CAE 208 Thermal-Fluids Engineering I
MMAE 320: Thermodynamics

Fall 2022

September 1, 2022

Basic Concepts of Thermodynamics (III)

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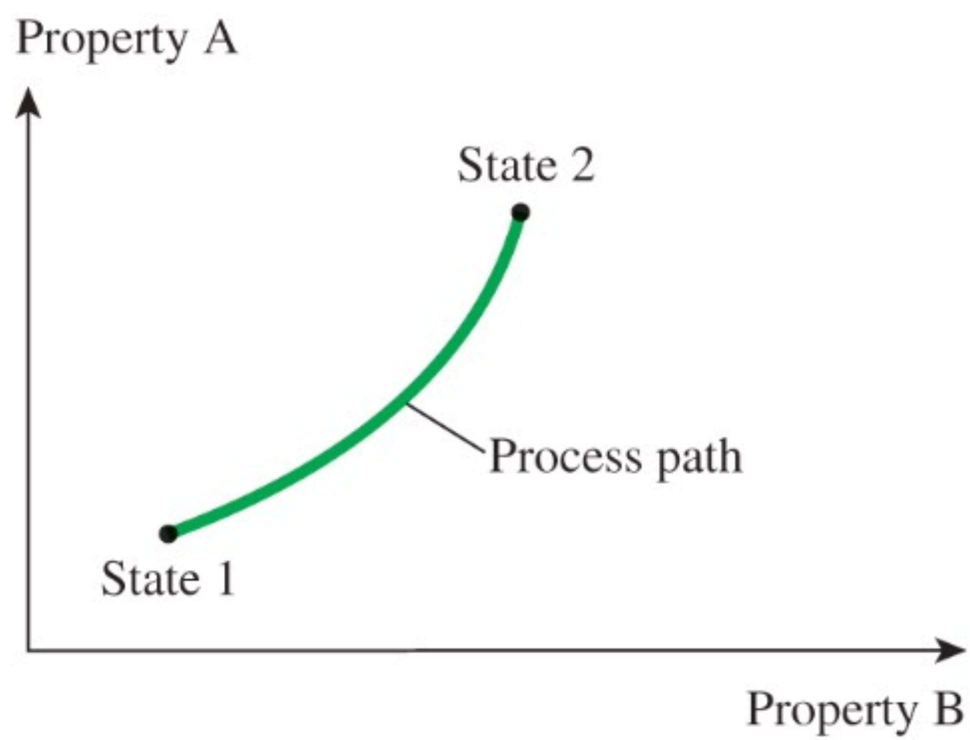
Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

RECAP

Recap

- Thermodynamics deals with equilibrium states
  - ❑ All properties can be measured
  - ❑ Given a set of properties we can describe the condition or the state of the system
  - ❑ All properties are fixed till one of them changes

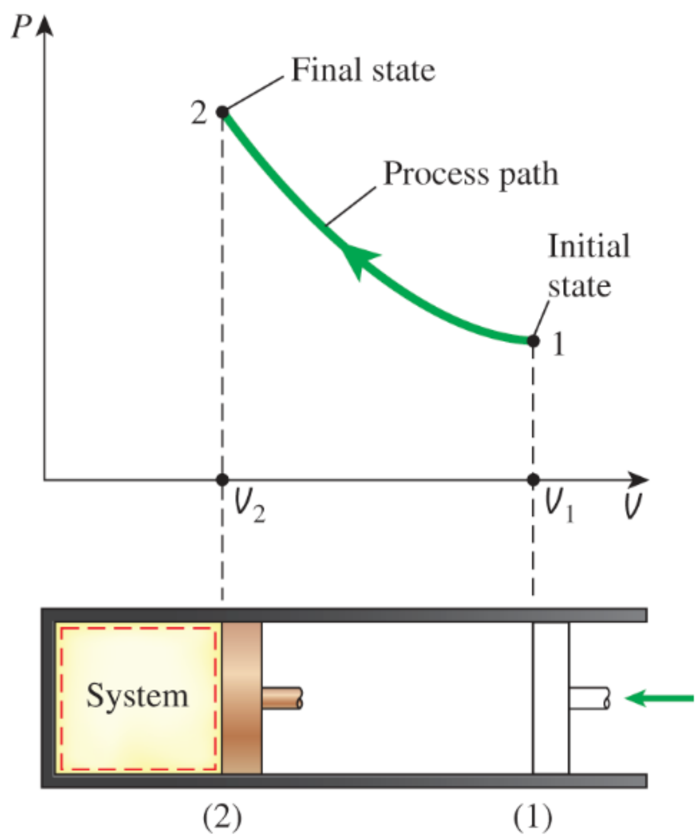


Recap

- Equilibrium means a state of balance, meaning no driving forces or unbalanced potential
  - ❑ Thermal equilibrium
  - ❑ Mechanical equilibrium
  - ❑ Phase equilibrium
  - ❑ Chemical equilibrium

Recap

- Two independent “intensive” properties
  - ❑ Temperature and specific volume
  - ❑ Temperature and pressure for a single phase
  - ❑ Temperature and pressure are not independent (multiphase)



Recap

- "iso-" is often used to designate a process for which a particulate property remains constant
  - ❑ Isothermal process: A constant temperature process
  - ❑ Isobaric process: A constant pressure process
  - ❑ Isomeric process: A constant specific volume process

Recap

Next Artemis 1 launch attempt set for Sept. 3

by **Jeff Foust** — August 30, 2022

NASA officials said the apparent failure of one of the core stage engines to cool to the proper temperature during the Aug. 29 launch attempt may be an artifact of a faulty temperature sensor rather than a problem with the flow of liquid hydrogen into the engine. Credit: Jordan Sirokie

Recap

John Honeycutt, NASA SLS program manager, said the hydrogen bleed is intended to cool the engines to about −250 degrees Celsius. Three of the engines, #1, 2 and 4, got down to about −245 degrees Celsius, but engine #3 was only at about −230 degrees Celsius, according to temperature sensors in the engines.

How close did they get to the absolute zero?

How is this difference in °F?

PRESSURE

Pressure

- Pressure is defined as a normal force exerted by a fluid per unit area

Pressure

- Other units

$$1\ bar = 10^5 Pa = 0.1\ MPa = 100\ kPa$$

$$1\ atm\ = 101{,}325\ Pa = 101.325\ kPa$$

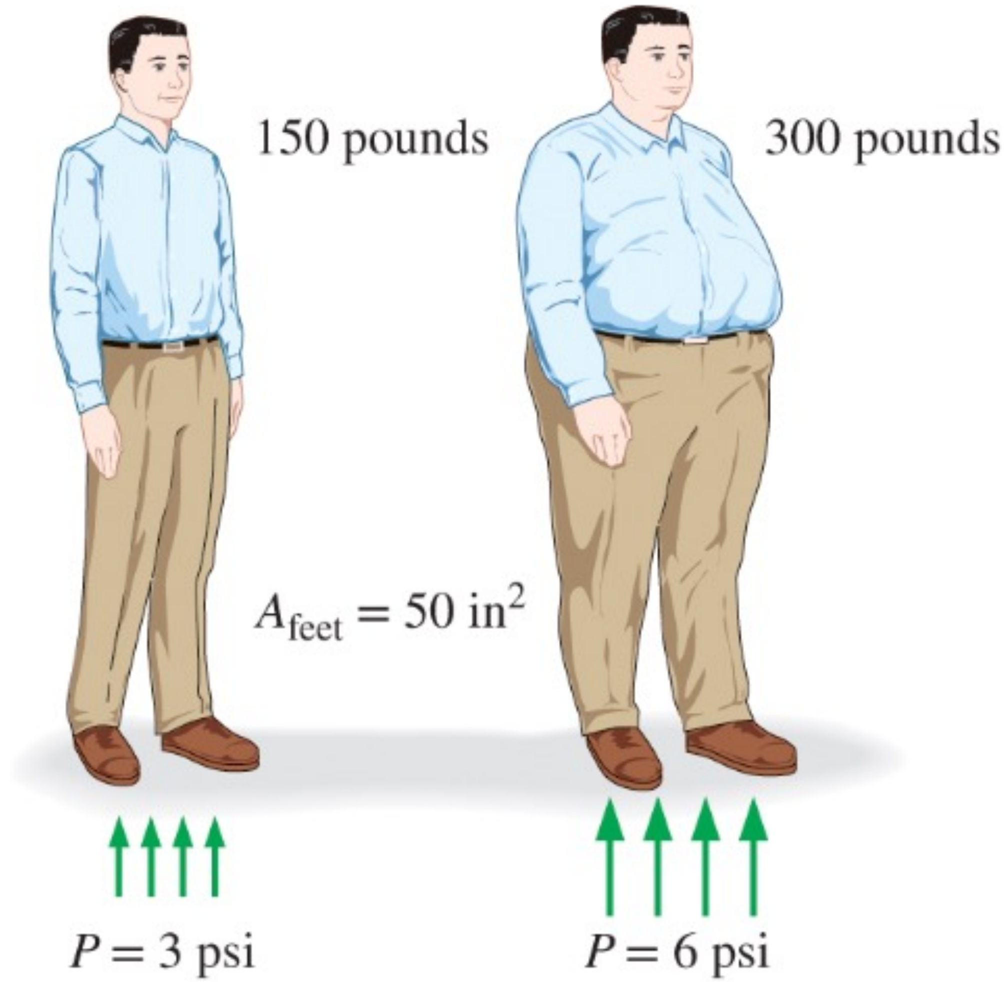
$$1\ \frac{kgf}{cm^2} = 0.9807\ bar = 0.9679\ atm$$

Pressure

- IP units

$$1\ atm = 14.696\frac{lbf}{in^2}\ (or\ psi)$$

Pressure



$$P = \sigma_n = \frac{W}{A_{feet}} = \frac{150\ \text{lbf}}{50\ \text{in}^2} = 3\ \text{psi}$$

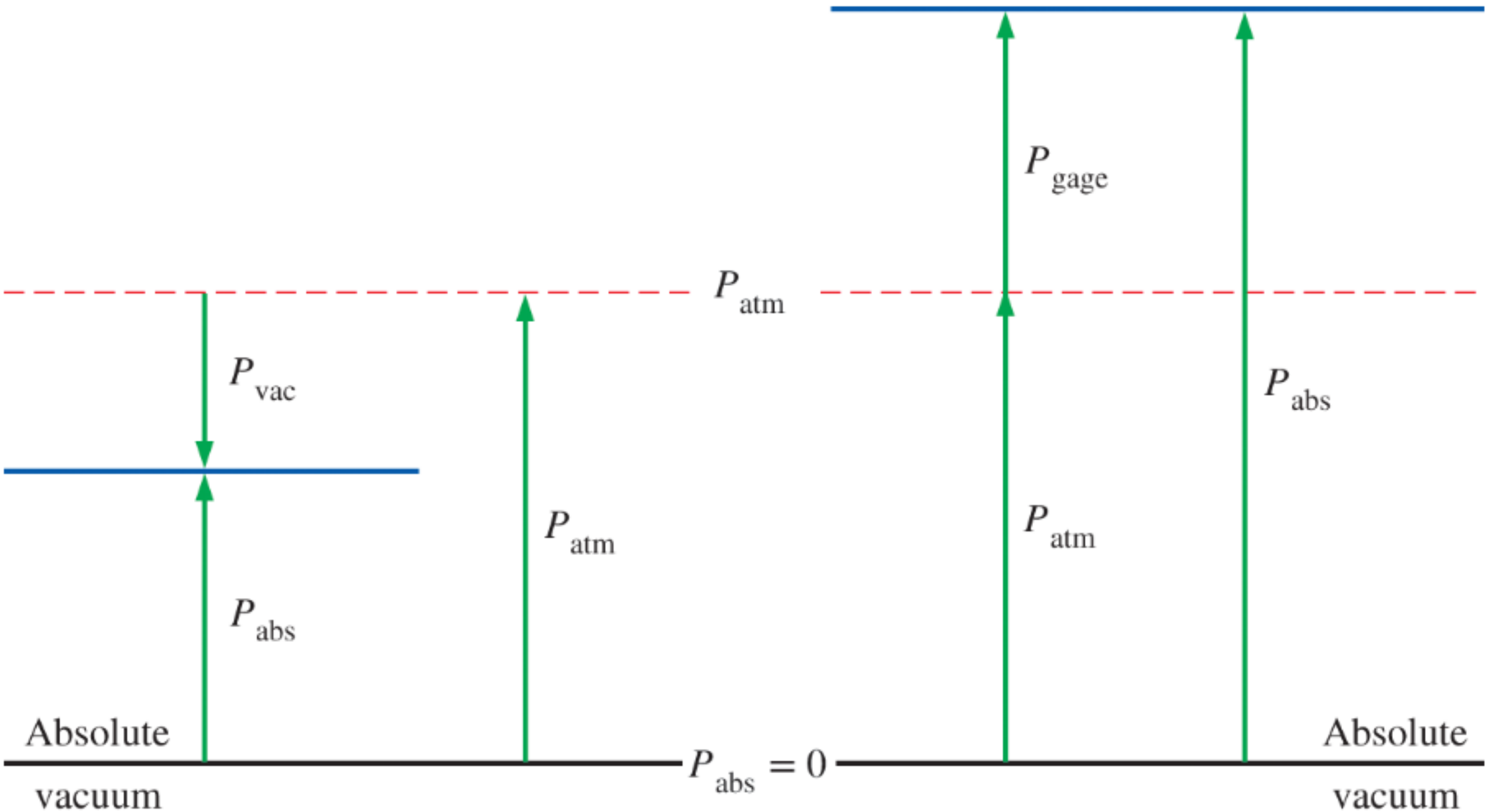
Pressure

- Actual pressure at a given position is called the absolute pressure (measured relative to absolute vacuum)

- The difference between the absolute pressure and the local atmosphere pressure is called the gage pressure

- Pressure below atmospheric pressure is called vacuum

Pressure



P atm
P vac
P abs
P atm
Absolute
vacuum
P abs = 0
P gage
P atm
P abs
Absolute
vacuum

CLASS ACTIVITY

Class Activity

- A vacuum gage connected to a chamber reads 5.8 psi at a location where the atmospheric pressure is 14.5 psi. Determine the absolute pressure in the chamber

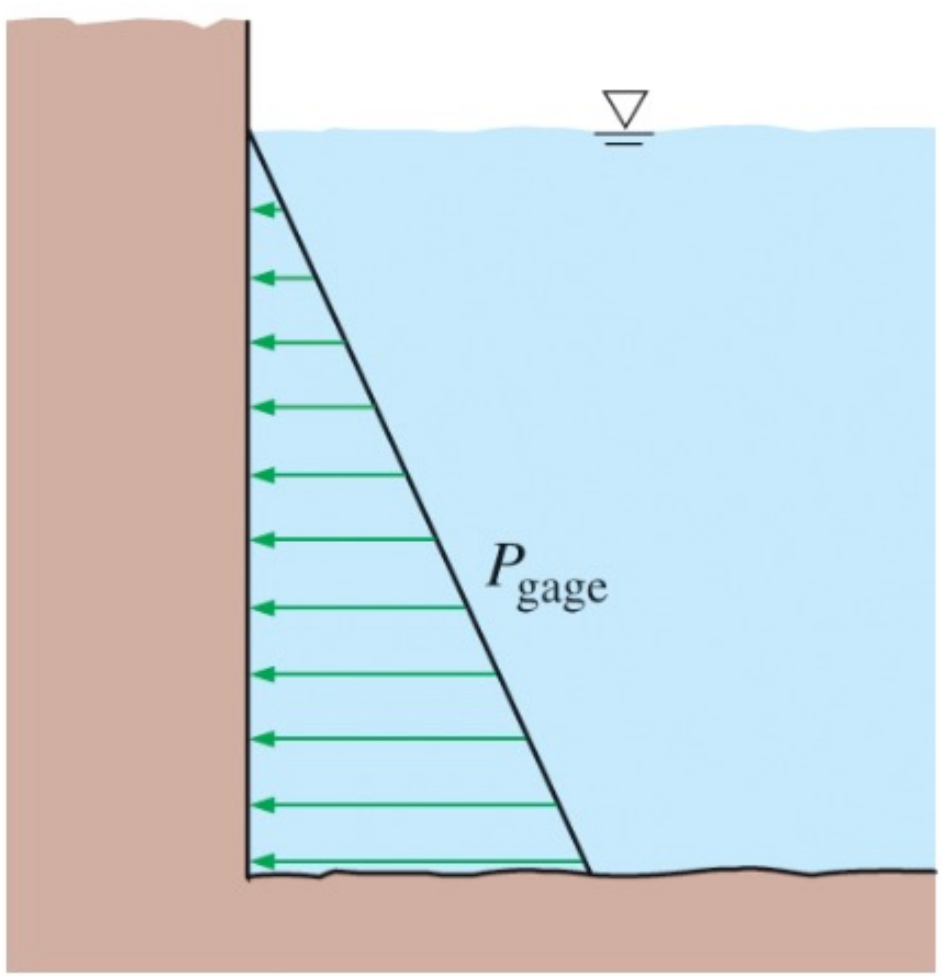
CLASS ACTIVITY

Class Activity

- The hydraulic piston/cylinder system has a cylinder diameter of D = 0.1 m with a piston and rod mass of 25 kg. The rod has a diameter of 0.01 m with an outside atmospheric pressure of 101 kPa. The inside hydraulic fluid pressure is 250 kPa. How large a force can the rod push with in the upward direction?

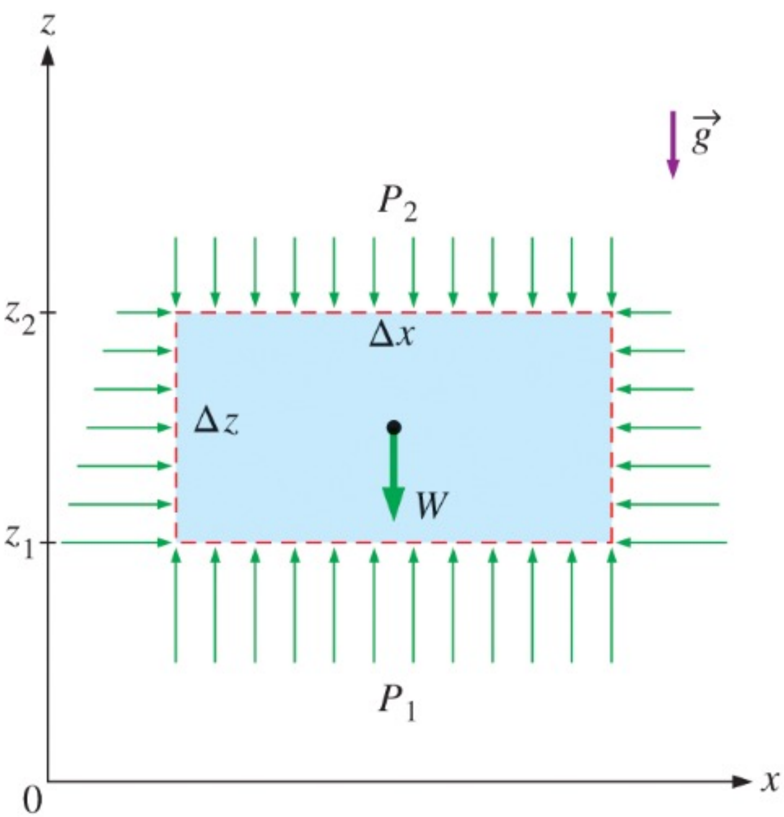
Pressure

- Variation of pressure with depth is due to the gravity field



Pressure

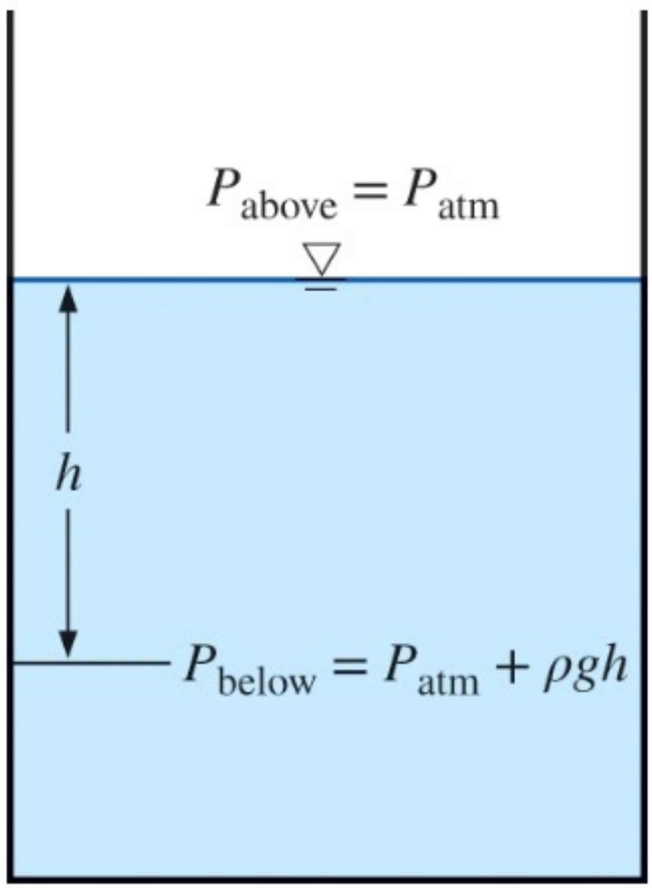
- Pressure in a static fluid increases linearly with depth



$$P_{below} = P_{above} + \gamma_s |\Delta z|$$

Pressure

- We define P_{above} and P_{below}



Pressure

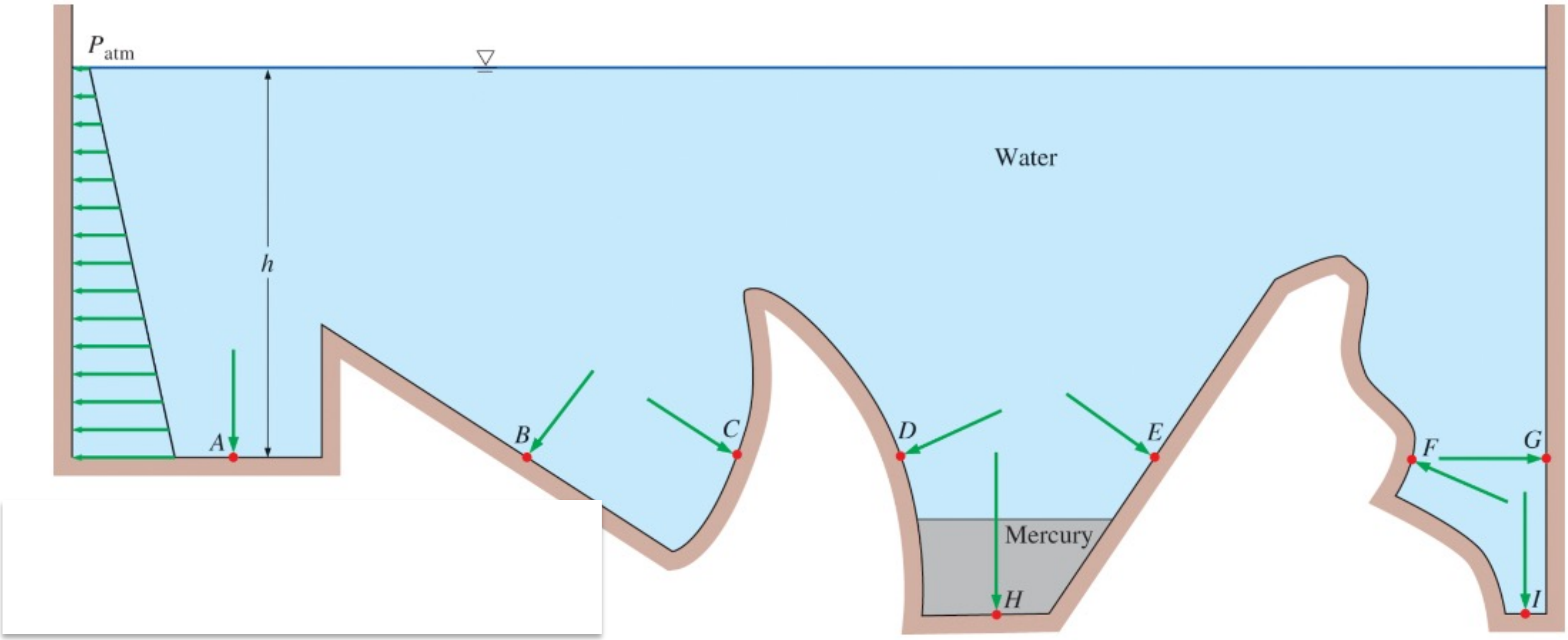
- ”g” varies from 9.807 m/s^2 at the sea level to 9.764 m/s^2 at an elevation of 14,000 m (0.4% in the extreme)

$$\frac{dP}{dz} = -\rho g$$

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g dz$$

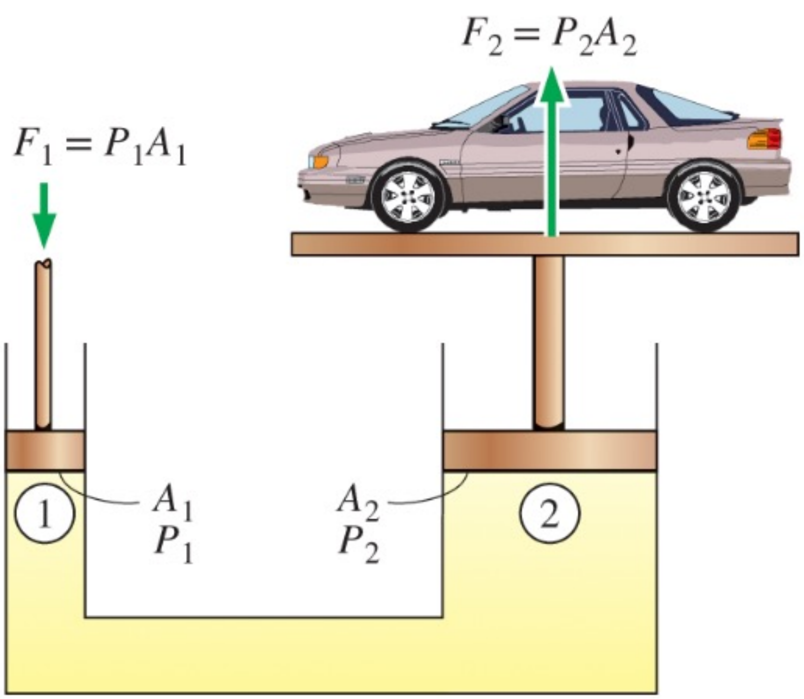
Pressure

- What do you think about the pressure at points A, B, C, D, E, F, G, H, I?



Pressure

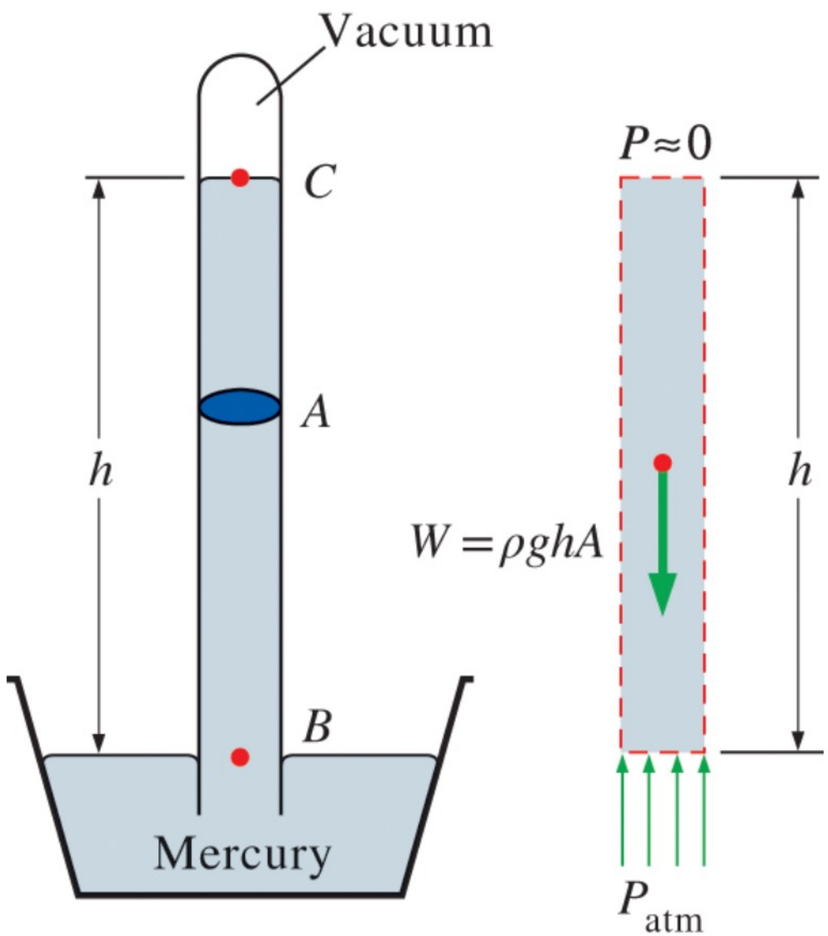
- Pascal's law: The pressure applied to a confined fluid increases the pressure throughout the same amount



PRESSURE MEASUREMENT DEVICES (BAROMETER)

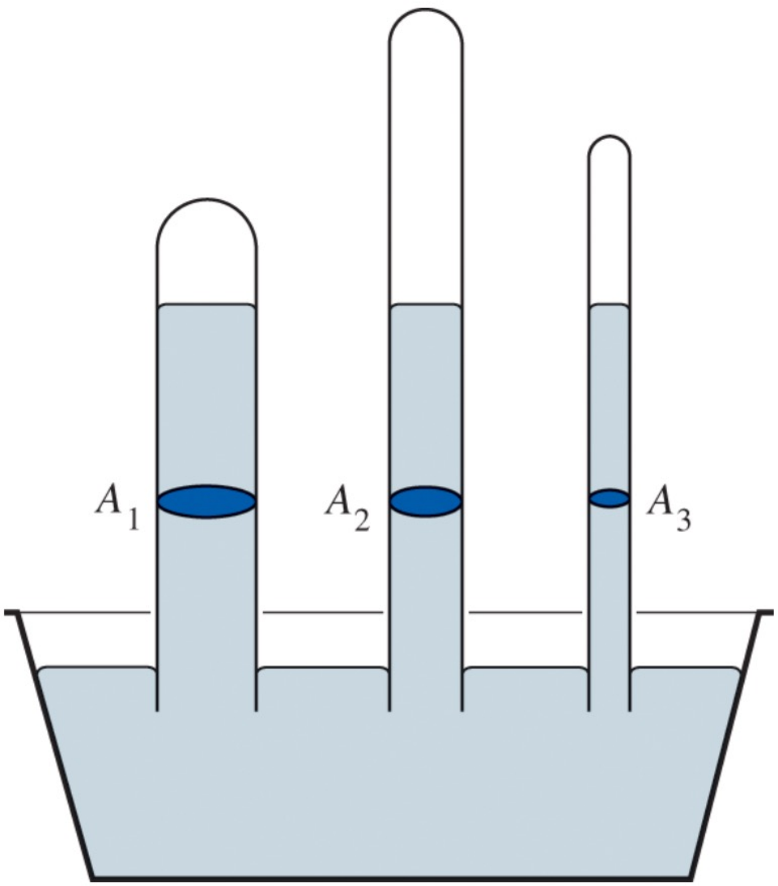
Pressure Measurement Devices

- Atmospheric pressure is measured by a device called a barometer (atmospheric pressure is known as barometric pressure)



Pressure Measurement Devices

- What do you think about the pressure at A_1, A_2, A_3?



Pressure Measurement Devices

- A common pressure unit is the standard atmosphere which is equal to a column of mercury 760 mm in height at 0 °C ($\rho_{Hg} = 13{,}595 \frac{kg}{m^3}$) under $g = 9.807 \frac{m}{s^2}$

Why mercury and not water?

Pressure Measurement Devices

- 760 mmHg = 29.92 inHg
- mmHg = torr
- 1 atm = 760 torr

Pressure Measurement Devices

- P_{atm} changes based on the elevation

Elevation	Pressure (kPa)
Sea Level	101.325
1,000	89.88
2,000	79.50
5,000	54.05
10,000	26.5
20,000	5.53

Pressure Measurement Devices

- How many of you are from a high elevation hometown?

SPORTSMONEY

Study Affirms Altitude Boosts Denver Nuggets' Home Advantage, But Do Other Factors Blunt The Impact?

Joel Rush Contributor

Sep 12, 2018, 12:05pm EDT

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World news

Protests in Andes as Fifa bans international games over 2,500m

Rory Carroll, *Latin America correspondent*

@rorycarroll72

Mon 28 May 2007 19.26 EDT

Football's governing body, Fifa, has drawn angry protests from Andean nations after banning international matches from being played at more than 2,500 metres (8,200ft) above sea level.

The organisation's executive committee said there were medical concerns over playing at high altitudes because the thin air makes breathing difficult and strains the heart of those who are not acclimatised.

CLASS ACTIVITY

Class Activity

- Determine the atmospheric pressure at a location where the barometric reading is 740 mmHg and gravitational acceleration is 9.805 m/s^2. Assume density of mercury is 13,570 kg/m^3 at 10 °C.

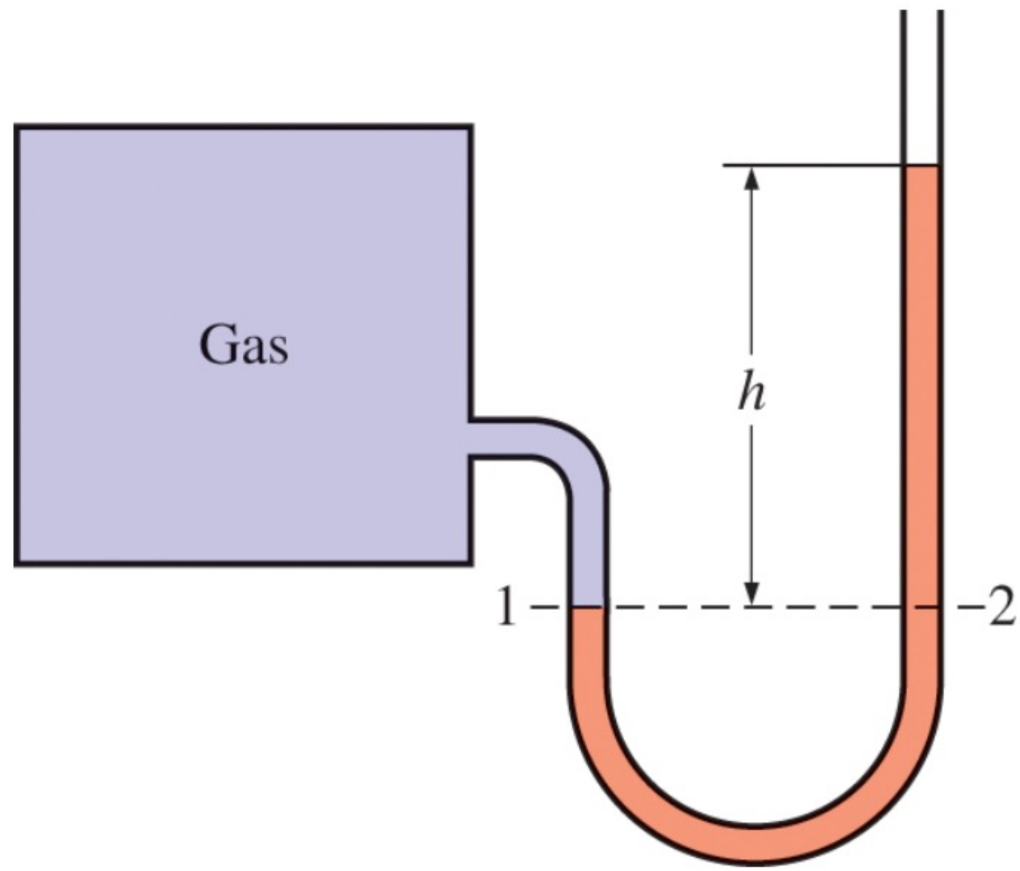
PRESSURE MEASUREMENT DEVICES (MANOMETER)

Manometer

- Manometer works best of the concept of a column of fluid to measure pressure

Manometer

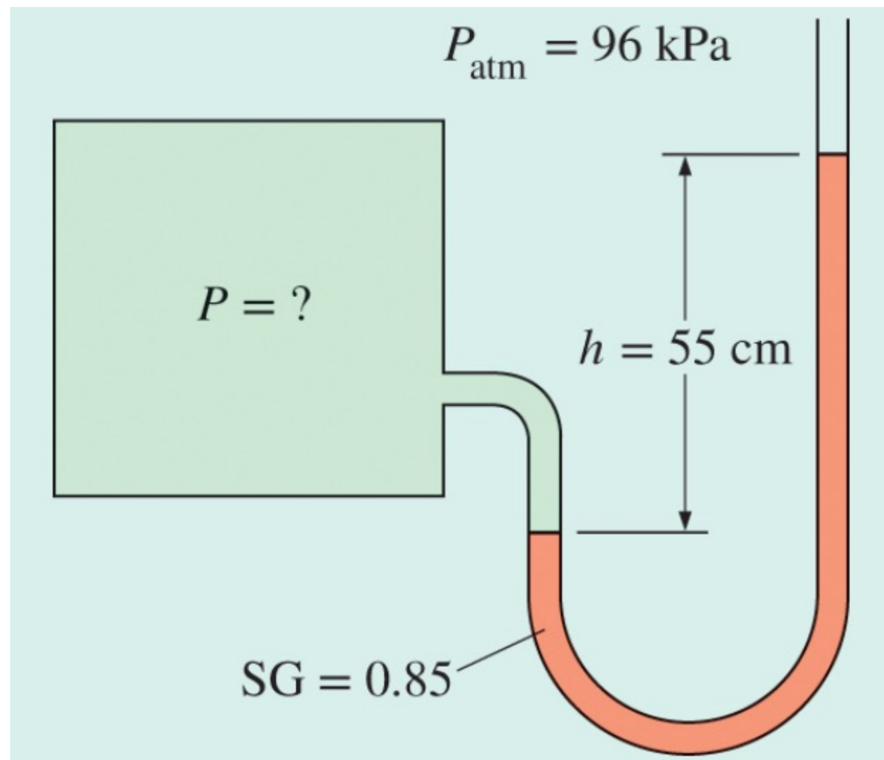
- Let's consider this manometer situation



CLASS ACTIVITY

Class Activity

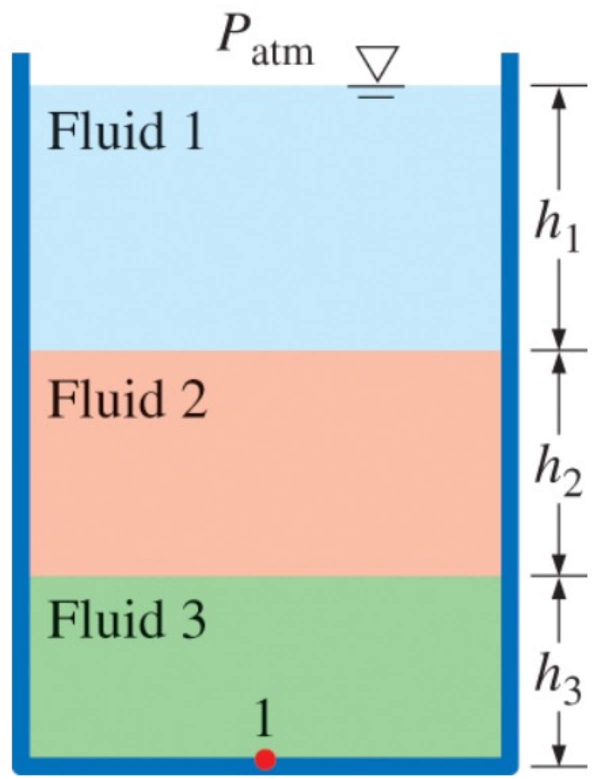
- A manometer is used to measure the pressure of a gas in a tank. The fluid used has a specific gravity of 0.85 and the manometer column height is 55 cm and shown below. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.



Manometer

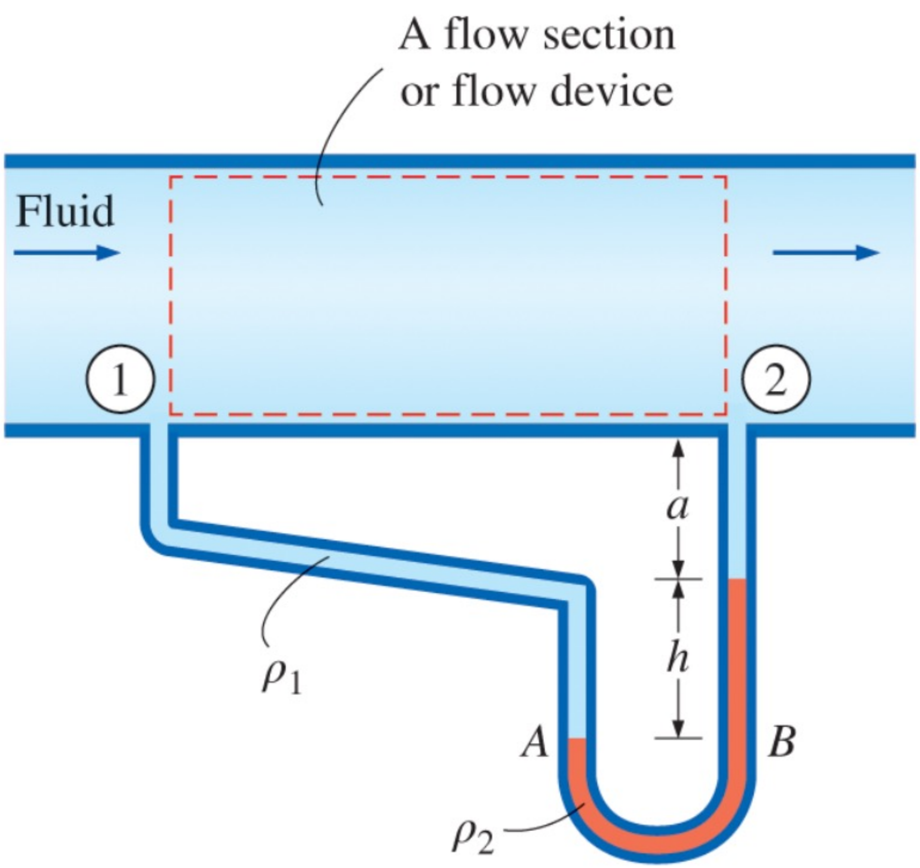
- Special manometer designs
  - ❑ Inclined manometer

  - ❑ Using the extension of Pascal's law



Manometer

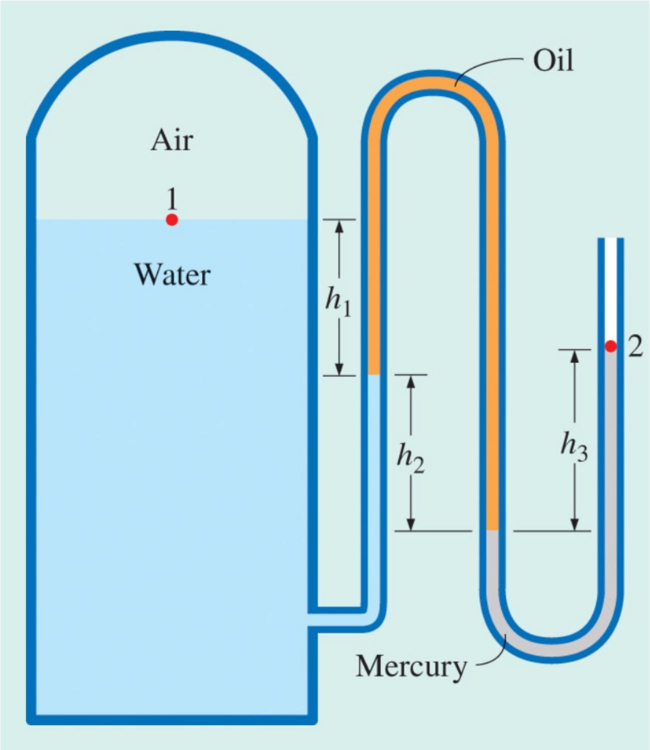
- Special manometer designs
  - ❑ Measure pressure drop in a duct due to other equipment



CLASS ACTIVITY

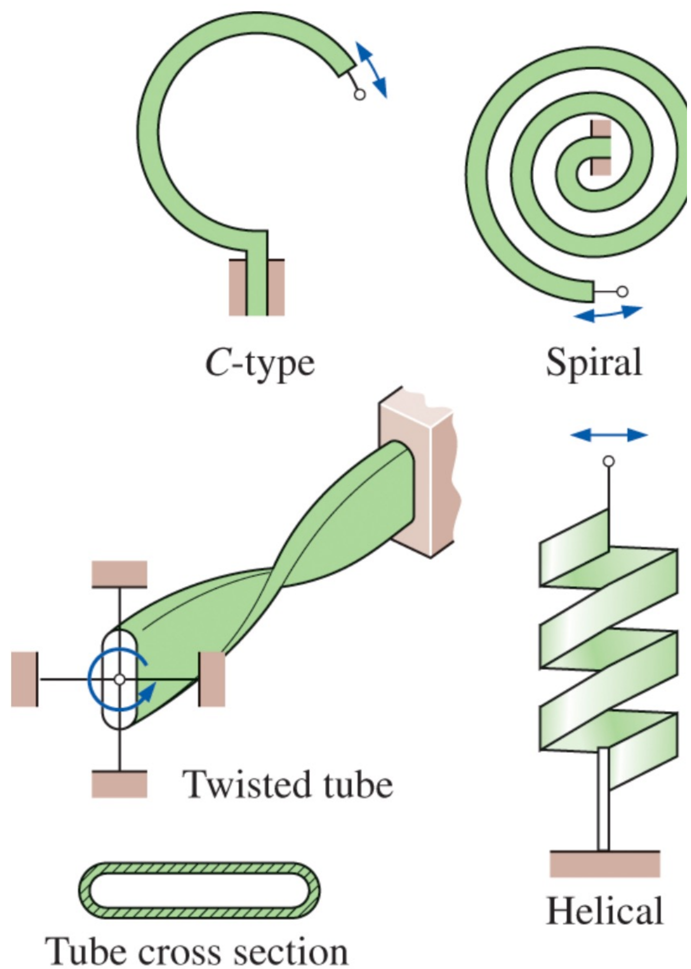
Class Activity

- Water in a tank is pressurized by air and the pressure is measured by a multifluid manometer. The tank location is on a mountain and the altitude of 140m where the atmospheric pressure is 85.6 kPa. Determine the air pressure in the tank is h_1 = 0.1 m, h_2=0.2m, and h_3=0.35. The densities of water, oil, and mercury is 1,000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively.



OTHER PRESSURE MEASUREMENT DEVICES

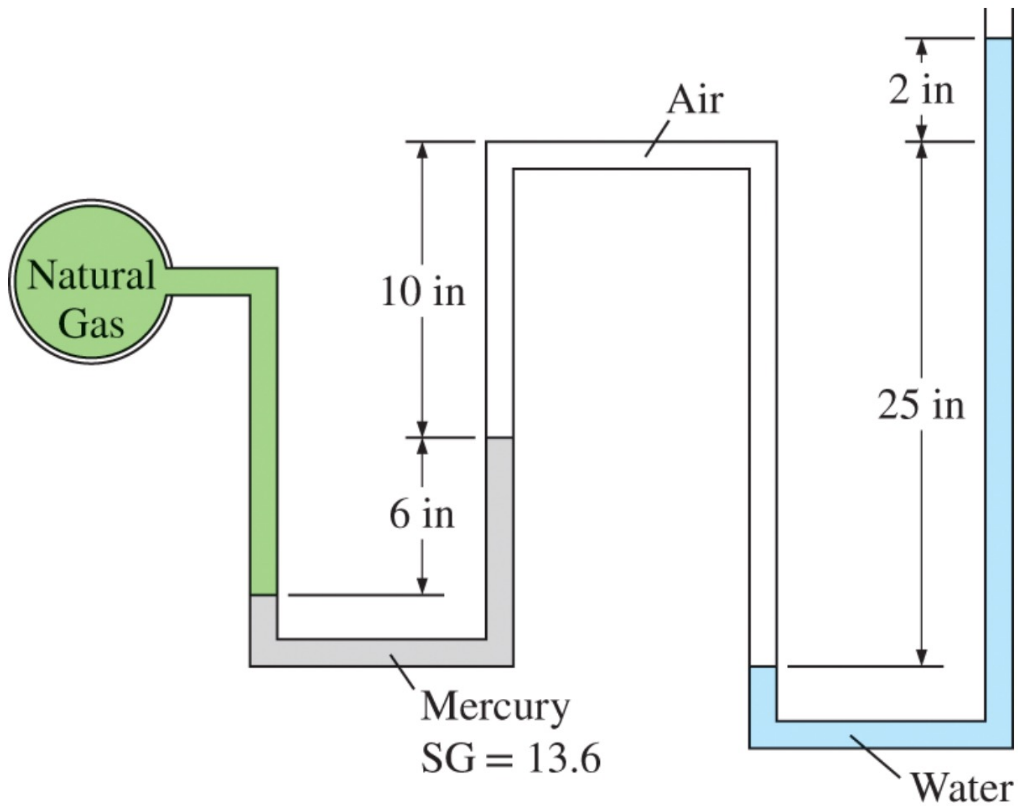
Other Pressure Measurement Devices



EXTRA PROBLEMS

Extra Problems

- **Problem 1:** The pressure in a natural gas pipeline is measured by the manometer shown below. One arm is open to the atmosphere where the local atmospheric pressure is 14.2 psi. Determine the absolute pressure in the pipeline.



Extra Problems

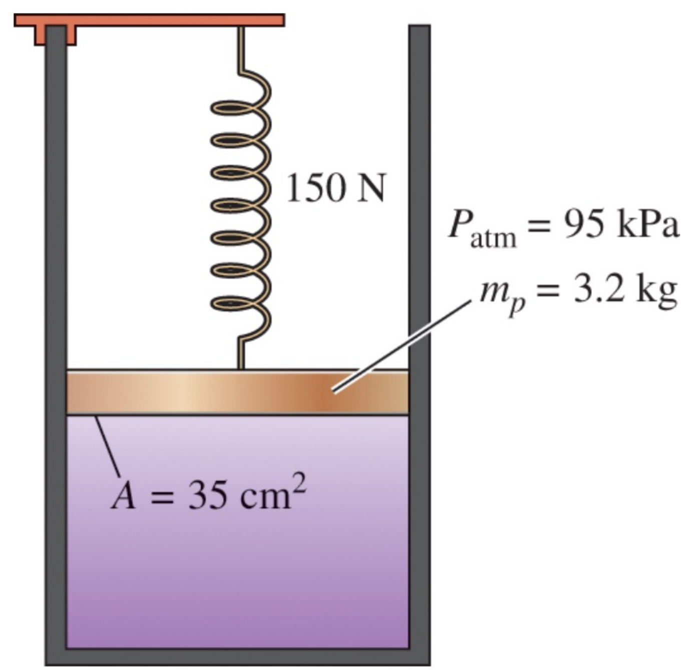
- **Solution:**

$$P_{NG} - \rho_{HG} \times g \times h_{HG} - \rho_a \times g \times h_{a1} + \rho_a \times g \times h_{a2} - \rho_w \times g \times h_w = P_{atm}$$

$$P_{NG} = 14.2\ psia + \left(32.2\frac{ft}{s^2}\right)\left[\left(848.6\frac{lbm}{ft^3}\right)\left(\frac{6}{12}\right) + \left(62.2\frac{lbm}{ft^3}\right)\left(\frac{27}{12}\right) - \left(0.075\frac{lbm}{ft^3}\right)\left(\frac{15}{12}\right)\right]\left(\frac{1\ lbf}{32.2\frac{lbm}{\frac{ft}{s^2}}}\right)\left(\frac{1\ ft^2}{144\ in^2}\right) \sim 18.1\ psia$$

Extra Problems

- **Problem 2:** The piston of a vertical piston-cylinder device containing a gas has a mass of 60 kg and a cross-sectional area of 0.04 m^2. The local atmosphere if 0.97 bar, and the gravitational acceleration is 9.81 m/s^2.
  - ❑ Determine the pressure inside the cylinder
  - ❑ If some heat is transferred to the gas and its volume is double, do you expected the pressure inside the cylinder to change?



Extra Problems

- **Solution:**

$$PA = P_{atm}A + W + F_{spring}$$

$$P = P_{atm} + \frac{mg + F_{spring}}{A}$$

$$P = (95\ kPa) + \frac{(3.2\ kg)\left(9.81\ \frac{m}{s^2}\right) + 150\ N\left(\frac{1kPa}{1000\ N/m^2}\right)}{35\times10^{-4}\ m^2}$$

$$P = 147\ kPa$$