Pressure

Select LEARNING OBJECTIVES:

- Introduce the macroscopic definition of pressure.
- Differentiate between atmospheric pressure, gauge pressure, and total pressure.
- Construct FBDs which include an associated net force due to a pressure difference.

TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7th) :: 10-4
- Knight (College Physics : A strategic approach 3rd) :: 13.2
- BoxSand :: Pressure

WARM UP: Suppose you measure a 10 N force exerted by on object resting on a table. You then divide this force by the contact area between the object and the table; you measured 2 m^2. How do you interpret the number 10/2 ? Basically, what does this number mean to you?

$\frac{10\ N}{2\ m^2} = 5\ \frac{N}{m^2} \longrightarrow$ AMOUNT OF FORCE FOR EVERY SQUARE METER OF CONTACT SURFACE

Pressure plays an important role in fluid mechanics because pressure gradients cause an associated net force. And as we will see in the hydrostatic section, there exists a pressure gradient in a fluid that is near a massive object like the Earth. So pressure and the associated net force due to pressure gradients are the foundations upon which we will build our fluid mechanics models.

While standing on a horizontal patch of ice, the normal force that you apply on the ice is equal to the force of gravity from the earth on you (mg). The ice supports this normal force no matter how you stand on the ice (e.g. lay down or stand with high heels on). However, you might already know that you would feel much more safe lying down on thin ice than standing with high heels on. Even though the ice is supporting the same weight (mg), the ice is more likely to break if you wear the high heels, thus we must introduce a new quantity to differentiate between these two scenarios. The new quantity introduced is called pressure. Pressure is defined as the perpendicular component of force divided by the area that the force is applied to. Mathematically this is written as…

$$\boxed{P = \frac{F_\perp}{A}}$$

*SI UNITS $\longrightarrow \frac{N}{m^2} \equiv$ PASCAL (Pa) $\quad 1\ \frac{N}{m^2} = 1\ Pa$

Notice how it is only the perpendicular component of force. Since area is a scalar and the perpendicular component of force is a scalar, then pressure must also be a scalar.

*NOTE: Pressure is often written as P = F/A , where it is implied that the force is only the perpendicular component.

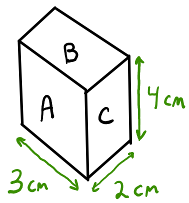
Pressure plays an important role in fluid mechanics because pressure differences cause an associated net force.

$$\boxed{\text{PRESSURE DIFFERENCES} \Longrightarrow \Sigma \vec{F}}$$

As we will see in the hydrostatics section, there exists a pressure gradient within a fluid near a massive object like the Earth - the pressure increases the deeper you go in the fluid. So pressure and the associated net force due to pressure differences are the foundations upon which we will build our fluid mechanics models.

PRACTICE: A rectangular block is at rest on a table. Three faces of the block are labeled A, B, and C. Face A has dimensions 3 cm x 4 cm; face B has dimensions 2 cm x 3 cm; and face C has dimensions 2 cm x 4 cm.

Rank the pressure exerted by the block on the table when it is resting on each labeled face.



$$P = \frac{F_\perp}{A}$$

w/ $m = \text{const}$

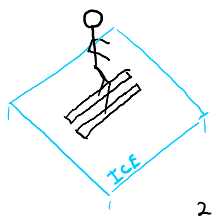
$F_\perp = \text{const}$

THEN $P \propto \frac{1}{A}$

w/ $A_A > A_C > A_B$

THEN $\boxed{P_A < P_C < P_B}$

PRACTICE: A 95 kg man walks out onto ice with cross-country skis that have a width of 12 cm. What length ski must he have if he is not to break the ice, assuming the ice breaks if the pressure exceeds 2040 N/m^2 ?



$$P_{max} = \frac{F_\perp}{A_{min}}$$

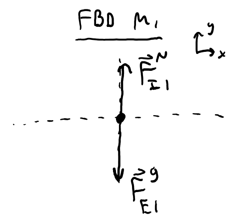
$$P_{max} = \frac{F_\perp}{2A_{min}}$$

2 SKIS

$$P_{max} = \frac{F_\perp}{2L_{min}W}$$

1 EQN 2 UNKNOWNS

$F_\perp = F_\perp^{ICE} = |\vec{F}^N| \ldots$ FBD...



$\Sigma F_y = m_1 \cancel{a_{1y}}^{\,0}$

$|\vec{F}^N_{I1}| - |\vec{F}^g_{E1}| = 0$

$|\vec{F}^N_{I1}| = m_1 g$

1 EQN 1 UNKNOWN

$$P_{max} = \frac{m_1 g}{2L_{min}W}$$

$$\boxed{L_{min} = \frac{m_1 g}{2P_{max}W}} \approx 1.90 \text{ m OR } 190 \text{ cm}$$

Atmospheric pressure (P_{atm})

We live in a mixture of gasses (the atmosphere) that surrounds us in all directions. Consider a column of atmosphere directly above us. This column of atmosphere has an associated weight, and just like our ice example, this atmospheric weight is supported by the surface of the Earth, or our heads as we stand on the Earth's surface. Thus if we consider the force that this column of atmosphere applies over the area of the column, we can define a pressure due to the atmosphere near the Earth's surface. The actual atmospheric pressure is complicated, depending on temperature, height, humidity, etc… However, at sea level in standard conditions according to the International Standard Atmosphere model (ISA), the standard atmospheric pressure is 101.325 kPa. This value is also defined as 1 atmosphere (atm).

$$1 \text{ atm} = 101.325 \text{ kPa}$$

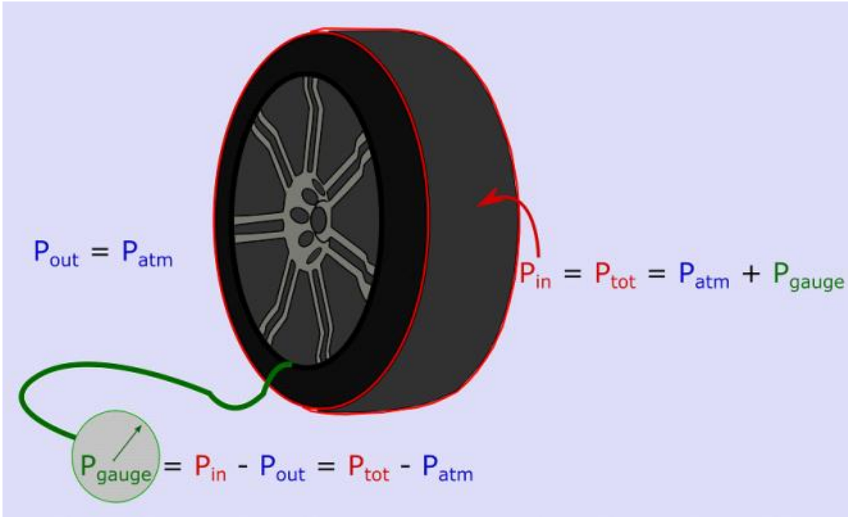
Gauge pressure (P_g)

The devices we use to measure pressure within a closed container often measure the pressure difference between the inside of a container and the outside. For example, if you use a tire pressure gauge to measure the pressure in your car tires, you are really measuring the difference between the outside atmospheric pressure and the total pressure inside the tire (as seen in the figure below under the absolute pressure section).

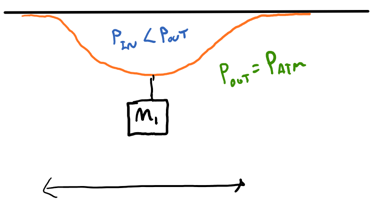
Absolute pressure (P_{abs})

The absolute pressure is then the sum of the atmospheric pressure and gauge pressure.

$$\boxed{P_{ABS} = P_{ATM} + P_g}$$



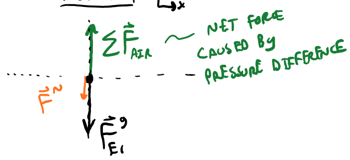
PRACTICE: A 10.0 cm diameter suction cup is pushed against a smooth ceiling. What is the theoretical maximum mass of an object that can be suspended from the suction cup without pulling it off the ceiling? The mass of the suction cup is negligible. P_{atm} = 101.3 kPa.



$d = 0.1\ m$

$r = \frac{d}{2}$

FBD m_1



$$\Sigma F_y = m_1 \cancel{a_{1y}}^{0}$$

$$|\Sigma \vec{F}_{air}| - |\vec{F}^g_{E1}| - |\vec{F}^N| = 0$$

$$A\Delta P - m_1 g - \cancel{|\vec{F}^N|}^{0} = 0$$

AT MAX m... $\vec{F}^N \to \vec{0}$

$$A(P_{OUT} - \cancel{P_{IN}}^{0}) - m_{1max} g = 0$$

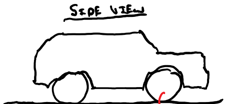
$$A P_{OUT} = m_{1max} g$$

$$\pi r^2 P_{ATM} = m_{1max} g$$

$$m_{1max} = \frac{\pi r^2 P_{ATM}}{g} \approx 81\ kg$$

PRACTICE: The gauge pressure in each of the four tires of a car is 35 PSI (pounds per square inch). You measure the area of contact for a single tire to be about 161.5 cm^2. Estimate the mass of the car.
1 PSI = 6.89476 kPa

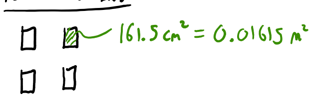
SIDE VIEW



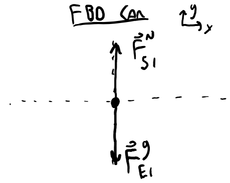
$P_g = 35\ PSI$

$\underbrace{P_g = 241317\ Pa}$

TOP VIEW OF TIRES



FBD CAR



$$\Sigma F_y = m_1 \cancel{a_{1y}}^{0}$$

$$|\vec{F}^N_{S1}| - |\vec{F}^g_{E1}| = 0$$

$$|\vec{F}^N_{S1}| = m_1 g$$

$$P_g = \underbrace{P_{IN} - P_{OUT}}$$

$P_g = \Delta P \to$ FORCE

$$P_g = \frac{F_\perp}{A}$$

$\frac{1}{4}|\vec{F}^N|$ — 4 TIRES

$$P_g = \frac{m_1 g}{4A}$$

$$m_1 = \frac{4AP_g}{g} \approx 1590\ kg$$

QUESTIONS FOR DISCUSSION:

(1) Consider what happens when you push both a pin and the blunt end of a pen against your skin with the same force. Decide what determines whether your skin is cut; the net force applied or the pressure.