CAE 208 / MMAE 320: Thermodynamics

Fall 2023

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Basic Concepts of Thermodynamics (3)

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ANNOUNCEMENTS

Announcements

- Assignment 1 is due tonight
- Assignment 2 is posted

Announcements

- Why do you think density is an intensive property?

Announcements

- Density

TABLE A–3E

Properties of common liquids, solids, and foods (*a*) Liquids

	Boiling data at 1 atm		*Freezing data*		*Liquid properties*		
Substance	Normal boiling point, °F	Latent heat of vaporization, h_{fg} Btu/lbm	Freezing point, °F	Latent heat of fusion, h_{if} Btu/lbm	Temperature, °F	Density, ρ lbm/ft^3	Specific heat, c_p Btu/lbm · R
Ammonia	−27.9	24.54	−107.9	138.6	−27.9	42.6	1.06
					0	41.3	1.083
					40	39.5	1.103
					80	37.5	1.135
Argon	−302.6	69.5	−308.7	12.0	−302.6	87.0	0.272
Propane	−43.7	184.0	−305.8	34.4	−43.7	36.3	0.538
					32	33.0	0.604
					100	29.4	0.673
Refrigerant-134a	−15.0	93.3	−141.9	–	−40	88.5	0.283
					−15	86.0	0.294
					32	80.9	0.318
					90	73.6	0.348
Water	212	970.1	32	143.5	32	62.4	1.01
					90	62.1	1.00
					150	61.2	1.00
					212	59.8	1.01

Announcements

- How do we know accounted for all the intensive properties?

TABLE A–4E

Saturated water—Temperature table

Temp., T °F	Sat. press., P_{sat} psia	*Specific volume,* ft^3/lbm		*Internal energy,* Btu/lbm			*Enthalpy,* Btu/lbm			*Entropy,* Btu/lbm · R		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
32.018	0.08871	0.01602	3299.9	0.000	1021.0	1021.0	0.000	1075.2	1075.2	0.00000	2.18672	2.1867
35	0.09998	0.01602	2945.7	3.004	1019.0	1022.0	3.004	1073.5	1076.5	0.00609	2.17011	2.1762
40	0.12173	0.01602	2443.6	8.032	1015.6	1023.7	8.032	1070.7	1078.7	0.01620	2.14271	2.1589
45	0.14756	0.01602	2035.8	13.05	1012.2	1025.3	13.05	1067.8	1080.9	0.02620	2.11587	2.1421
50	0.17812	0.01602	1703.1	18.07	1008.9	1026.9	18.07	1065.0	1083.1	0.03609	2.08956	2.1256

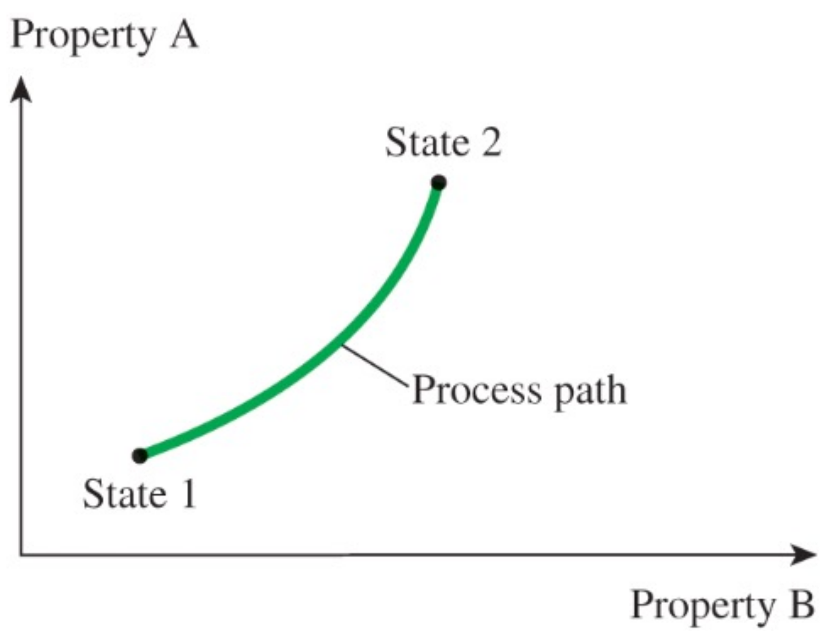
Announcements

- The TA office hour is:
  - ❑ Monday 13-14:30
  - ❑ Friday 11:30-13

RECAP

Recap

- Thermodynamics deals with equilibrium states

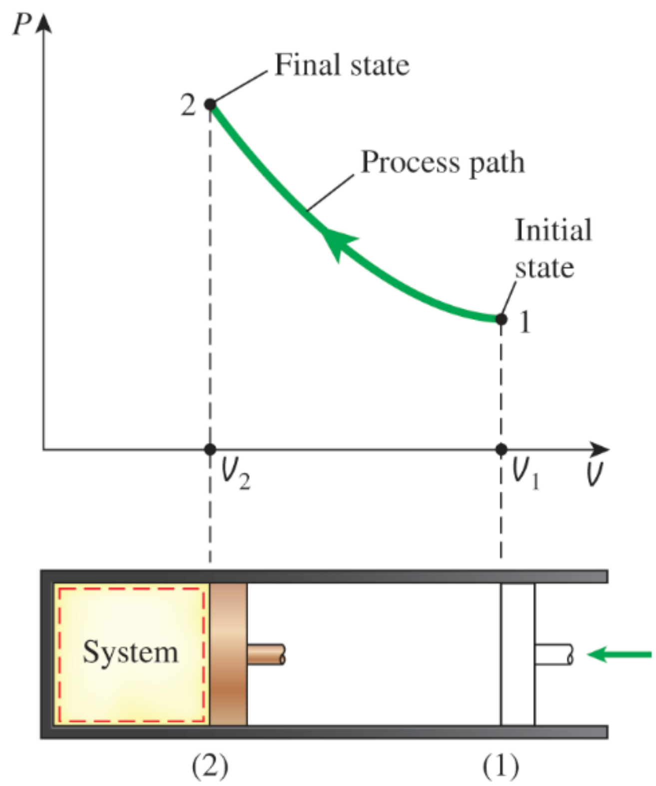


Recap

- 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

CLASS ACTIVITY

Class Activity

- A system at a 100 Pa pressure goes from 68 °F to 77 °F. Calculate the temperature difference in °F, °C, K, R

PRESSURE

Pressure

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

Pressure

- Other units

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

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

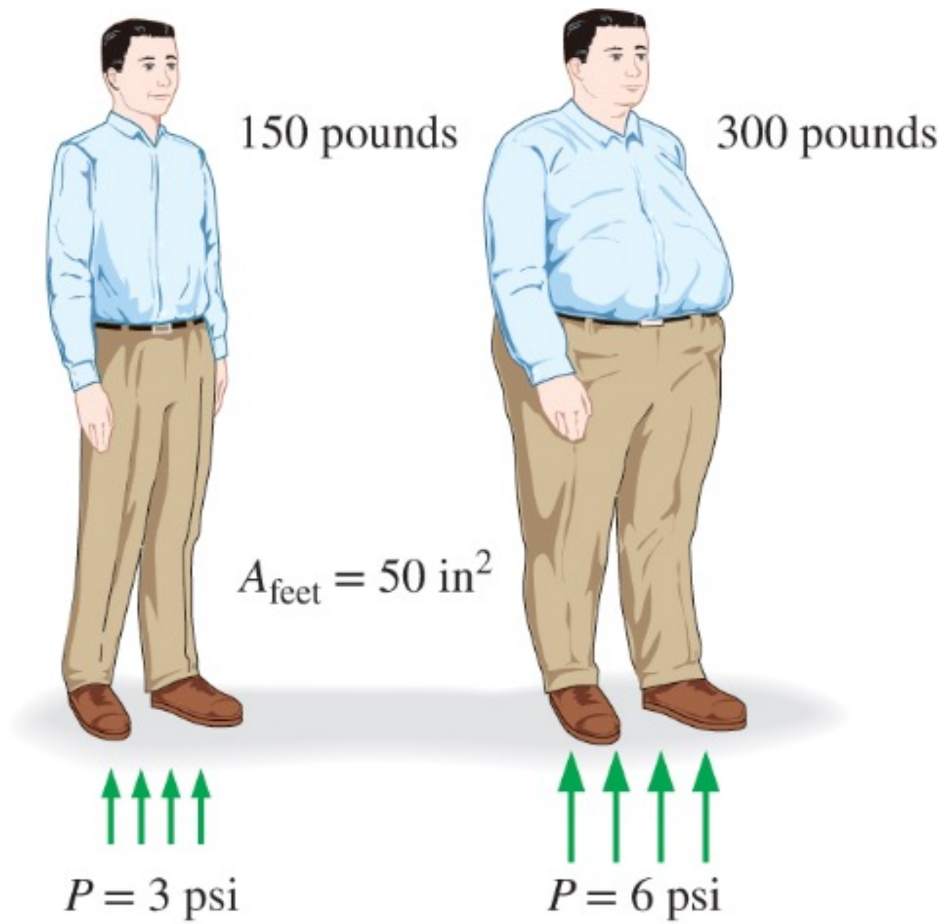
$$1\frac{kgf}{cm^2} = 0.9807\ bar = 0.9679\ atm$$

Pressure

- IP units

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

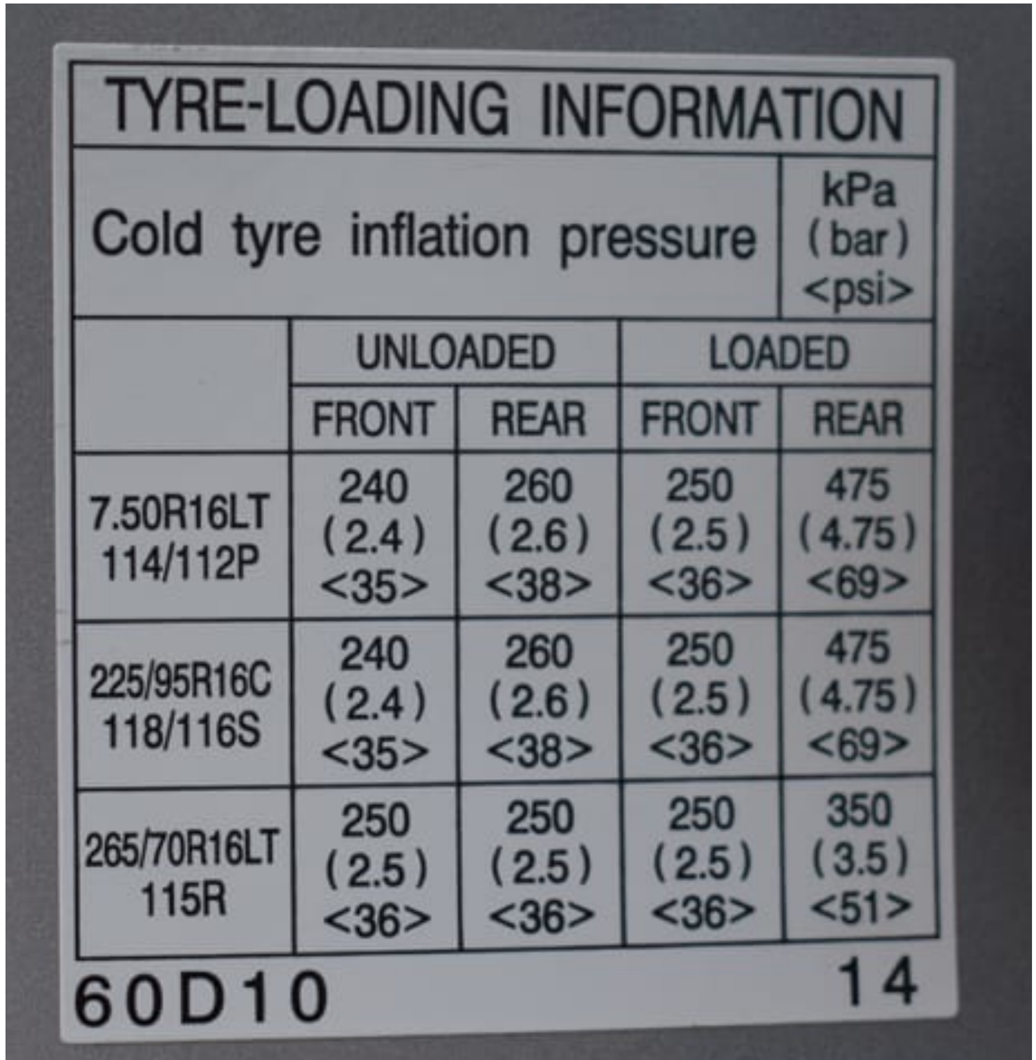
Pressure



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

Pressure

- How much air do we put in car and bike tires?



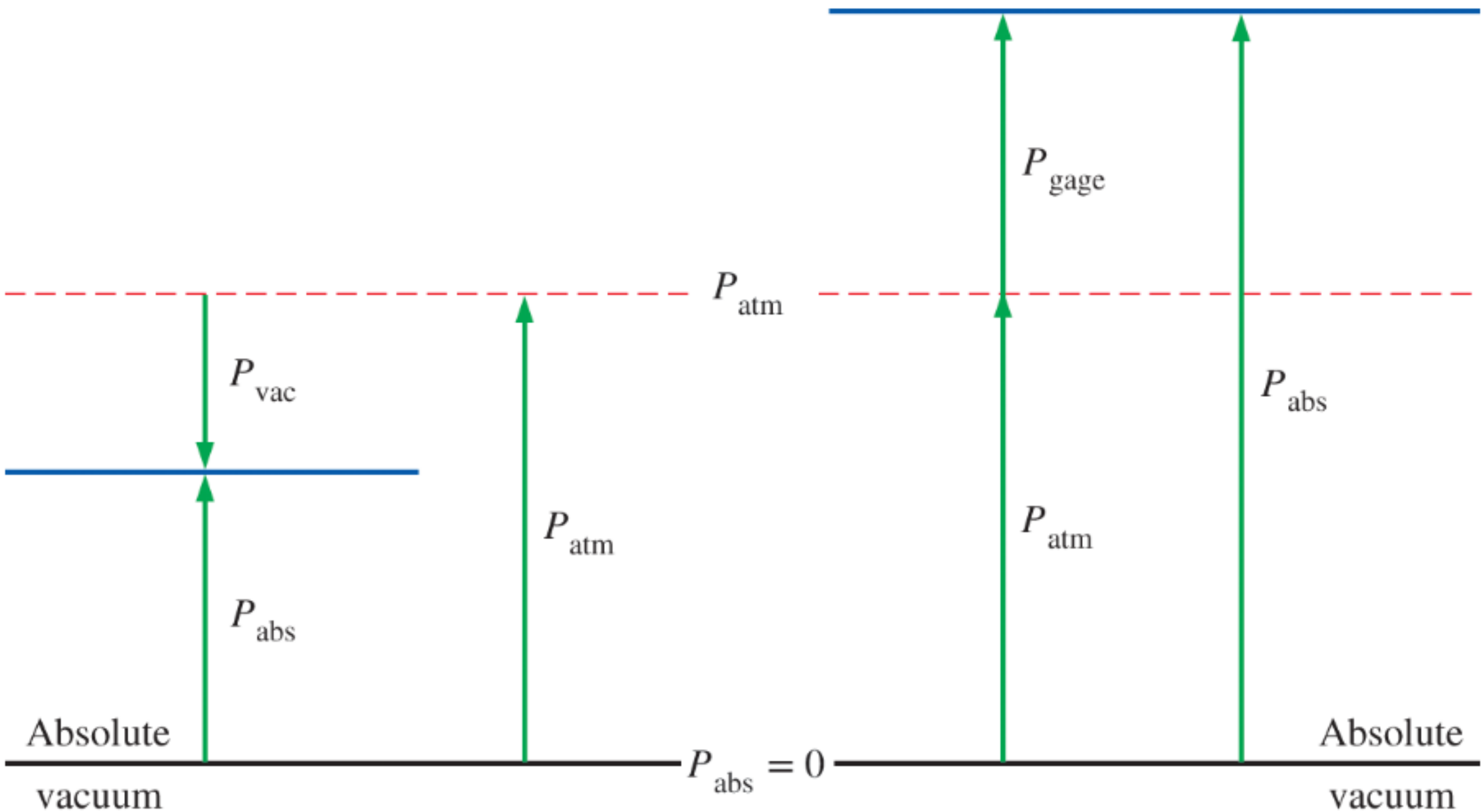
Pressure

- 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_{gage}
P_{atm}
P_{vac}
P_{atm}
P_{atm}
P_{abs}
P_{abs}
Absolute
vacuum
$P_{abs} = 0$
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

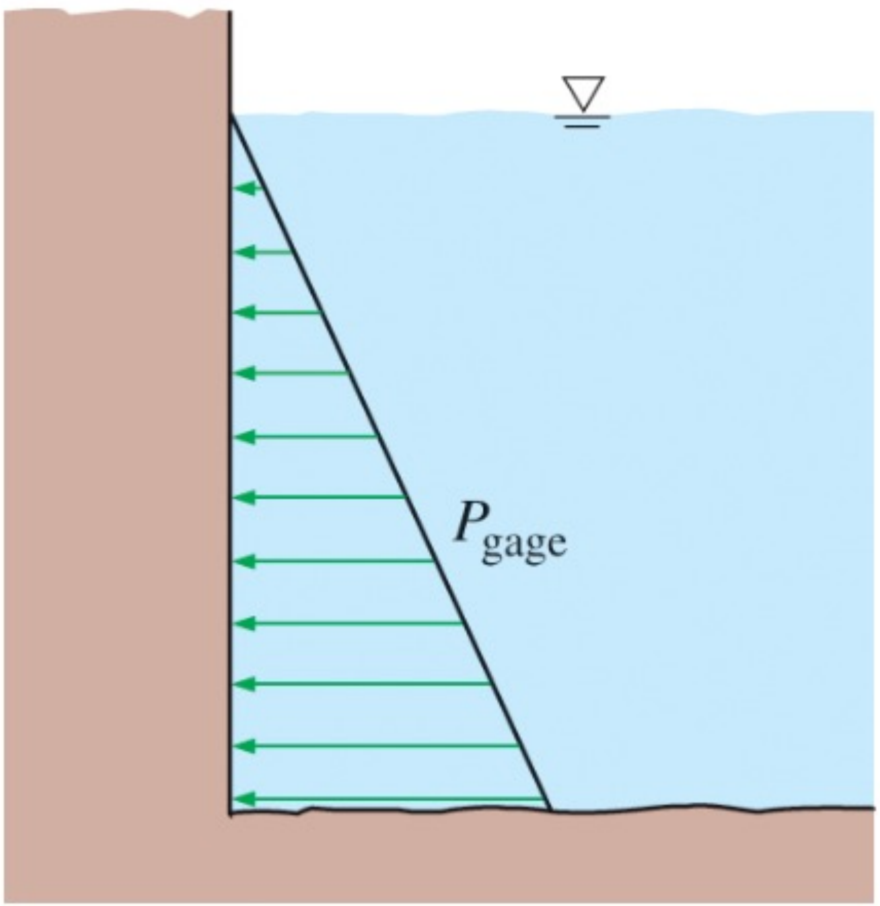
CLASS ACTIVITY

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?

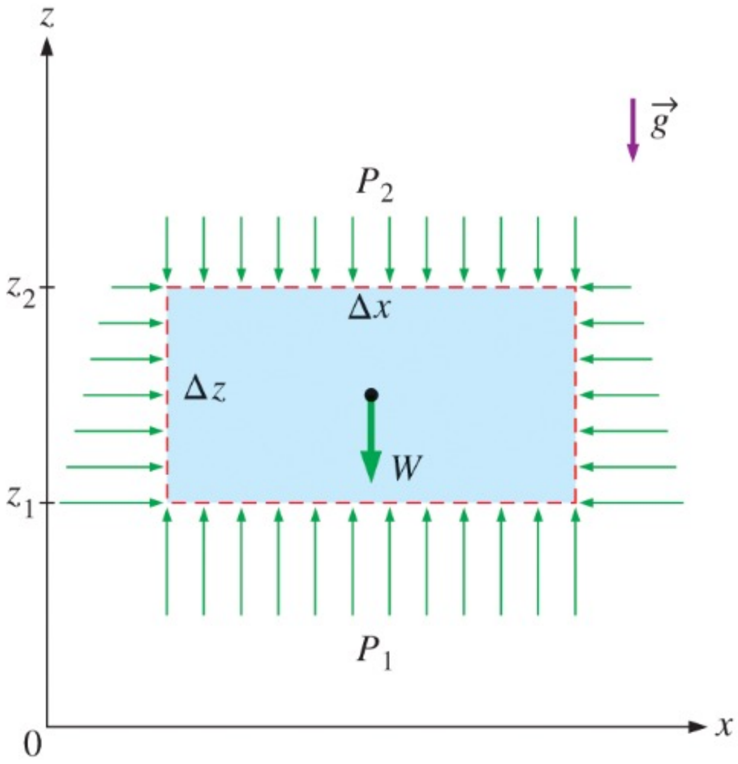
Pressure

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



Pressure

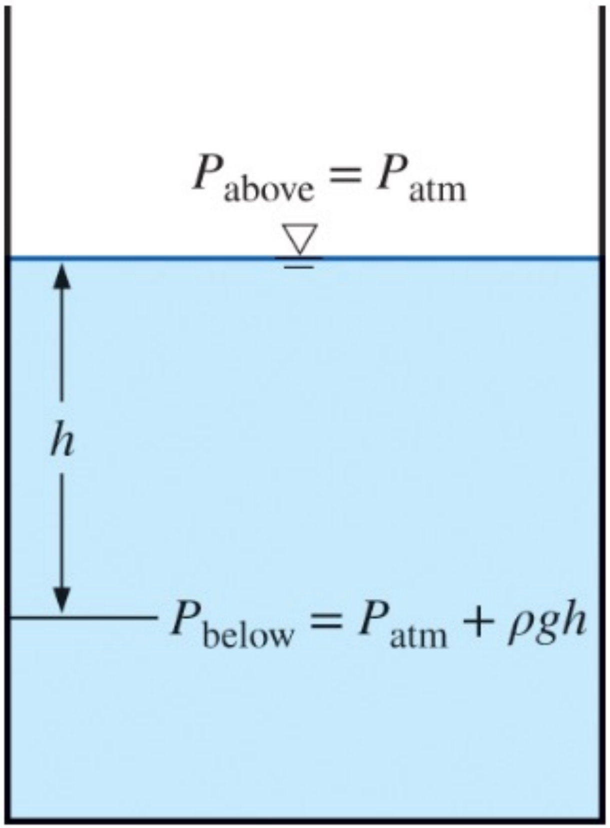
- Pressure in a static fluid increases linearly with depth



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

Pressure

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



Pressure

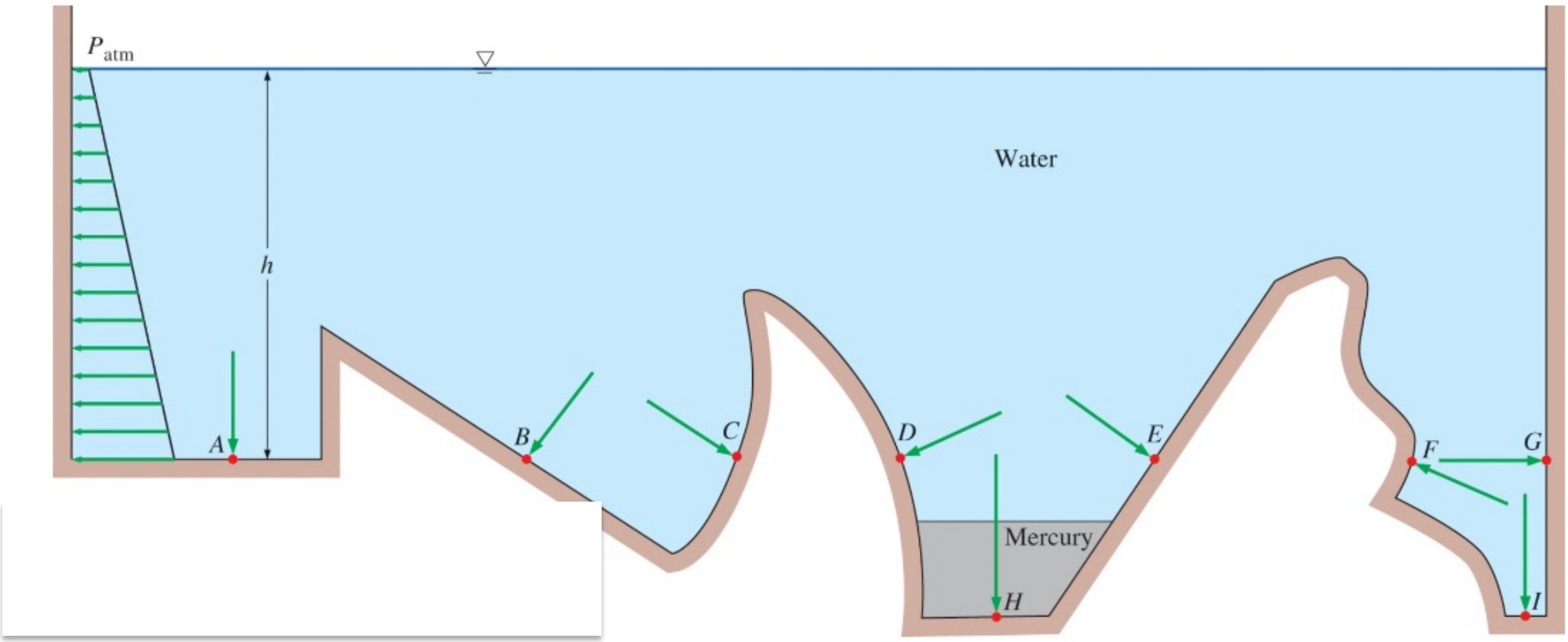
- ”g” varies from 9.807 m/s^2 at the sea level to 9.764 m/s^2 at an elevation of 14,000 m (0.4% in the extreme)

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

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

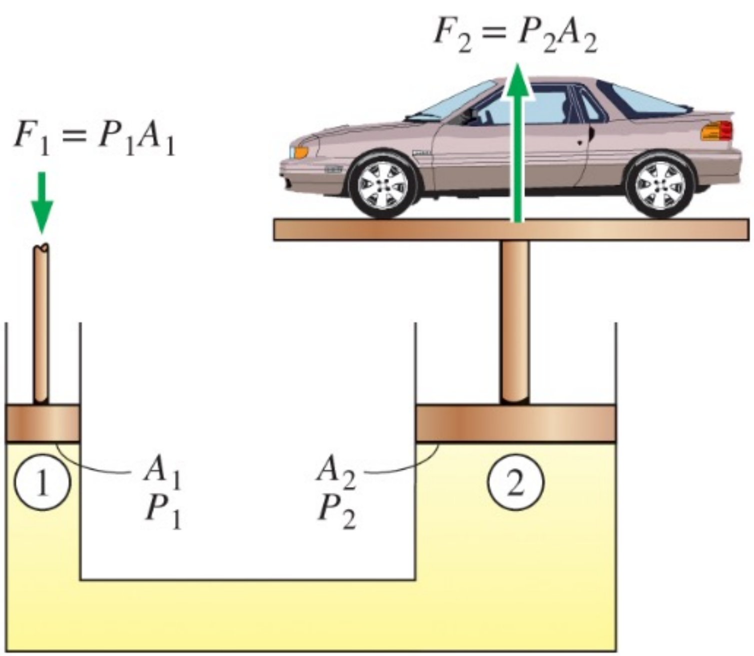
Pressure

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



Pressure

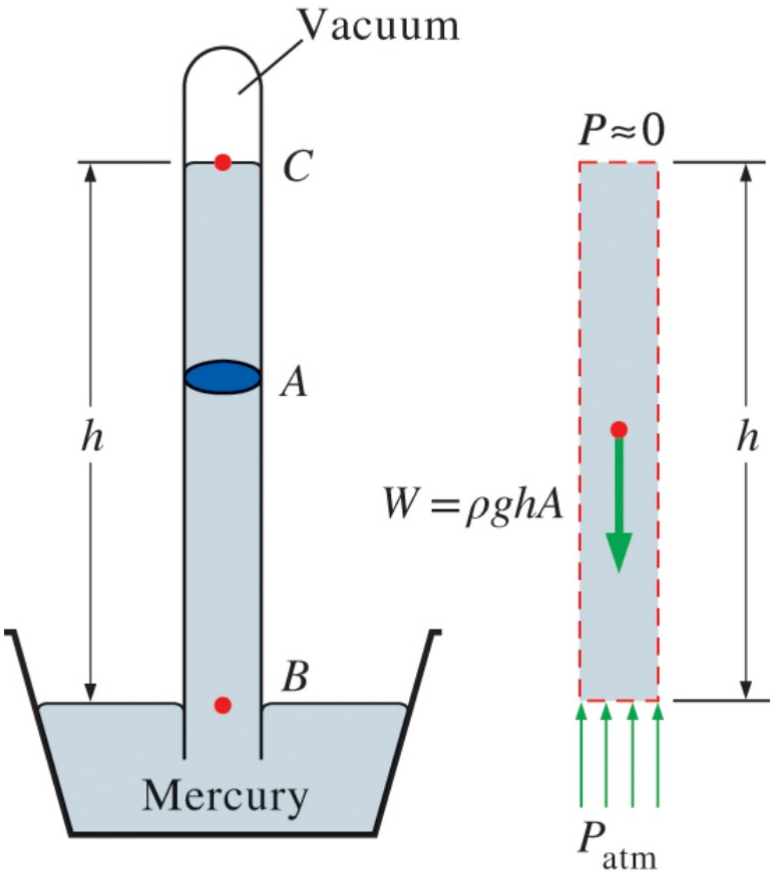
- Pascal's law: The pressure applied to a confined fluid increases the pressure throughout the same amount



PRESSURE MEASUREMENT DEVICES (BAROMETER)

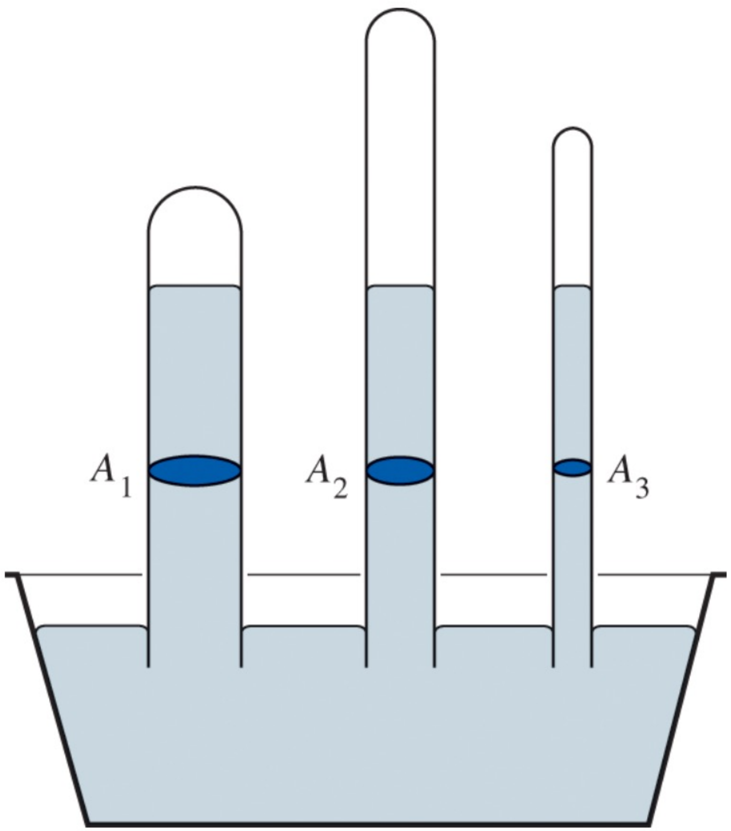
Pressure Measurement Devices

- 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

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Joel Rush Contributor

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WRITTEN BY MELISSA ROMERO | PUBLISHED ON MAY 16, 2012

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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.

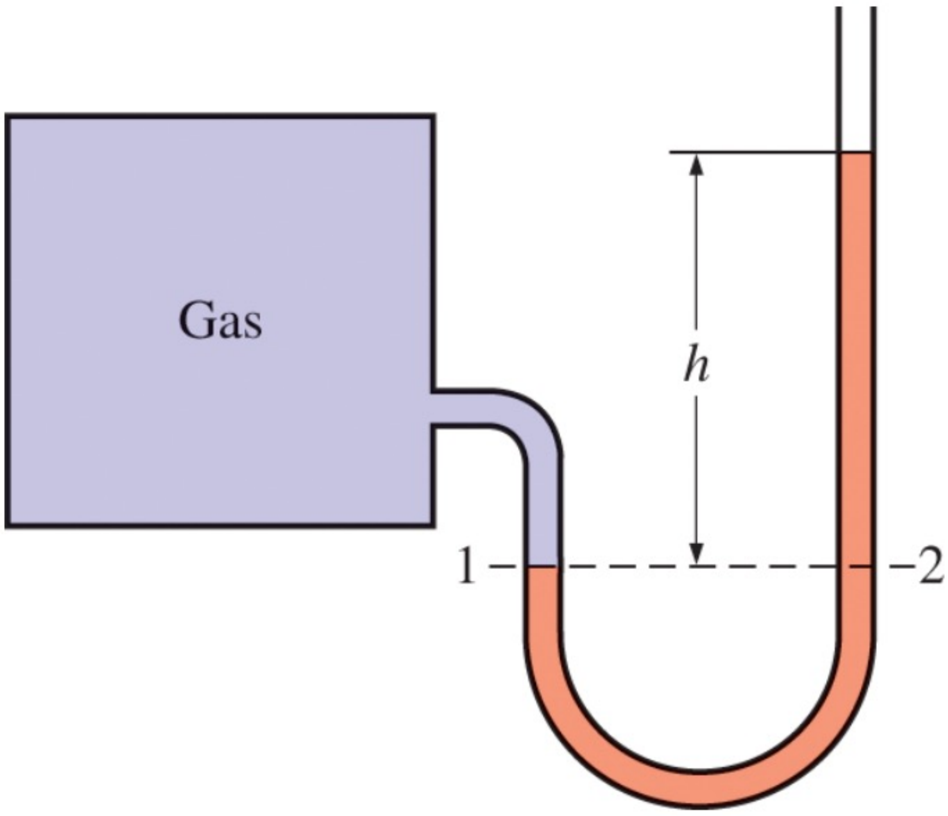
PRESSURE MEASUREMENT DEVICES (MANOMETER)

Manometer

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

Manometer

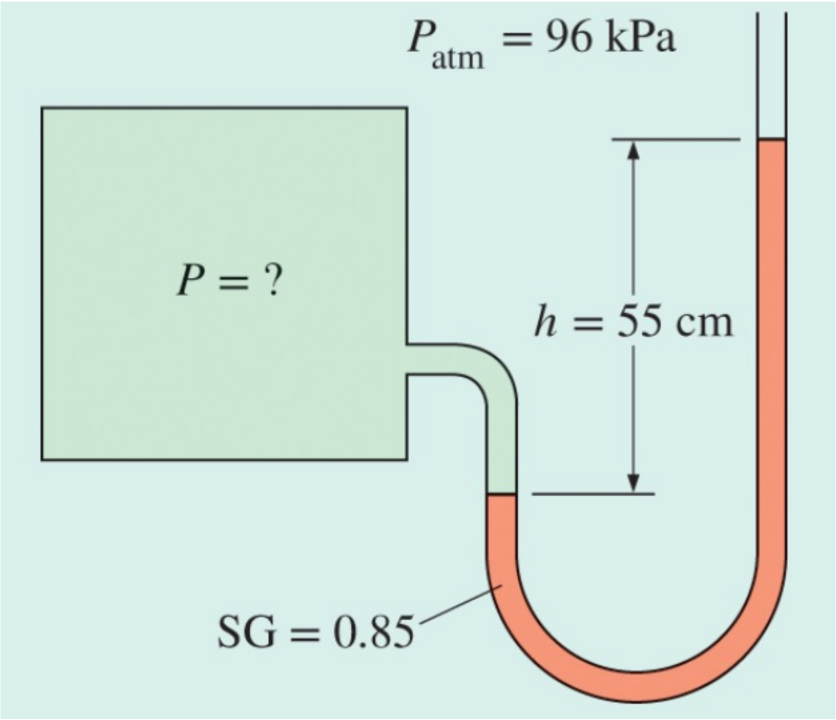
- Let’s consider this manometer situation



CLASS ACTIVITY

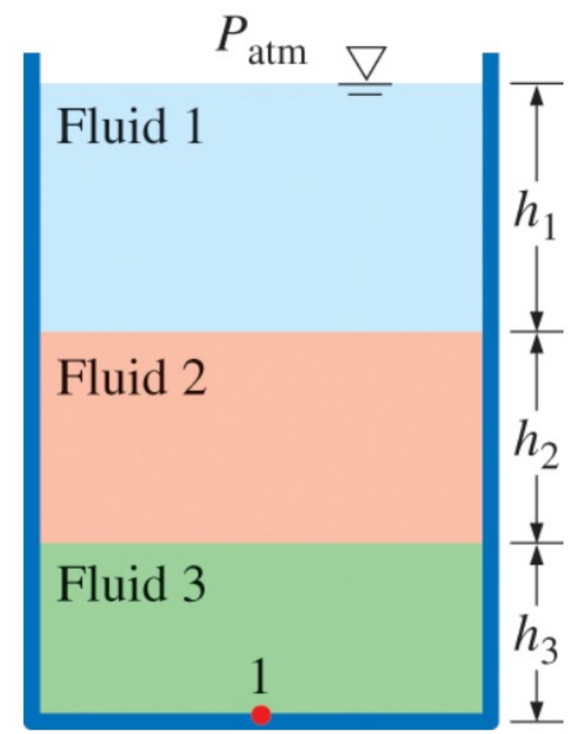
Class Activity

- 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.



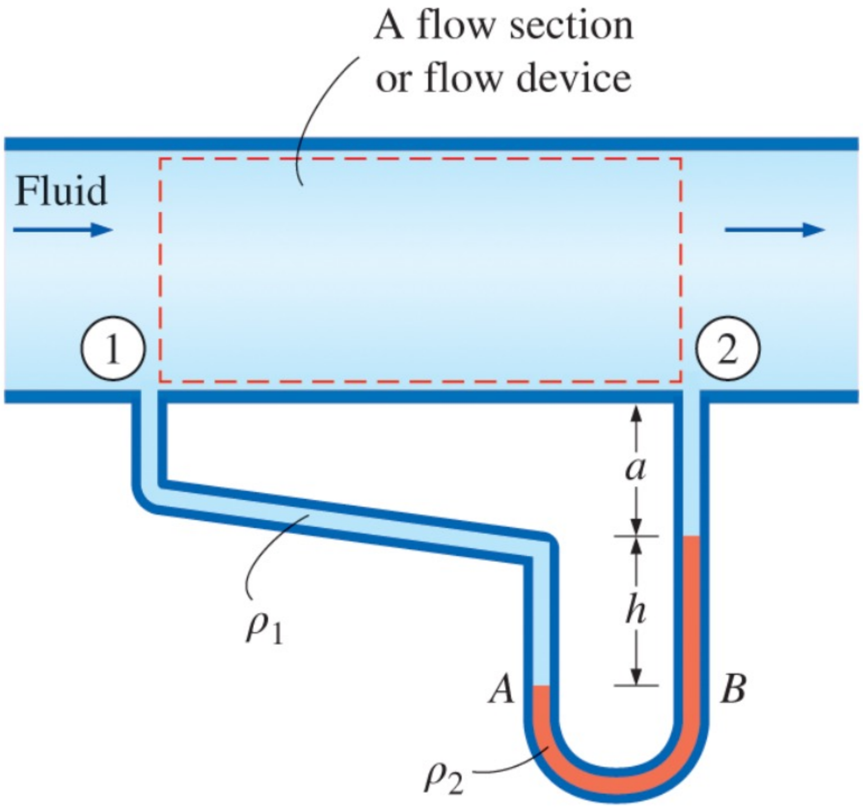
Manometer

- Special manometer designs
  - ❑ Inclined manometer
  - ❑ Using the extension of Pascal's law



Manometer

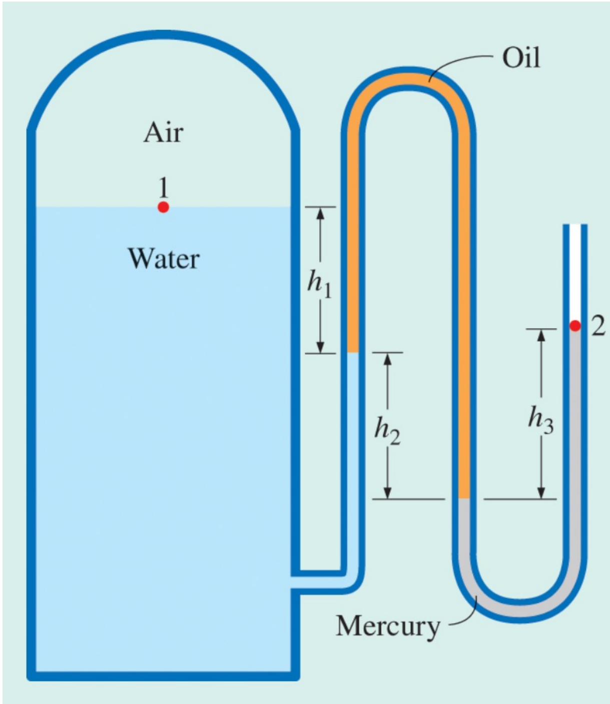
- Special manometer designs
  - ❑ Measure pressure drop in a duct due to other equipment



CLASS ACTIVITY

Class Activity

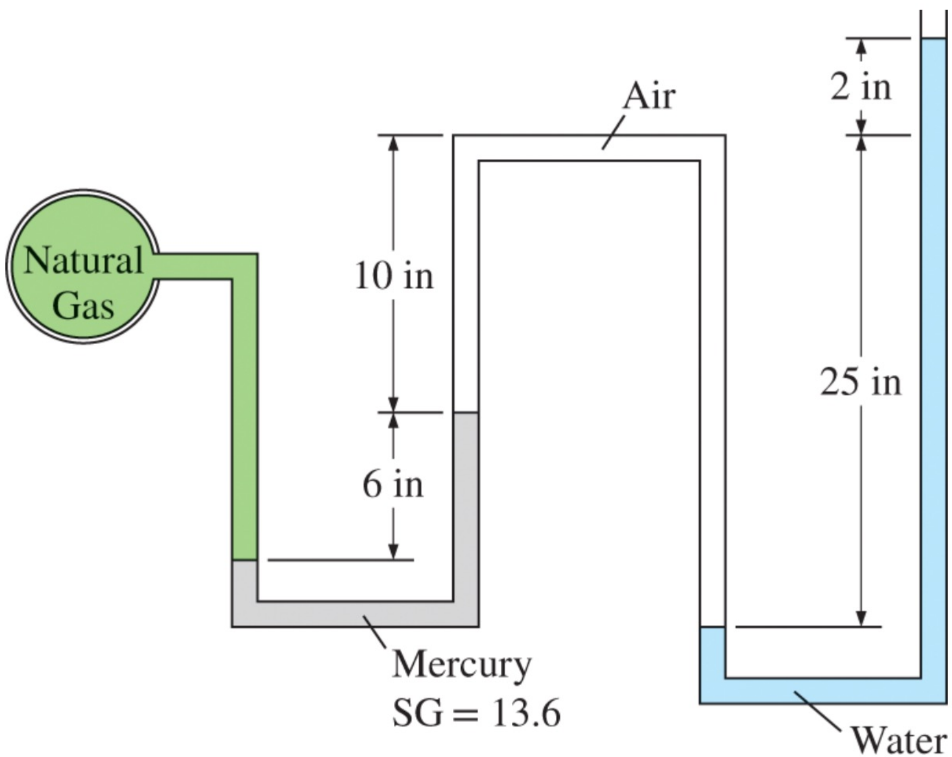
- Water in a tank is pressurized by air and the pressure is measured by a multifluid manometer. The tank location is on a mountain and the altitude of 140m where the atmospheric pressure is 85.6 kPa. Determine the air pressure in the tank is h_1 = 0.1 m, h_2=0.2m, and h_3=0.35. The densities of water,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



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

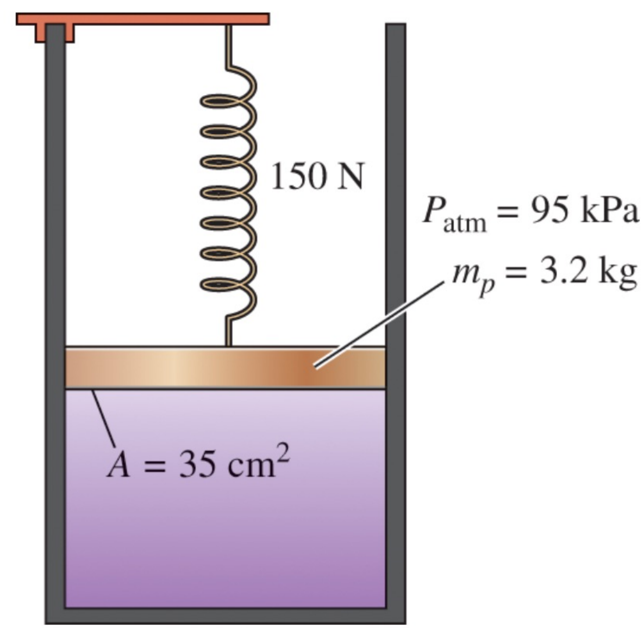
- **Solution:**

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

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

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:**

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

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

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

$$P = 147\ kPa$$