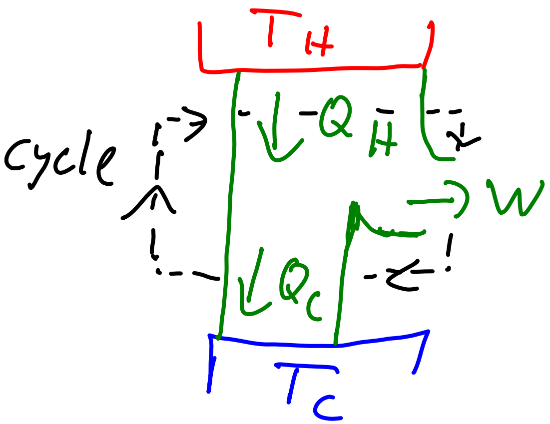
Recap: Heat and Work

Lecture 32

- 1st Law of Thermodynamics:

$$\Delta E_{int\ of\ system} = Q_{net\ added\ \underline{to}\ system} - W_{net\ \underline{by}\ system}$$

- Heat Engines:



- $|W| = |Q_H| - |Q_C| \Leftrightarrow \Delta E_{int}$ in one cycle $= 0$
- Efficiency ε:

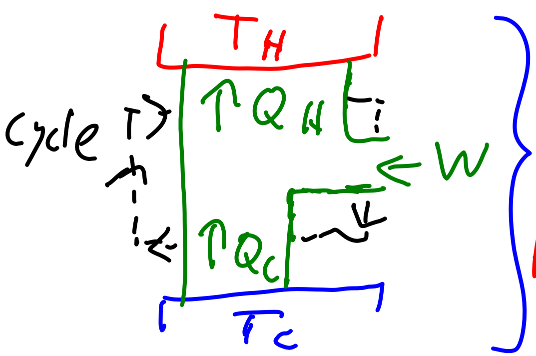
$$\varepsilon = \frac{\text{useful energy output}}{\text{energy we pay for}} = \frac{|W|}{|Q_H|} = 1 - \left|\frac{Q_C}{Q_H}\right|$$

- max. efficiency: Carnot efficiency

$$\varepsilon_{max} = 1 - \frac{T_C}{T_H} < 1 \Leftrightarrow \left|\frac{Q_C}{Q_H}\right| = \frac{T_C}{T_H} \Big\} \text{at } \varepsilon_{max}$$

(T_H ← in kelvin!!)

- Refrigerators:



- $|Q_H| = |Q_C| + |W|$
- Coefficient of Performance:

$$K = \frac{\text{useful out}}{\text{energy we pay for}} = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|} \leq \overbrace{\frac{T_C}{T_H - T_C}}^{\text{Carnot}}$$

The atmospheric pressure from the air above you presses against all parts of your body. What is the **force against every square-inch** of your skin?

A. 8 N (~1.9 lb)

B. 16.5 N (~3.7 lb)

C. 33 N (~7.5 lb)

D. 66 N (~15 lb)

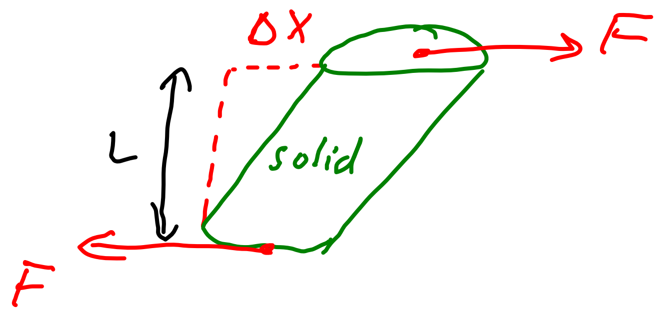
E. 132 N (~30 lb)

1 atm = 15 psi

So far: Forces on solids:

Solid:

- well defined shape
- atoms are at well defined positions
- can sustain shear:



$$\frac{F}{A} = G \frac{\Delta X}{L}$$

G: shear modulus

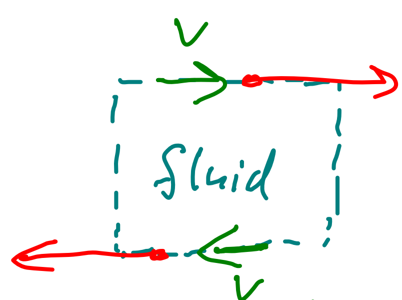
G > 0 for solids

⇒ useful quantities:
mass, forces, ...

Now: Fluids (liquid or gas) and forces

Fluids:

- conform to container
- atoms/molecules are in relative translational motion ⟹ fluid flow
- can not sustain shear forces



$\Delta x \to \infty$ for a finite force

⟹ $G = 0$ for fluids

(good definition for fluids)

↖ shear flow of fluid instead of deformation

⟹ useful quantities: density, pressure

→ **Density ρ:** ("replaces" mass)

$$\rho_{fluid} = \frac{m}{V}$$

m ← mass of fluid

V ← volume of fluid

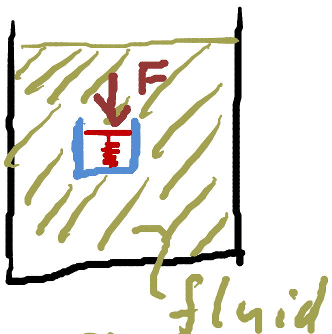
$$[\rho] = \frac{kg}{m^3}$$

Example:

- $\rho_{water} = 1000 \ kg/m^3$
- $\rho_{air} = 1.2 \ kg/m^3 \approx \frac{1}{800} \rho_{water}$
- $\rho_{Hg} = 13{,}600 \ kg/m^3$

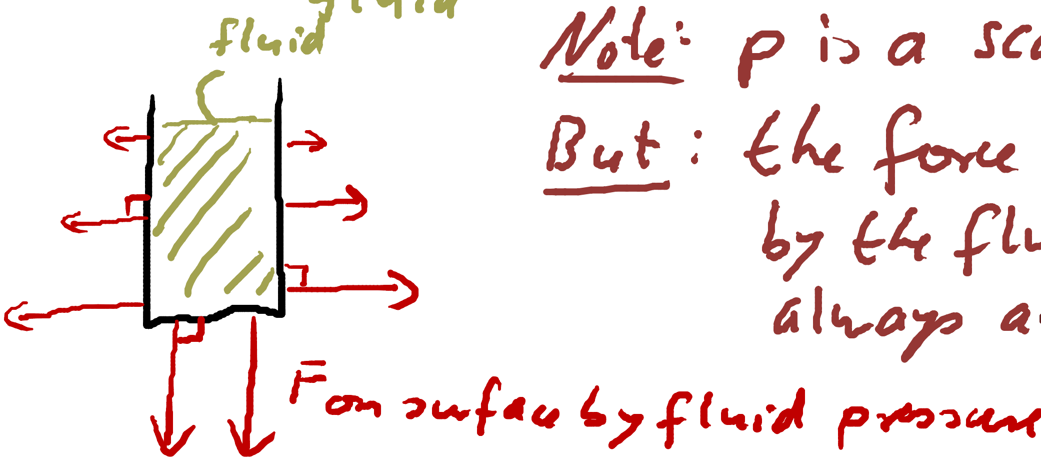
→ Pressure P : ("replaces" force)

$$P = \frac{F}{A} = \frac{\text{uniform force exerted on a surface by a fluid}}{\text{area of flat surface}}$$



$$[P] = \frac{N}{m^2} = Pa = \text{Pascal}$$

$$= \frac{Nm}{m^3} = \frac{J}{m^3} = \text{"energy density"}$$



Note: p is a scalar (no direction)

But: the force exerted on a surface by the fluid due to its pressure always acts perpendicular to surface!

other units for pressure:

1 atm = P_{atm} at sea level $= 1.01 \cdot 10^5$ Pa

$= 101$ kPa

$= 14.7$ lb/in^2 (tires, ...)

$= 760$ torr (vacuum systems, ...)

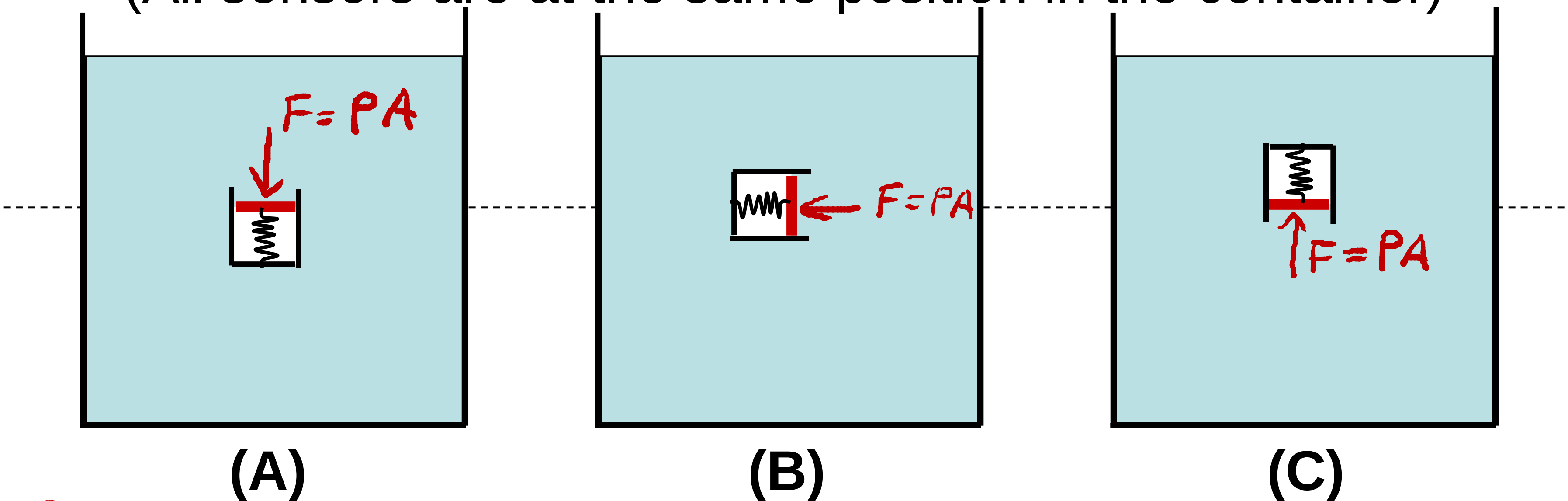
$= 1000$ millibars

1 Torr = "1 mm of Hg" = pressure difference corresponding to height/level difference of $h = 1$ mm in a mercury-filled manometer

(bood pressure ...)

Three identical water-filled containers are shown below.

Which pressure sensor reads the **largest pressure**?
(All sensors are at the same position in the container)



• same position
⇒ same pressure

• same A
⇒ same |F|

Note: $\vec{F}$ always ⊥ to surface

A. (A)

B. (B)

C. (C)

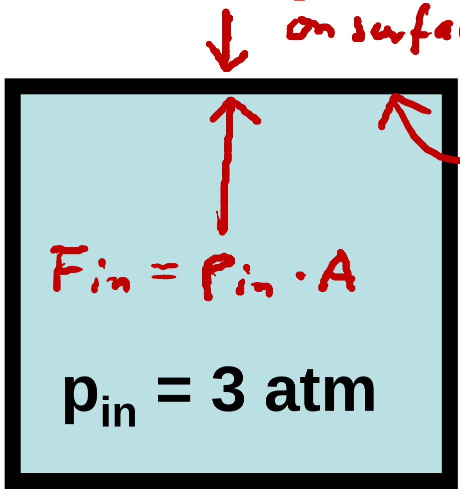
D. All pressures are the same

A container is filled with gas at a pressure of $\mathbf{p_{in}=3\ atm}$. The outside is a atmospheric pressure.

What is the net force on the top surface of area *A* of the container from the gas pressures?

$P_{out} = 1\,atm$

$F_{out} = P_{out} A$ on surface



F_{net}= ? (from gas pressures only)

A. **1 atm * A**

B. **2 atm * A**

C. **3 atm * A**

D. **2 atm / A**

E. **3 atm / A**

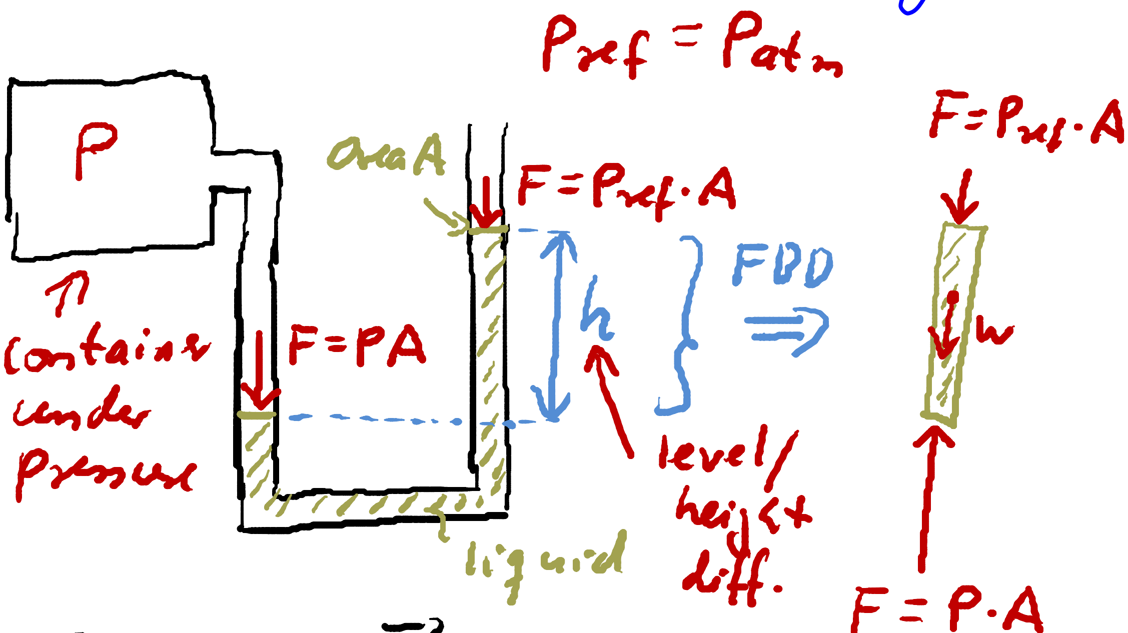
$|F_{net}| = |F_{in}| - |F_{out}|$ from pressures

$= P_{in}A - P_{out}A$

$= \Delta P A$

$= (3\,atm - 1\,atm) \cdot A = \underline{2\,atm\ A}$

→ Measuring Pressure (- differences)



- if $p > P_{ref}$, fluid rises by h
- $\Delta P = p - P_{ref}$ is just enough to support weight of liquid in volume $V = A \cdot h$

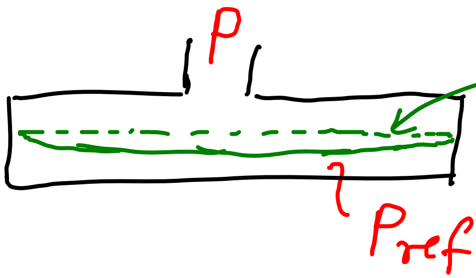
⟹ need $\sum \vec{F} = 0$ ⟹ $(p - P_{ref})A = W_{liquid} = m_{liquid} \cdot g$

$= \rho_L V g = \rho_L A h g$

⟹ $\Delta P = p - P_{ref} = \rho_L g h$ (← ρ_L: density of liquid)

} note: reads $\Delta p = p - P_{ref}$, not p

• Strain gauge pressure sensor:



membrane

→ bends due to $\Delta p = p - p_{ref}$

→ creates strain in membrane

→ sensor converts strain into an electric signal

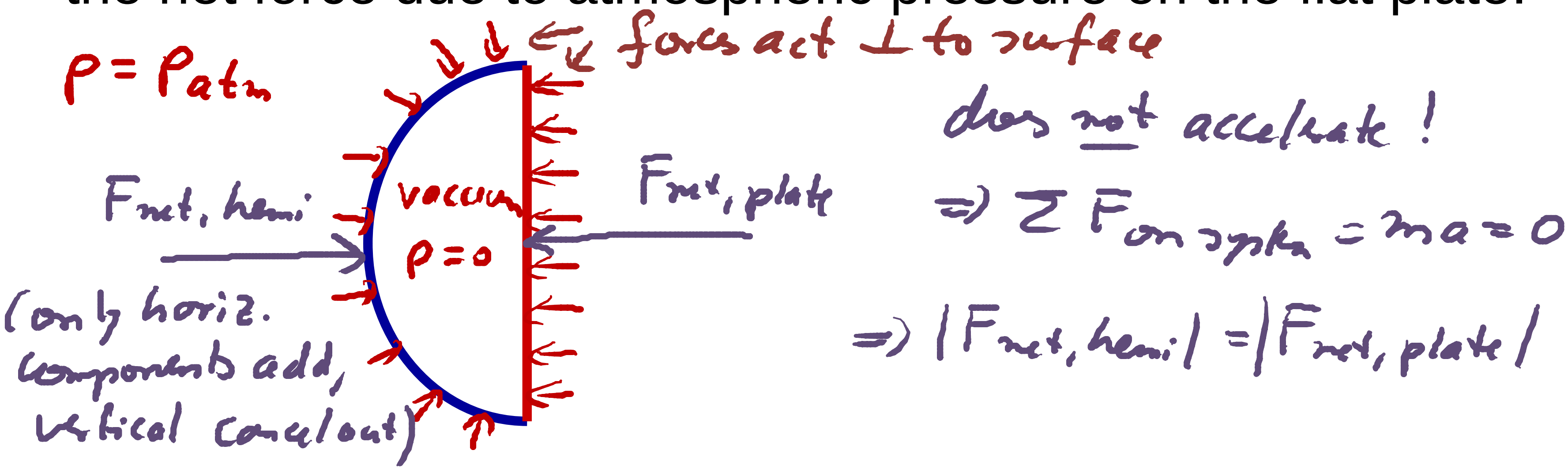
⇒ reads $p_{gauge} = \Delta p = p - p_{ref}$

A hollow **hemisphere** is placed against a **flat circular plate** of the same radius *r*. **The air in between is pumped out so that atmospheric pressure *P* holds them together.**

The **net force** on the outer surface of the hemisphere due to atmospheric pressure is:

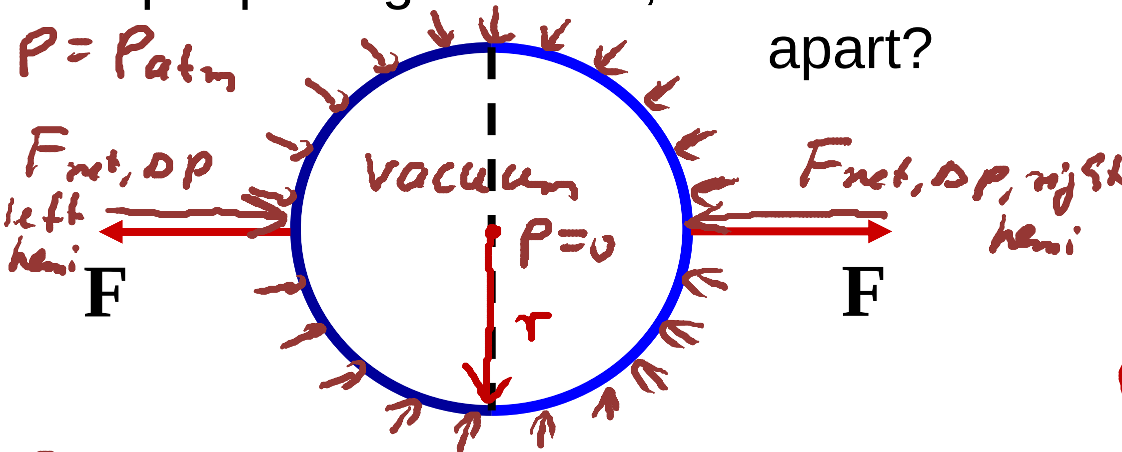
A. less than B. the same as C. greater than

the net force due to atmospheric pressure on the flat plate.



Two hollow **hemispheres** of **radius *r*** are placed against each other. The air in between is pumped out so that **atmospheric pressure *P* pushes them together**.

If two people tug on them, what force much each exert to pull them apart?



from previous problem:

$|F_{hemi, net}| = |F_{flat\ plate\ of\ same\ radius\ r}|$

$= P_{atm} \cdot A_{flat\ plate} = P_{atm} \cdot \pi r^2$

$\Rightarrow F > \pi r^2 P_{atm}$ to pull apart

F = ?

A. $\pi r^2 p / 2$

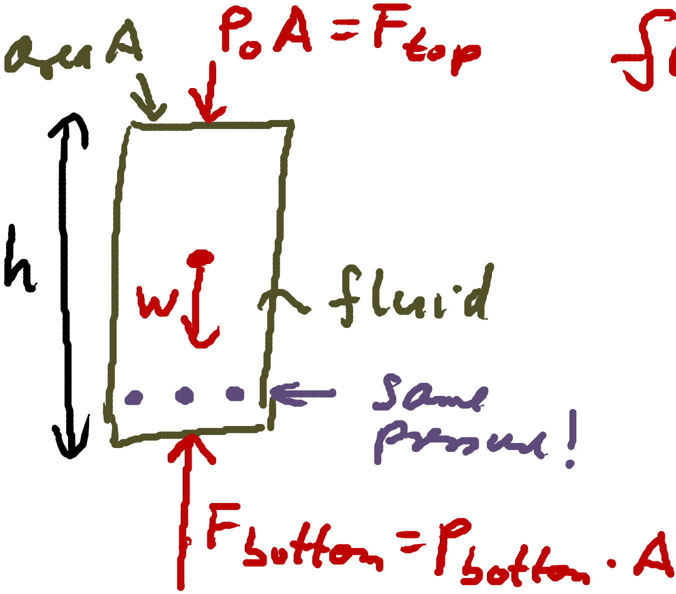
B. $\pi r^2 p$

C. $2 \pi r^2 p$

D. $4 \pi r^3 p / 3$

E. $\pi r^3 p$

→ Pressure Variation with Depth in a Liquid:



For static fluids only!

p in a static fluid at a given depth h must support weight/area of everything above it!

need $\Sigma \vec{F} = 0 \Rightarrow$

$$|F_{bottom}| = |W| + |F_{top}|$$

$$\Rightarrow P_{bottom} A = W + P_0 A$$

$$\Rightarrow \boxed{P_{bottom} = P_0 + \frac{W}{A}}$$

⇒ p in a static fluid depends on the depth h only!