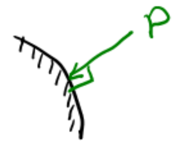
INTRODUCTION TO PRESSURE

In this lesson, we will:

- Define **pressure** and discuss three types of pressure measurement – **absolute pressure**, **gage pressure**, and **vacuum pressure**
- Discuss **equivalent column height** or **head** and its usage
- Do some example problems

P, T



Pressure Principles

- Pressure is a ***scalar*** and is defined at a ***point*** in a fluid.
- Pressure is a ***normal stress*** with dimensions of force per unit area.
- Common units of pressure are atmospheres (**atm**), pascals (**Pa**), kilopascals (**kPa**), bar (**bar**), and pound-force per square inch (**psi**).

Absolute Pressure

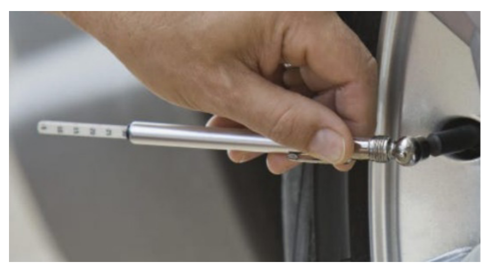
- Always use ***absolute pressure***, ***P*** or P_{abs}, in equations where *P* stands alone as, for example, in the ideal gas law, $\boxed{P = \rho RT}$. P is the same as P_{abs}
  abs abs
- When analyzing a *change* in pressure, however, either absolute or relative pressure can be used, provide that the units are consistent. $\Delta P = P_2 - P_1$

Similar to $\Delta T = T_2 - T_1$ [°C or K]

Gage (or gauge) pressure

- ***Gage pressure***, P_{gage}, is the value of pressure ***above*** local atmospheric pressure, $\boxed{P_{gage} = P_{abs} - P_{atm}}$. ✱

Example: Gage Pressure



Given: Jared measures the air pressure in his car tire with a tire pressure guage. The reading is 241.3 kPa. The local atmospheric pressure is 99.62 kPa.

To do: Calculate the absolute pressure inside the tire and give answers in kPa, atm, bar, and psi.
✓ ✓ ✓ ✓

Solution:

$$P_{abs} = P_{atm} + P_{gage} = (99.62 + 241.3)\text{ kPa} = 340.92\text{ kPa}$$

$$\boxed{P_{abs} = 340.9\text{ kPa}}$$

$$P_{abs} = (340.92\text{ kPa})\left(\frac{1\text{ atm}}{101.325\text{ kPa}}\right) = \boxed{3.365\text{ atm}}$$

close

$$\text{"} \quad \text{"} \quad \left(\frac{1\text{ bar}}{100\text{ kPa}}\right) = \boxed{3.409\text{ bar}}$$

$$\text{"} \quad \text{"} \quad \left(\frac{1\text{ psi}}{6.894757\text{ kPa}}\right) = \boxed{49.45\text{ psi}}$$

[or 49.45 psia]

[psia — absolute
psig — gage]

Vacuum Pressure

- ***Vacuum pressure***, P_{vac}, is the value of pressure ***below*** local atmospheric pressure, $P_{vac} = P_{atm} - P_{abs}$. ★ NOTE: $\boxed{P_{vac} = -P_{gage}}$ ★
- P_{vac} is a ***positive*** value, used only when $P < P_{atm}$ (absolute pressure < local atmospheric pressure) as, for example, in a vacuum chamber. $\boxed{\text{use } P_{vac} \text{ only when } P_{vac} > 0}$ ★

Not proper to use a negative vacuum pressure

Example: Vacuum Pressure

Image from sanatron.com

Given: Elizabeth measures the air pressure in a vaccum chamber using a vacuum pressure guage. The reading is 98.27 kPa. The local atmospheric pressure is 99.62 kPa.

To do: Calculate the gage pressure inside the chamber. Also calculate the absolute pressure inside the chamber and give answers in kPa, atm, bar, and mbar.

Solution:

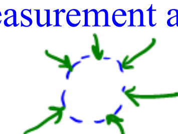
- $P_{gage} = -P_{vac} = \boxed{-98.27 \text{ kPa}}$
- $P_{abs} = P_{atm} - P_{vac} = (99.62 - 98.27)\text{ kPa} = \boxed{1.35 \text{ kPa}}$

Conversions:

$$P_{abs} = (1.35 \text{ kPa})\left(\frac{1 \text{ atm}}{101.325 \text{ kPa}}\right) = \boxed{0.0133 \text{ atm}}$$

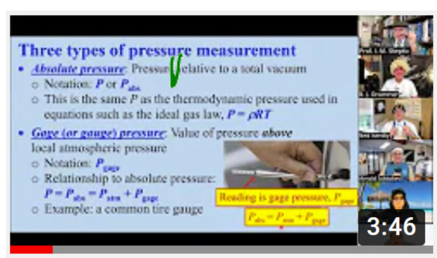
$$P_{abs} = (\;''\;)\left(\frac{1 \text{ bar}}{100 \text{ kPa}}\right) = \boxed{0.0135 \text{ bar}} \times \left(\frac{1000 \text{ mbar}}{\text{bar}}\right) = \boxed{13.5 \text{ mbar}}$$

See my short YouTube video called "***Principal Principles about Pressure***" for more about the fundamentals of pressure measurement and terminology.
https://youtu.be/e4lM-rfYWRM



From the video:

- Pressure acts inwardly normal on any object, real or imaginary.
- One standard atmosphere is equivalent to 760 mm of mercury column height (head).



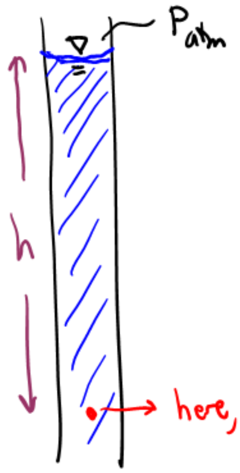
Principal Principles About Pressure

Equivalent Column Height (Head)

In the next lesson, we derive the hydrostatic pressure relation for incompressible liquids with gravity acting in the $-z$ direction,

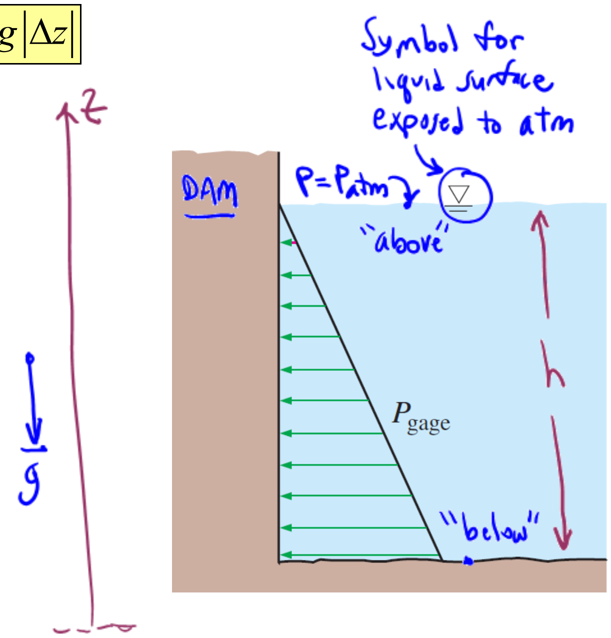
$$\boxed{P_{\text{below}} = P_{\text{above}} + \rho g |\Delta z|}$$

$$P_{\text{bottom}} = P_{\text{atm}} + \rho g h$$



"head"

here, $P = P_{\text{atm}} + \rho g h \Rightarrow \boxed{P_{\text{gage}} = \rho g h}$



Head = column height of liquid equivalent to the pressure, either gage or absolute

Example: Pressure Expressed as a Head

Given: The first example problem above.

To do: Express the absolute pressure as an equivalent column height of mercury and of water at 20°C for the first example problem above.

Solution:

@ 20°C, $\rho_{H_2O} = 998.0 \text{ kg/m}^3$

$\rho_{Hg} = 13{,}600 \text{ kg/m}^3$

h_{H_2O} = equiv. column height of water $\Rightarrow \boxed{P_{abs} = \rho g h}$

$$h_{H_2O} = \frac{P_{abs}}{\rho_{H_2O}\, g} = \frac{340.92 \text{ kPa}}{\left(998.0 \frac{\text{kg}}{\text{m}^3}\right)\left(9.807 \frac{\text{m}}{\text{s}^2}\right)}\left(\frac{\text{kg}\cdot\text{m}}{\text{s}^2\cdot\text{N}}\right)\left(\frac{1000 \text{ N}}{\text{m}^2\cdot\text{kPa}}\right) = \boxed{34.83 \text{ m of } H_2O}$$

repeat for Hg

ρ_{Hg}

$$\boxed{h_{Hg} = 2.556 \text{ m of Hg}}$$