Class 4 - Pressure

1. Definitions
2. Gauge Pressure
3. Pressure and Height of Liquid Column (Head)
4. Pressure Measurement and Manometers

- Please don't forget the special problem for the next HW assignment (Sp3.1)!
- HW hint for 3-63 in on web page

Comments on Homework

- Temperature conversion
  - $T\ (°R) = T\ (K) \times 1.8$
  - $T\ (°C) = T(K) - 273.15$
  - $T\ (°F) = T(°R) - 460$
- However, difference in temperature is:
  - $\Delta T\ (°C) = \Delta T\ (K)$
  - $\Delta T\ (°F) = \Delta T\ (°R)$
  - $\Delta T\ (°R) = 1.8 \times \Delta T\ (°C)$

1. Definitions

Pressure: Force per Area

- Units of N/m^2, lb_f/in^2 (i.e., psi), etc.
- Force usually caused by a fluid (gas or liquid)
  - Gravity
  - Change in temperature (constant volume)
  - Pump
- Measurement devices
  - Pressure gauge (dial or tire gauge)
  - Pressure transducer (electronic)
  - Manometer or barometer





Atmospheric Pressure

Definition: The local pressure of the atmosphere or the pressure of the surrounding air

- Can be thought of as the pressure at the base of a column of air ($\rho_{air}gh$)
- Decreases with increase in elevation
- Ambient pressure is the same as atmospheric pressure (used interchangeably)
- **Atmospheric or Ambient Pressure is not necessarily 1 atm!** (only true at sea level)
  - **In Provo, $P_{amb} \cong 12.6$ psia**

2. Gauge vs. Absolute Pressure

- **Absolute pressure-** the pressure relative to a perfect vacuum (no molecules present)
- **Gauge pressure-** the pressure relative to the ambient or atmospheric pressure at the measurement point

$$P_{gauge} = P_{absolute} - P_{ambient}$$

$$P_{gauge} = P_{vessel} - P_{outside\ air}$$

- **psig = lb_f/in^2 gauge pressure**
- **psia = lb_f/in^2 absolute pressure**

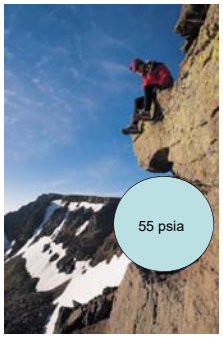
Gauge vs. Absolute Pressure

What is the gauge pressure of the spherical container?

Gauge vs. Absolute Pressure

Because of elevation, $P_{ambient}$ = 11 psia

What is the gauge pressure of the spherical container?



Gauge vs. Absolute Pressure

- How can the gauge pressure change when the absolute pressure remains the same?
- What does a tire pressure gauge read when the bike tire is totally flat?
- What is the absolute pressure inside of a flat tire?
- In a pressurized gas bottle, what does the gauge read when it is empty?

Gauge vs. Absolute Pressure

- This type of pressure gauge only measures a pressure difference! (usually)

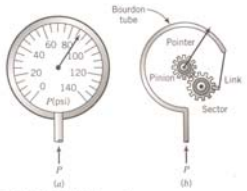


FIGURE 3.4-3 Bourdon gauge.

Caution

- Always use absolute pressure when:
  - Using pressure in a formula like ideal gas equation (PV = nRT)
  - Taking ratios of pressures
- You can use gauge pressure when:
  - Taking differences in pressure ($\Delta P_{gauge} = \Delta P_{absolute}$)

3. Pressure Head

- Weight of the fluid produces a force
  - pressure is highest at the bottom of the column
  - Why?
- Force/Area provides the pressure
- The pressure at the bottom does not depend on the diameter of the column (height only)
  - Why?
- Any pressure can be expressed as an equivalent height of a liquid
  - called a Pressure Head, P_h
  - units of length, like "mm Hg" or "inches of H_2O"

- We walk around with a column of air pressing down on our head
- Weight of air per area is the atmospheric pressure
- Kind of like the pole throw in Celtic games

Pressure Head Example

- Use Eq. 3.4-2 to calculate P_h for a column of Hg (SG = 13.6) that is equivalent to 1 atm.

  $P = \rho_{fluid} g P_h$ (P_h = head of fluid, units of height)
- Repeat the above calculation for H_2O.

This is why we can have units such as mm Hg or ft H_2O for a pressure, even though this is not strictly a force per unit area!

Table in front of book

Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb$_f$/in.^{2} (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C

Note that a length of a liquid is a pressure head, and refers to ρgh or $\rho g P_h$ (where P_h is the pressure head).

4. Pressure Measurement- Manometers

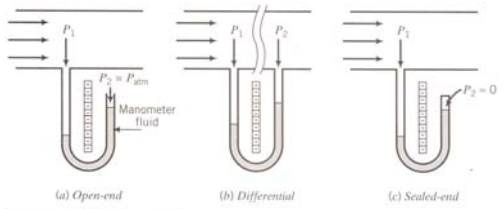
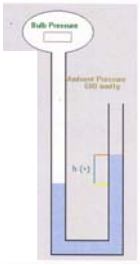


FIGURE 3.4-4 Manometers.

(Barometer)

Pressure Measurement- Manometers

- **Principle**: Any two points at the same height in a static continuous fluid must be at the same pressure.
- Otherwise, the column height would move!
- Where does this apply?



Pressure Measurement- Manometers

- Procedure
  - Draw a horizontal line at the level where the same type of fluid exists in both arms of the tube
    (i.e., points a and b in Fig. 3.4-5)
  - Add up the pressures on the left ($P_1 + \rho_1 g d_1$)
  - Add up the pressures on the right ($P_2 + \rho_2 g d_2 + \rho g h$)
  - Set the two equal and rearrange to solve for the unknown pressure (or $P_1 - P_2$)

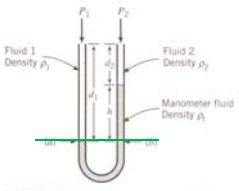


FIGURE 3.4-5 Manometer variables.

Note: forces must be used if the area isn't constant

Manometer Practice Problems

- See Eqns. 3.4-5, 6, & 7
  - These are specific equations
  - Better to learn general concept and derive equation for each scenario

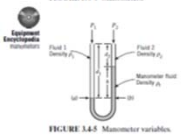


FIGURE 3.4-5 Manometer variables.

The formula that relates the pressure difference $P_1 - P_2$ to the difference in manometer fluid levels is based on the principle that the fluid pressure must be the same at any two points at the same height in a continuous fluid. In particular, *the pressure at the height of the lower surface of a manometer fluid is the same in both arms of the manometer.* (See Figure 3.4-5.) Writing and equating expressions for the pressures at points (*a*) and (*b*) in Figure 3.4-5 yields the general manometer equation

General Manometer Equation: $\boxed{P_1 + \rho_1 g d_1 - P_2 + \rho_2 g d_2 + \rho_3 g h = 0}$ (3.4-5)

In a differential manometer, fluids 1 and 2 are the same, and consequently $\rho_1 = \rho_2 = \rho$. The general manometer equation then reduces to

Differential Manometer Equation: $\boxed{P_1 - P_2 = (\rho_3 - \rho) g h}$ (3.4-6)

If either fluid 1 or 2 is a gas at a moderate pressure (e.g., if one arm is open to the atmosphere), the density of this fluid is 100 to 1000 times lower than the density of the manometer fluid, so that the corresponding $\rho g d$ term in Equation 3.4-5 may be neglected. If both fluids are gases, then the equation becomes

$$P_1 - P_2 = \rho_3 g h$$

and if both P_1 and P_2 are expressed as heads of the manometer fluid, then

Manometer Formula for Gases: $\boxed{P_1 - P_2 = h}$ (3.4-7)

If P_2 is atmospheric pressure, then the gauge pressure at point 1 is simply the difference in the levels of the manometer fluid.

Problem 3-53 (4th Ed.)

- Two mercury manometers, one open-end and the other sealed-end, are attached to an air duct. The reading on the open-end manometer is 25 mm and that on the sealed-end manometer is 800 mm. Determine the absolute pressure in the duct, the gauge pressure in the duct, and the atmospheric pressure, all in mm Hg.

Shortcut with Head Form

$$\rho_a g h_a + \rho_b g h_b + \cdots = \rho_r g h_r + \rho_s g h_s + \ldots$$

- Now convert to the equivalent height of water by dividing by g and ρ_{water}

$$SG_a h_a + SG_b h_b + \cdots = SG_r h_r + SG_s h_s + \ldots$$

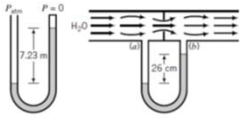
and all terms have units of h_{H_2O}

- Proof: Given P_1 as a height of Hg, divide by ρ_{water}g and see what the units become

$$P_1 = \rho_{H_2O} g h_{H_2O} = \rho_{Hg} g h_{Hg}, \text{ so}$$

$$h_{H_2O} = \frac{\rho_{Hg} g h_{Hg}}{\rho_{H_2O} g} = SG_{Hg} h_{Hg}$$

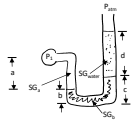
3.43. A fluid of unknown density is used in two manometers—one sealed-end, the other across an orifice in a water pipeline. The readings shown here are obtained on a day when barometric pressure is 756 mm Hg.



What is the pressure drop (mm Hg) from point (*a*) to point (*b*)?

Concrete is pumped 100 ft in the air.
What pressure is need in the pump (neglecting velocity and friction)?

2. (25 pts) A gauge and manometer are attached to a column of water, as shown.

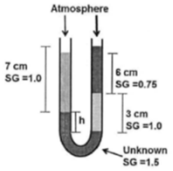


(a) (10 pts) Derive an equation that can be solved to find pressure P_1 if P_{atm}, a, b, c, d, SG_a, and SG_b are known. *Use the head form of the pressure balance equation.*
(b) (15 pts) Find P_1 (in psig) when a = 6 inches, b = 3 inches, c = 7 inches, d = 50 inches, SG_a = 0.001 (a gas), and SG_b is that of mercury (SG_{Hg} = 13.546), SG_w = specific gravity of water.

- Remember that ρ_{water} = 62.43 lbm/ft^3, and that 14.7 psi = 1 atm = 33.9 ft H_2O.
- If you can justify that one term in the pressure balance equation is very small, please neglect that term.

2. The unknown fluid is exchanged with a fluid of specific gravity (SG) = 1.1. Therefore the value of h _____.

If Time



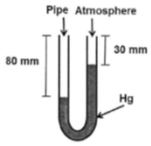
A. increases

B. decreases

C. remains the same

D. need more information

1. A manometer containing mercury is used to measure the gas pressure in a pipe. What is the gauge pressure of the gas in mm Hg?



A. 10

B. 30

C. 50

D. 80

3. Which statements are true?

1) An open-end manometer provides a direct reading of the gauge pressure of a fluid.

2) A sealed-end manometer provides a direct reading of the absolute pressure of a fluid, provided that the fluid pressure in the sealed end may be neglected.

3) The reading of a differential manometer does not depend on the density of fluid in the pipeline but only on that of the manometer fluid.

A. 1 & 3

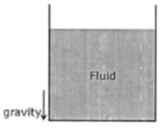
B. 3

C. 1 & 2

D. 2

E. 1, 2, & 3

4. A fluid sits in an open tank at sea level. The pressure at the top of the fluid is _____ the pressure at the bottom of the tank.



A. greater than

B. less than

C. equal to

D. not enough information