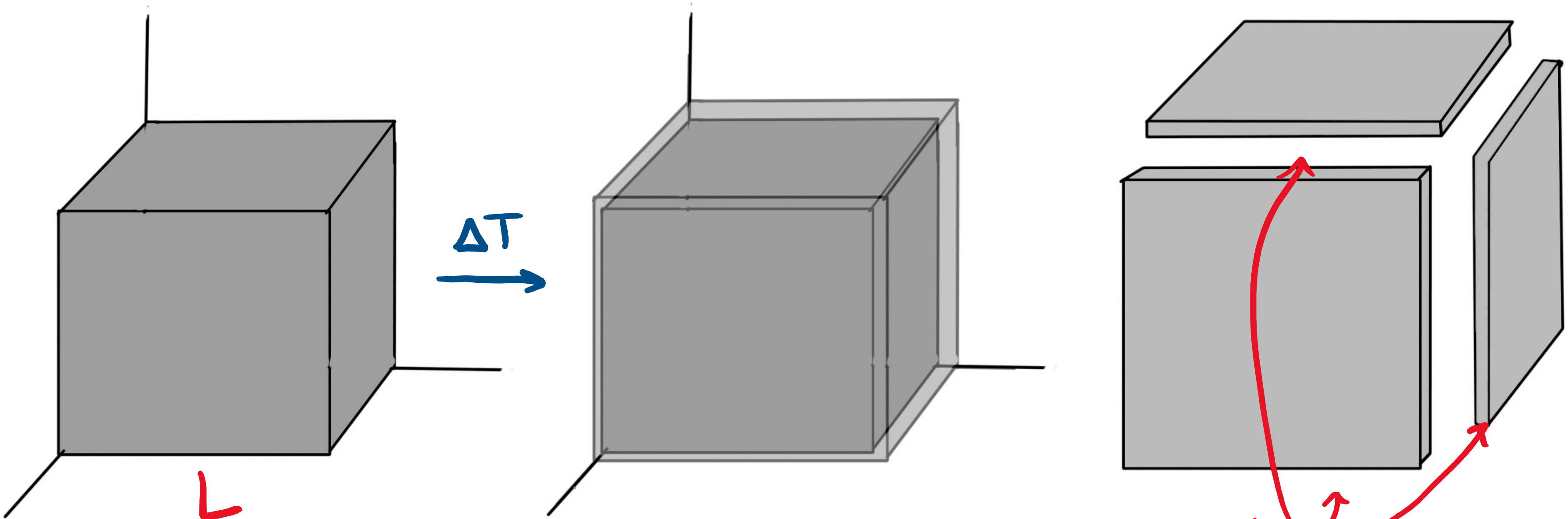
also applies to liquids



Clicker: When heated, each side of a cube of material expands by 0.1%. As a percentage of the original volume of the cube, the extra volume (shown in the third picture) after the expansion is

A) 0.0000001% B) 0.001% C) 0.1% D) 0.3%

E) There is not enough information



each part:
≈0.1% of original volume

Clicker: When heated, each side of a cube of material expands by 0.1%. As a percentage of the original volume of the cube, the extra volume (shown in the third picture) after the expansion is

Since sides are L, L, $0.1\% \times L$

A) 0.0000001%

B) 0.001%

C) 0.1%

D) 0.3%

so volume $0.1\% \times L^3$

E) There is not enough information

total: 0.3%

Mathematical derivation:

original volume: L^3

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

so 0.3% bigger

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

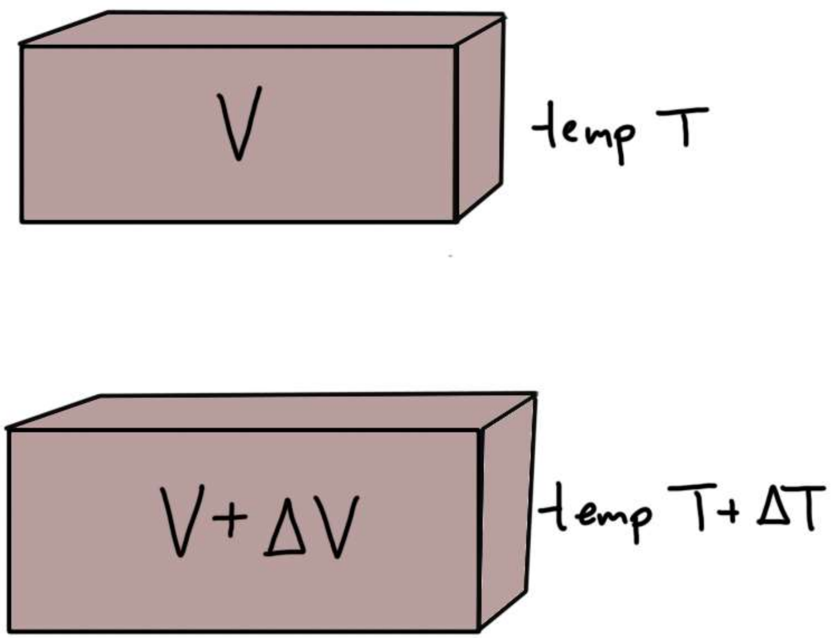
$$\frac{\Delta V}{V} = 3 \cdot \frac{\Delta L}{L} + 3\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta L}{L}\right)^3$$

this means

$\beta = 3\alpha$

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

Volume expansion:

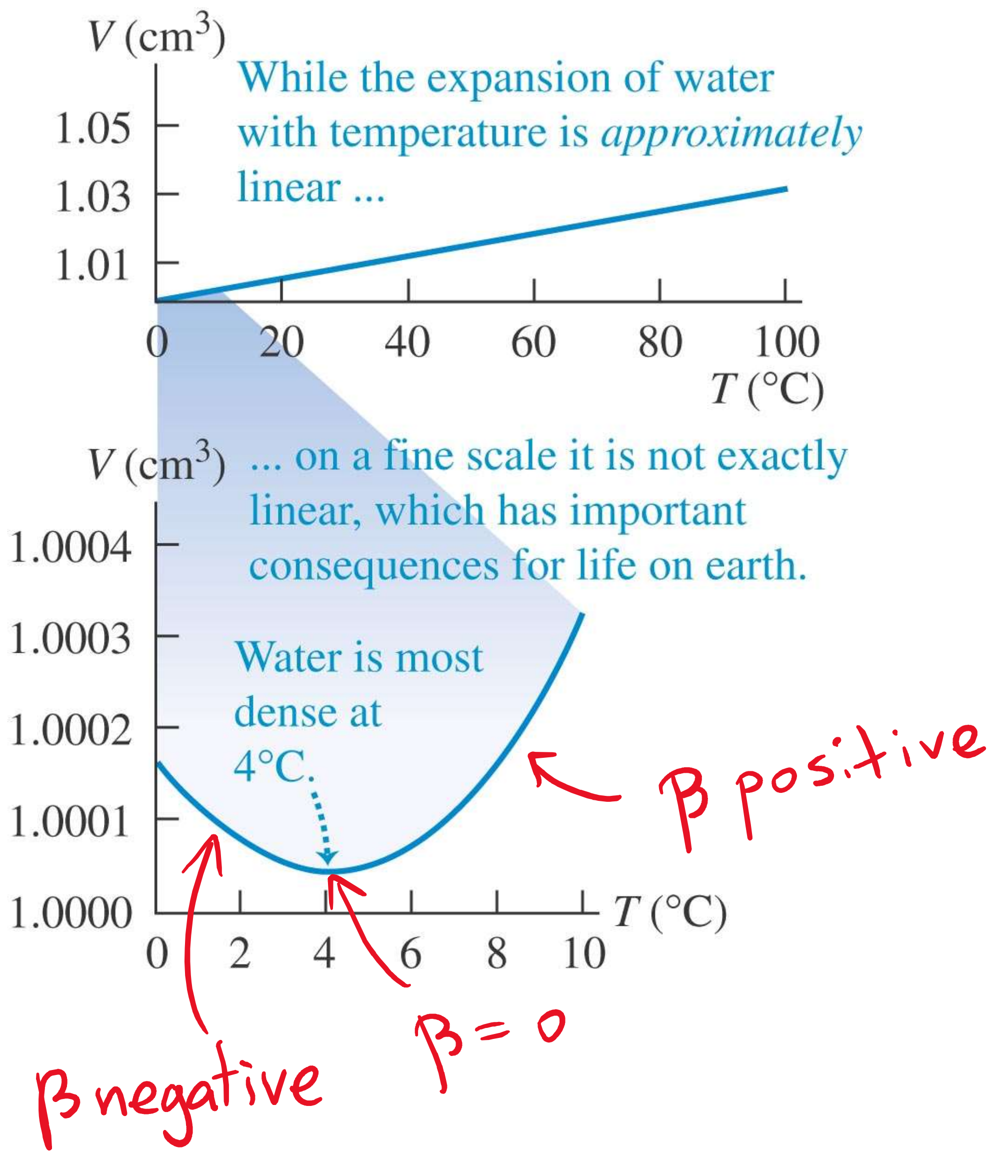


$$\boxed{\Delta V = \beta V_0 \Delta T}$$

$\beta = 3\alpha$ for solids

also applies to liquids

- Water, a special example



Back to stress & strain

Clicker: Which of these is closest to the order of magnitude of the Young's modulus of your marshmallow?

A. 10^2 Pa
B. 10^4 Pa
C. 10^6 Pa
D. 10^8 Pa
E. 10^{10} Pa

Clicker: Which of these is closest to the order of magnitude of the Young's modulus of your marshmallow?

A. 10^2 Pa
B. 10^4 Pa
C. 10^6 Pa
D. 10^8 Pa
E. 10^{10} Pa

$$\frac{\Delta l}{l} \sim 0.1$$

$$F = mg \sim 1\ N$$

$$1\ cm^2 < A < 10\ cm^2$$

$10^{-4}\ m^2$ $10^{-3}\ m^2$

$$Y = \frac{F/A}{\Delta l / l}$$ between 10^4 and 10^5

Clicker: Do you expect that the Young's modulus you measured for a marshmallow is higher or lower than for steel?

A. Higher

B. Lower

C. Could be higher or lower depending on the relative dimensions of the steel/marshmallow

$$\boxed{\frac{F}{A} = Y \frac{\Delta L}{L_0}}$$

Clicker: Do you expect that the Young's modulus you measured for a marshmallow is higher or lower than for steel?

Y only depends on what the object is made of, not its size

A. Higher

B. Lower

$\frac{F}{A} = Y \frac{\Delta L}{L}$: Y bigger if it takes more force to give same change in L.

C. Could be higher or lower depending on the relative dimensions of the steel/marshmallow

Y has units of pressure: roughly, the pressure required to produce a significant fractional change in length.

Young Modulus of Various Materials

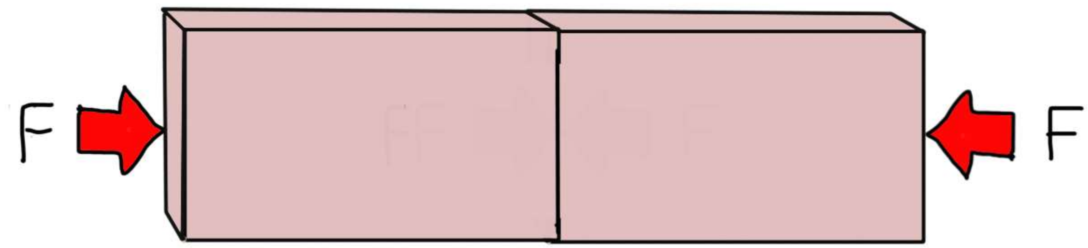
Material	Young's Modulus, *Y* (Pa)
Aluminum	7.0×10^{10}
Brass	9.0×10^{10}
Copper	11×10^{10}
Crown glass	6.0×10^{10}
Iron	21×10^{10}
Lead	1.6×10^{10}
Nickel	21×10^{10}
Steel	20×10^{10}

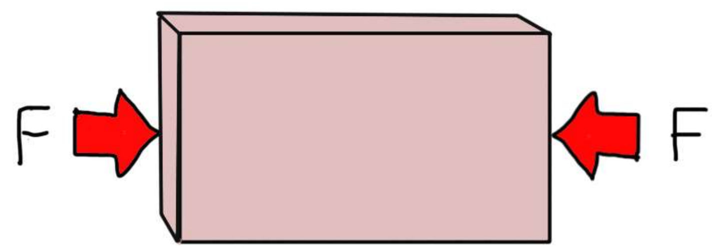
Clicker: In the top picture, the force on the right brick from the left brick has magnitude

A) 0

B) F

C) 2 F



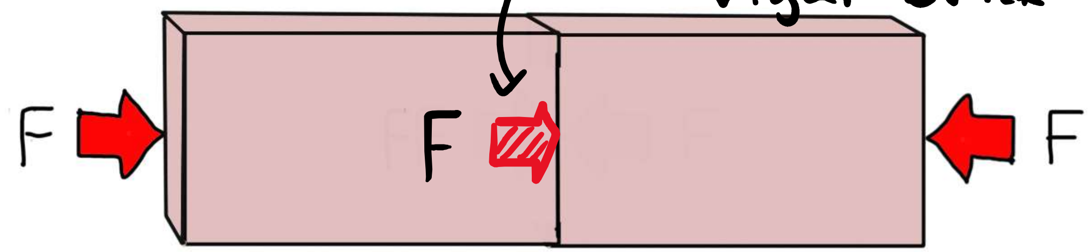


All forces shown have the same magnitude.

EXTRA: How much is the right brick compressed compared to the brick in the bottom picture?

Clicker: In the top picture, the force on the right brick from the left brick has magnitude

force from left brick on right brick

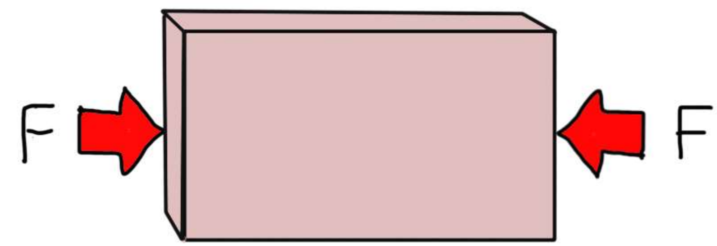


A) 0

B) F

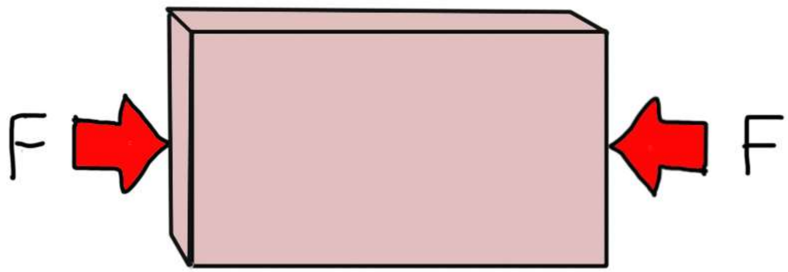
C) 2 F

- bricks not moving so net force on right brick must be zero, so force of left brick on right exactly opposes force from right

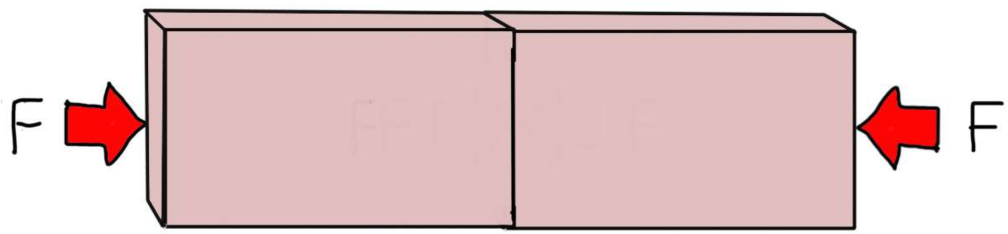


All forces shown have the same magnitude.

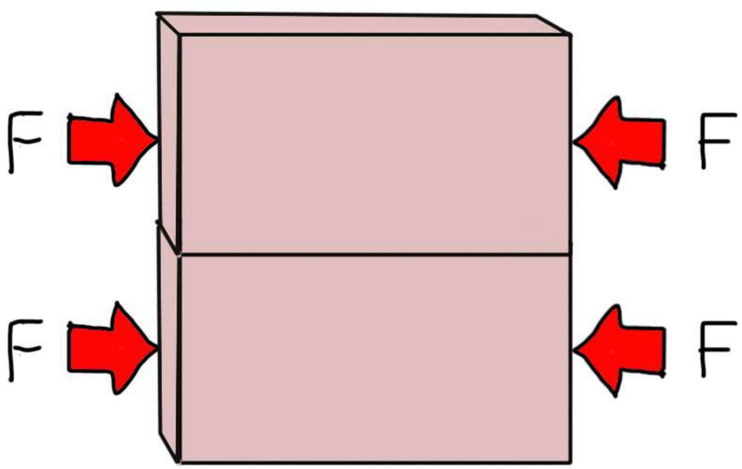
EXTRA: How much is the right brick compressed compared to the brick in the bottom picture? → same forces, same compression



$$Y = \frac{F/A}{\Delta L / L_0}$$



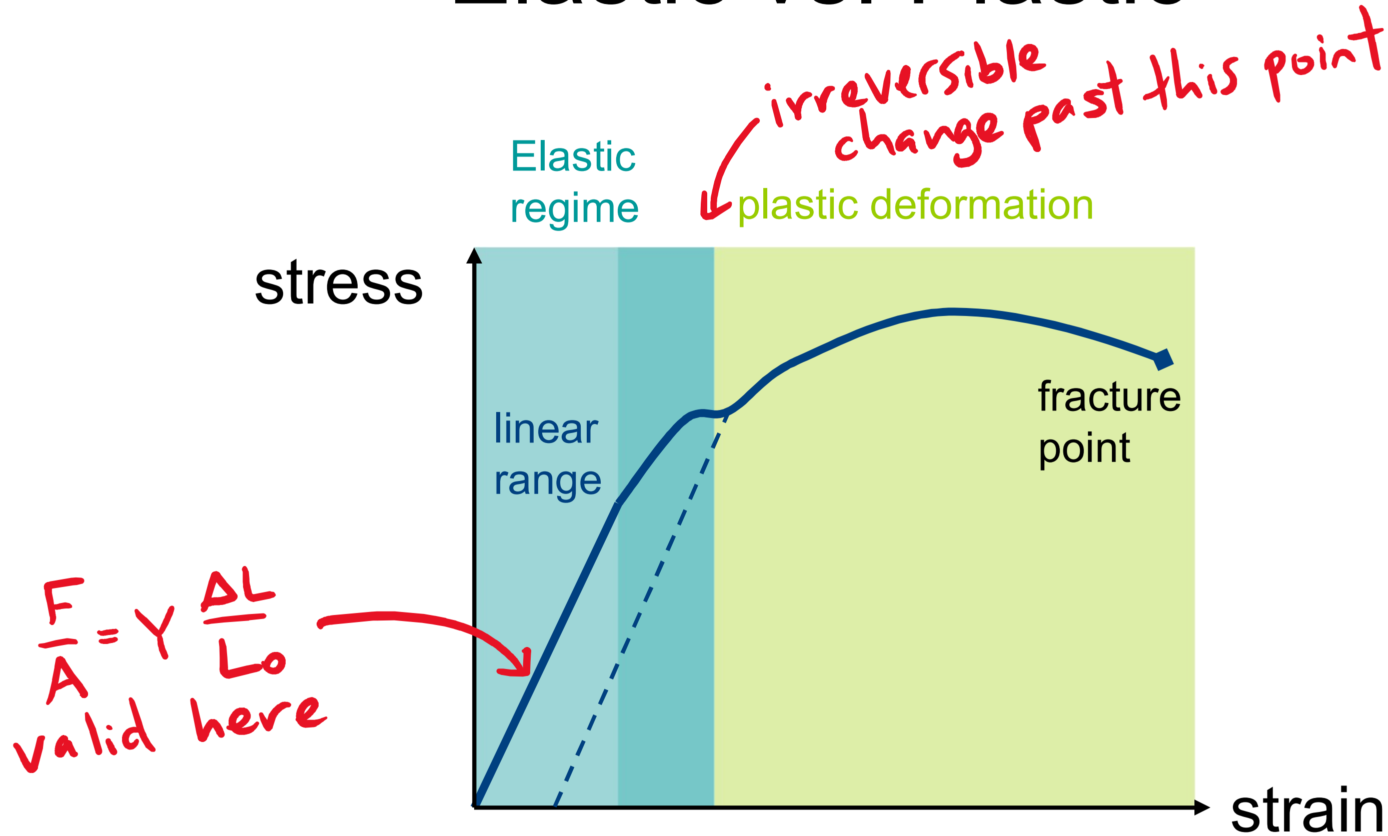
same F, A
double L_0, double ΔL
$\therefore$ same Y

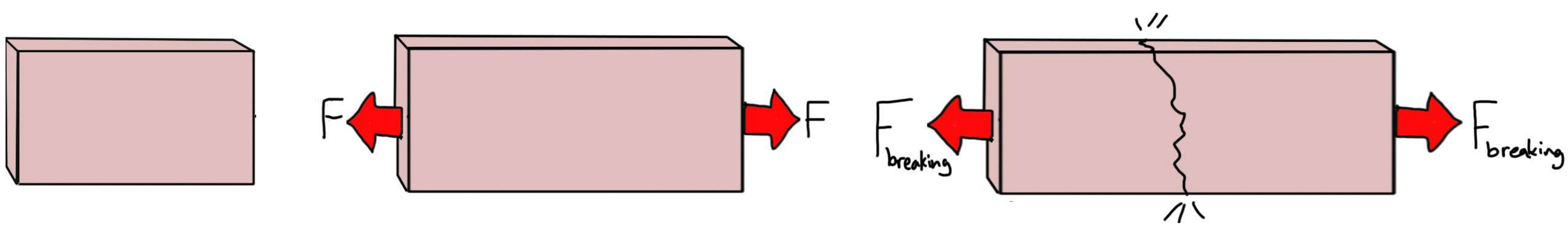


double F, double A
same ΔL, L
$\therefore$ same Y

Y is the same in all cases
→ it only depends on the material

Elastic vs. Plastic





Next time:

THERMAL STRESS: forces on a material preventing expansion/contration due to heating/cooling