Chapter 5: Common Forces

Monday, June 21, 2021 12:51

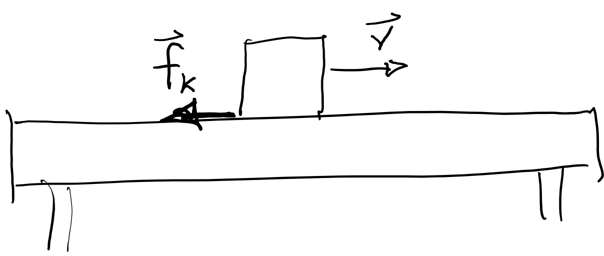
Last week: Newton's Laws

1. inertia - objects will keep moving at constant speed unless acted upon by an external force.
2. $F_{net} = ma$
3. every action has an equal + oppossite reaction.

today: some more common forces

5.1) friction - the force that opposes relative motion between two surfaces in contact.

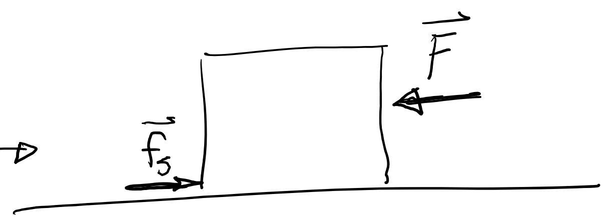
kinetic friction



moving box slowed down by friction with the table

static friction

friction prevents a weak force from moving a stationary box



- both cases: friction is proportional to the normal force.
- kinetic friction: $f_k = \mu_k N$

magnitude of kinetic friction

Coefficient of kinetic friction

magnitude of normal force

table 5.1 in book lists values of μ_k

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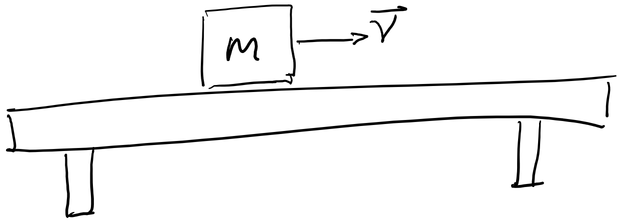
e.g. wooden box sliding on wooden table

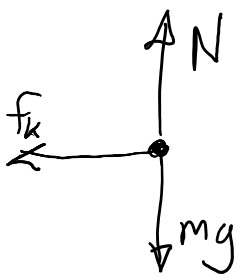
$m = 1.0\,kg$

$v_0 = 2\,m/s$



how much is it decelerating?

free body diagram



$$F_{net,y} = N - mg = ma_y = 0$$

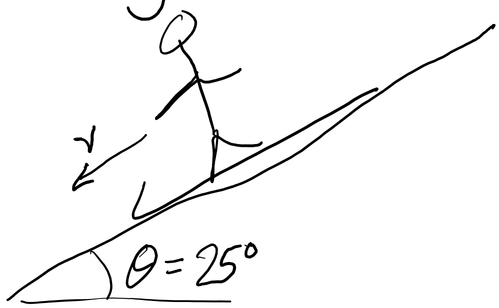
$$F_{net,x} = -f_k = ma_x$$

$$N - mg = 0 \qquad ma_x = -\mu_k N$$

$$N = mg \qquad ma_x = -\mu_k mg$$

$$a_x = -\mu_k g = -(0.3)(9.81\,m/s^2) = \boxed{-2.94\,m/s^2}$$

e.g. skiing down a slope

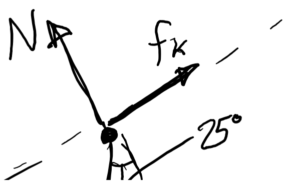


$m = 62\,kg$

$f_k = 45\,N$

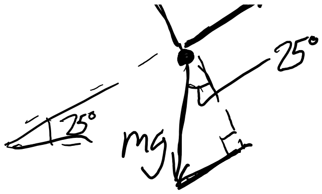
what is μ_k?

free body diagram



$$F_{net,\parallel} = mg\sin 25° - f_k = ma_\parallel$$

$$F_{net,\perp} = N - mg\cos 25° = 0$$



$$F_{net,\perp} = N - mg\cos 25° = 0$$

$$N = mg\cos 25° \qquad f_k = \mu_k N$$

$$f_k = \mu_k mg\cos 25°$$

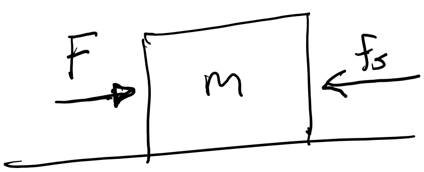
$$\mu_k = \frac{f_k}{mg\cos 25°} = \frac{45\,N}{(62\,kg)(9.8\,m/s^2)\cos 25°} = \boxed{0.082}$$

- static friction: $f_s \leq \mu_s N$ ← normal force

f_s ← static friction

μ_s ← coefficient of static friction

static friction will match the strength of the applied force until the applied force becomes too big.



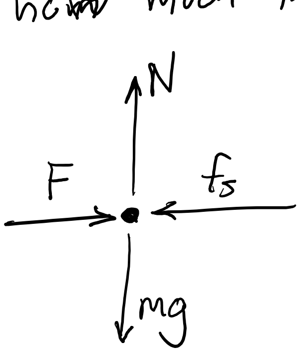
this force F is opposed by f_s.

if $F < \mu_s N$ then it stays still.

if $F \geq \mu_s N$ then it will start to move.

e.g. wood box on wood table. $m = 1.0\,kg$

how much force needs to be applied for it to move.



$$F_{net,x} = N - mg = ma = 0$$

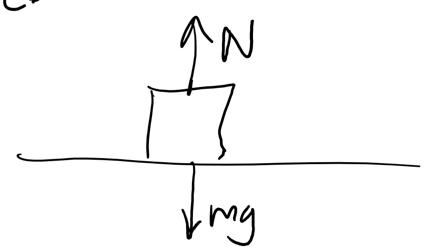
$$N = mg$$

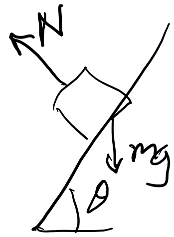
$$F \geq \mu_s N = (0.5)(1\,kg)(9.81\,m/s^2)$$

$$= \boxed{4.9\,N}$$

- generally $\mu_s > \mu_k$. This means it is harder to start

- generally $\mu_s > \mu_k$. this means it is harder to start something moving then to keep it moving.
- porportional to N. this means that heavier objects are slowed fastest. also means easier to move things on a slope.





$N = mg\cos\theta$

large N → large f

smaller N → smaller f

5.2 **drag** – the force that opposes motion through a **fluid**. (air resistance)

fluid → liquid or gas

$$\boxed{F_D = \frac{1}{2} C \rho A v^2}$$

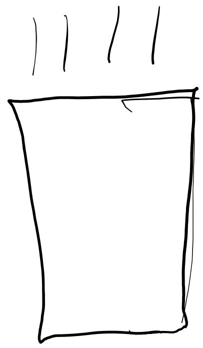
F_D: force of drag.

C: drag coefficient depends on the shape of the object.

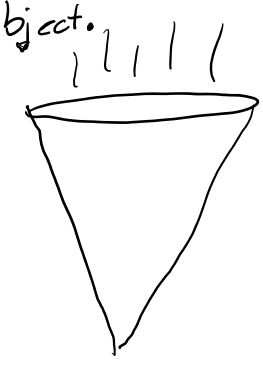
ρ: (mass) density of the fluid. (unit: kg/m^3)

A: Cross-sectional area of the object.

v: velocity of the object.



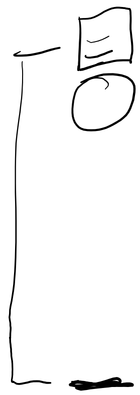
high drag



lower drag

table 5.2 lists some drag coefficients

terminal velocity - fastest speed an object can fall.



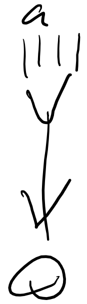
time how long it takes the sphere to fall.
want large height so more accurate measurements are easier.

$$F_{net,y} = F_D - mg = ma_y = 0$$

$$F_D = \frac{1}{2} C \rho A v^2 = mg$$

$$\boxed{v_t = \sqrt{\frac{2mg}{C\rho A}}}$$

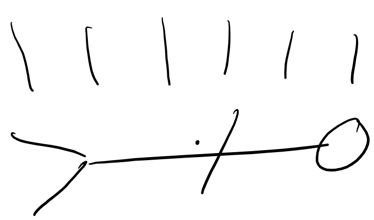
e.g. a skydiver falling headfirst



density of air: $\rho = 1.21 \ kg/m^3$
mass of skydiver: $m = 75.0 \ kg$
area of skydiver: $A = 0.18 \ m^2$
drag coefficient: $C = 0.70$

$$v_t = \sqrt{\frac{2(75 \cancel{kg})(9.8 \ m/s^2)}{0.7 (1.21 \cancel{kg}/m^{\cancel{3}})(0.18 \ \cancel{m^2})}} = \boxed{98 \ m/s}$$

$$= 350 \ km/hr$$



$\sim 200 \ km/hr$

The above only works for large, fast objects in less dense fluids.

if you are slow, small, or in a dense fluid you instead follow Stoke's law. (e.g. microorginisms, pollen, dust)

$$F_s = 6\pi r \eta v$$

velocity of object.

radius of object

viscosity of the fluid

water has low viscosity
honey has high viscosity
pitch has very high viscosity

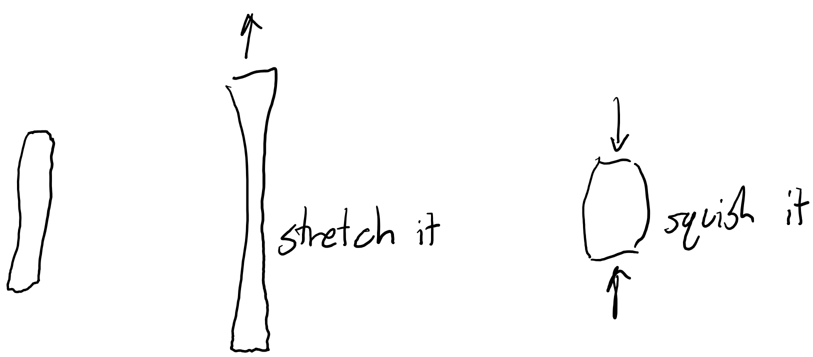
why can a squirrel jump from a tree branch to the ground and be unharmed?

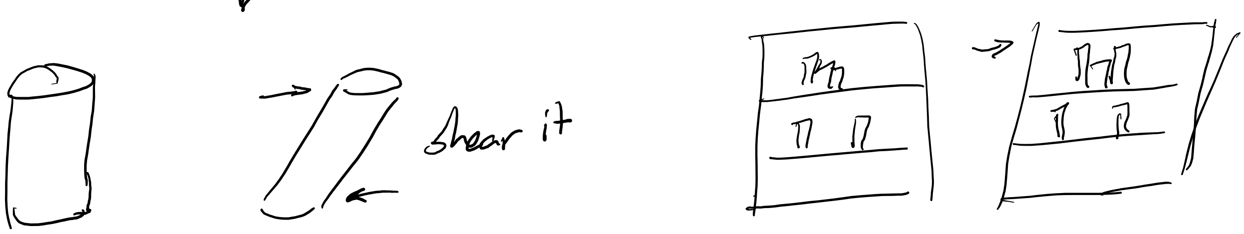
$$v_t = \sqrt{\frac{2mg}{\rho C A}}$$

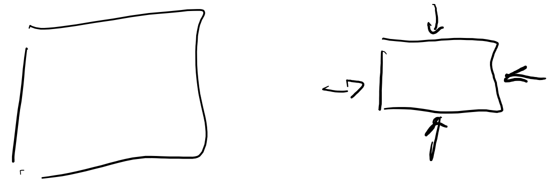
- squirrels weigh much less + thus have slower terminal velocity

5.3) elasticity

<u>deformation</u> - a change in shape due to an applied force



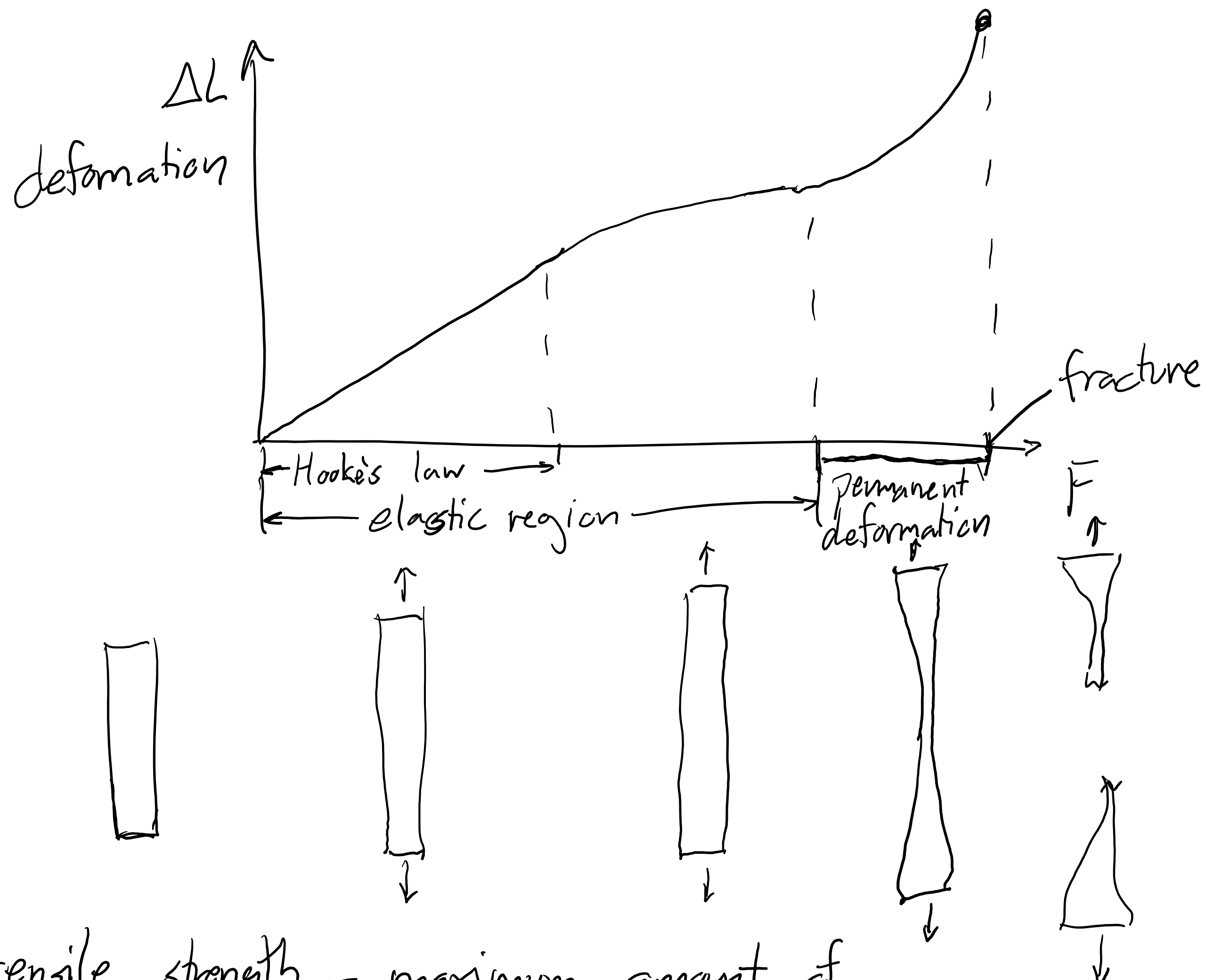




Hooke's law - relates the amount of deformation to the force

$$F = k \Delta L$$

force — constant — amount of deformation (e.g. change in length)

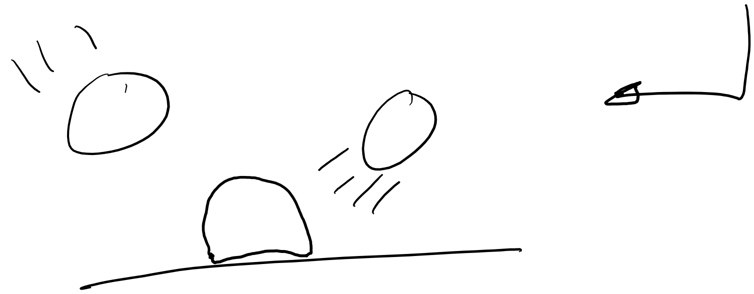


tensile strength - maximum amount of force that can be applied before permanent deformation

- for small forces + small deformations ($< \sim 0.1\%$) most materials will return to their initial state afterwards

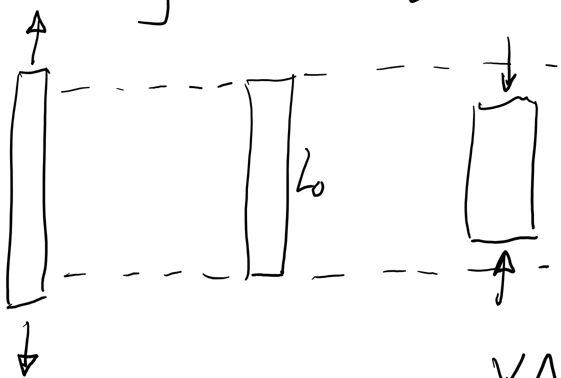
(elastic region)

- how springs work, how rubber bands work, why balls bounce



tension + compression

stretching squeezing



change in length force original length

$$\boxed{\Delta L = \frac{1}{Y}\frac{F}{A}L_0}$$

elastic modulus or Young's modulus cross-sectional area

Note: $F = \frac{YA}{L_0}\Delta L \leftarrow$ Hooke's law with $k = \frac{YA}{L_0}$

there is a list of values for Y in table 5.3

Note: often see this formula written as

$$\underbrace{\frac{F}{A}}_{\text{"stress" } (N/m^2)} = Y \underbrace{\frac{\Delta L}{L_0}}_{\text{"strain" (unitless)}}$$

e.g.

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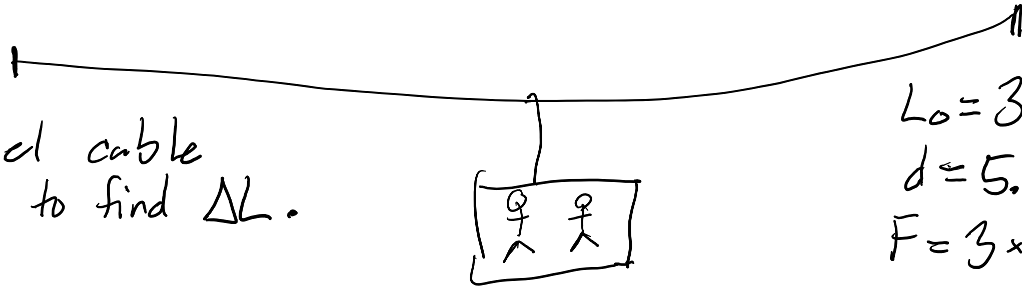


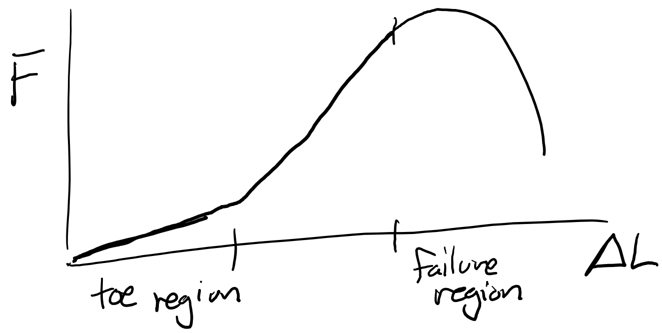
steel cable
want to find ΔL.

$L_0 = 3020\,m$
$d = 5.6\,cm$
$F = 3 \times 10^6\,N$

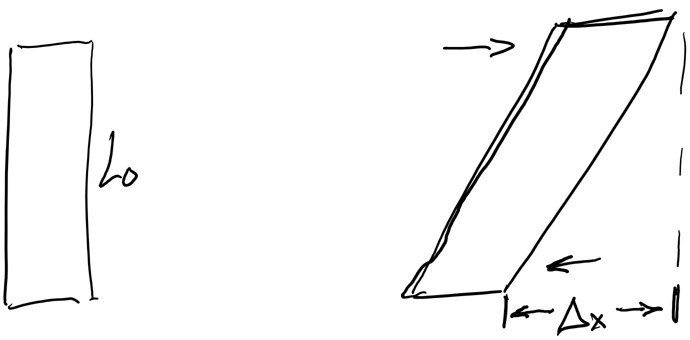
$$\Delta L = \frac{1}{Y}\frac{F}{A}L_0 = \frac{1}{\left(210 \times 10^9 \frac{N}{m^2}\right)} \underbrace{\frac{3 \times 10^6\,N}{\pi\left(\frac{0.056\,m}{2}\right)^2}}_{A = \pi r^2} (3020\,m)$$

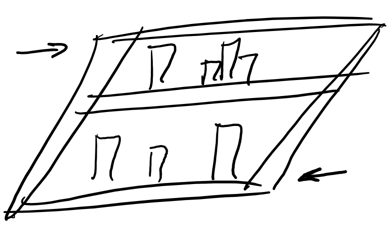
$$= \boxed{17.5\,m}$$

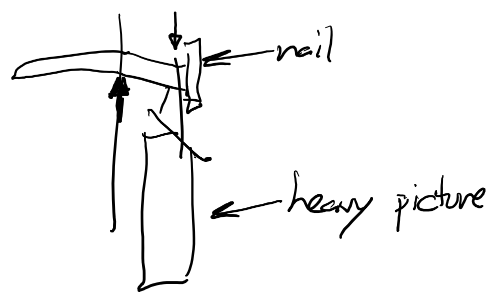
tendons



shear - sideways deformation







$$\Delta x = \frac{1}{S}\frac{F}{A}L_0$$

$$\Delta x = \frac{1}{S}\frac{F}{A}L_0$$

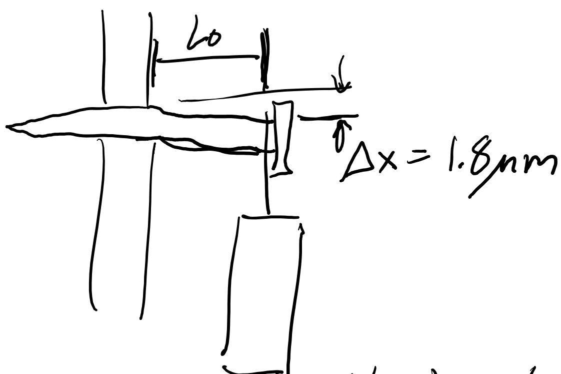
Δx: amount of shear

S: shear modulus

Usually: shear modulus < Young's modulus

easier to bend a nail than stretch a nail

e.g. find the mass hanging from a nail if it shears $1.8\,\mu m$ (its length is $L_0 = 5\,mm$, its radius is $r = 1.5\,mm$)



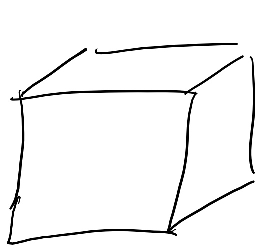
$$S = 80\times 10^9\, N/m^2$$

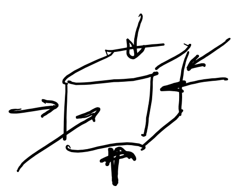
$$F = \frac{SA}{L_0}\Delta x$$

$$F = \frac{(80\times 10^9\, N/m^2)\,\pi\,(0.0015\,m)^2}{0.005\,m}(1.8\times 10^{-6}\,m) = 51\,N$$

$$F = mg \longrightarrow m = \frac{51\,N}{9.8\,m/s^2} = \boxed{5.2\,kg}$$

bulk deformation - change in volume





$$\Delta V = \frac{1}{B}\frac{F}{A}V_0$$

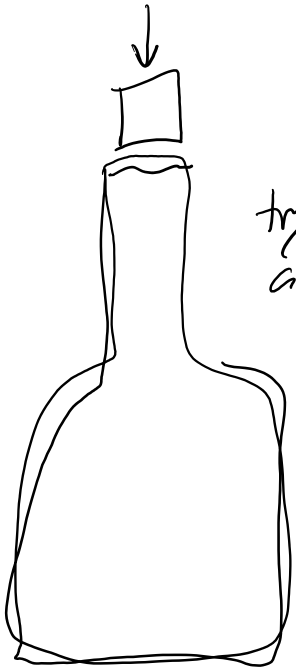
B: bulk modulus

e.g. how much is water compressed at the bottom of the ocean?

$$\frac{F}{A} = 5\times10^{7}\,\frac{N}{m^2}$$

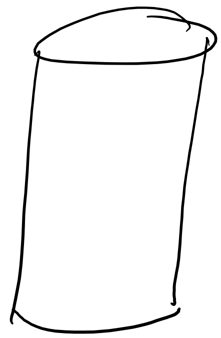
$$\frac{\Delta V}{V_0} = \frac{F/A}{B} = \frac{5\times10^{7}\,N/m^2}{2.2\times10^{9}\,N/m^2}$$

$$= 0.023 = \boxed{2.3\%}$$



try to put a cork in an overfull bottle

this takes way too much force



Cool a full Can of water past freezing

volume of can stays constant

volume water wants to be gets bigger