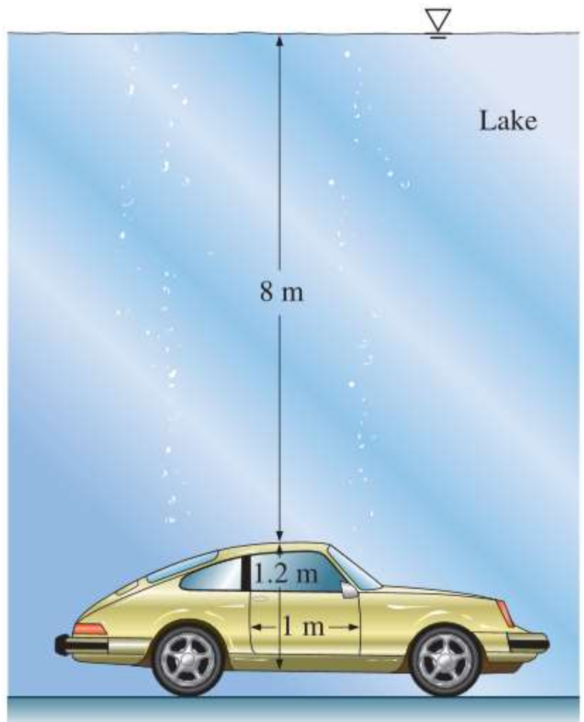
Fluid Statics



Instructor: Joaquín Valencia

ENGI 2420

Content

- Pressure
- Variation of Pressure with Depth
- Pressure Measurement Devices

Content

- **Pressure**

Pressure

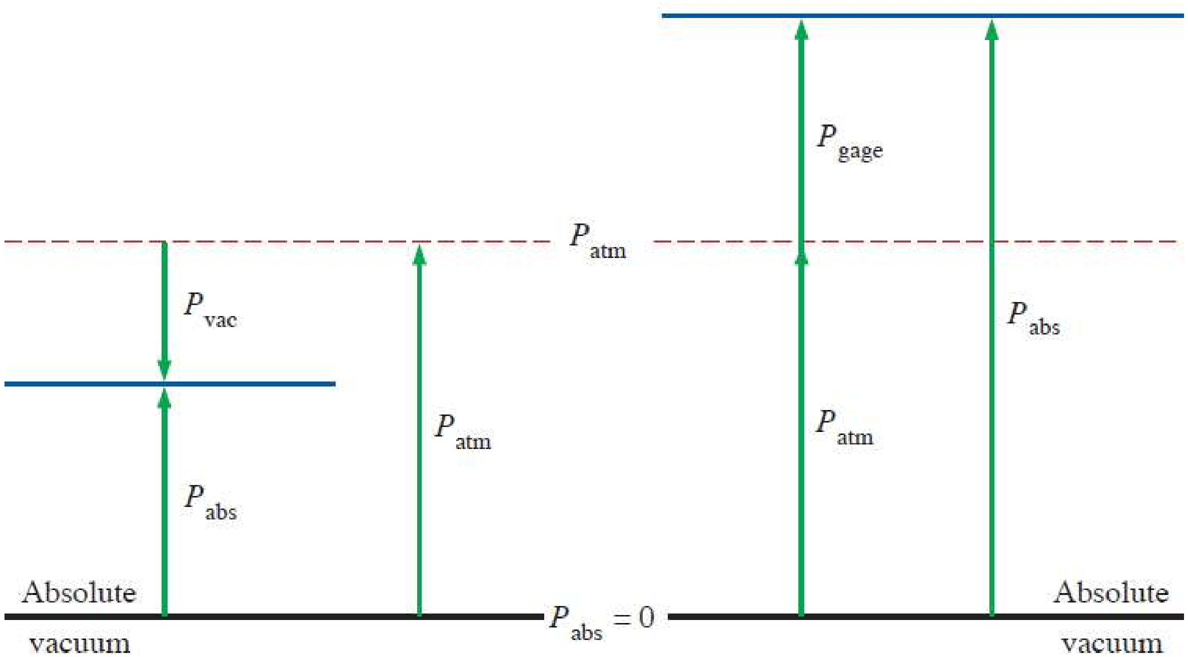
Pressure *P* is defined as a normal force exerted by a fluid per unit area.

$$P = \frac{F}{A}$$

SI units: $Pa = \frac{N}{m^2}$

English units: $lbf/in^2 = psi$

F **:** Normal force.



Absolute, gage, and vacuum pressures.

$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$

P_{gage} **:** Gage pressure.

P_{abs} **:** Absolute pressure.

P_{atm} **:** Atmospheric pressure.

P_{vac} **:** Vacuum pressure.

Pressure

Example 2.1

A pressure gage connected to a tank reads 50 psi at a location where the barometric reading is 29.1 inHg. Determine the absolute pressure in the tank. *Answer* : 64.3 psia

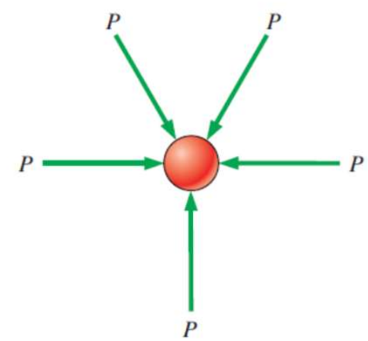
Pressure:

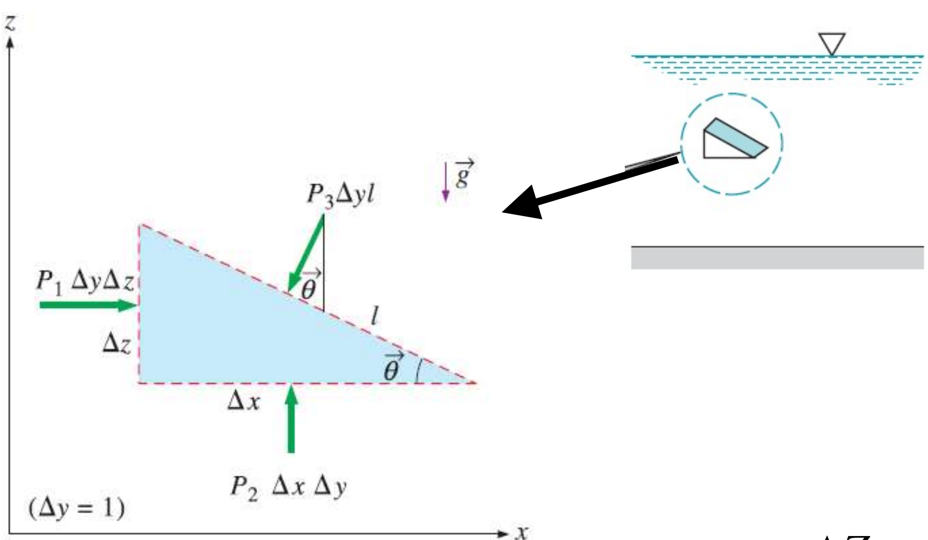
Pressure at a Point

Pressure at a point

The pressure at a point in a fluid at rest, or in motion, is independent of direction as long as there are no shearing stresses present.

Note: Pressure is a scalar quantity.





Forces acting on a wedge-shaped fluid element in equilibrium.

$$P_1 - P_3 = 0$$

$$P_2 - P_3 - \frac{1}{2}\gamma \Delta z = 0$$

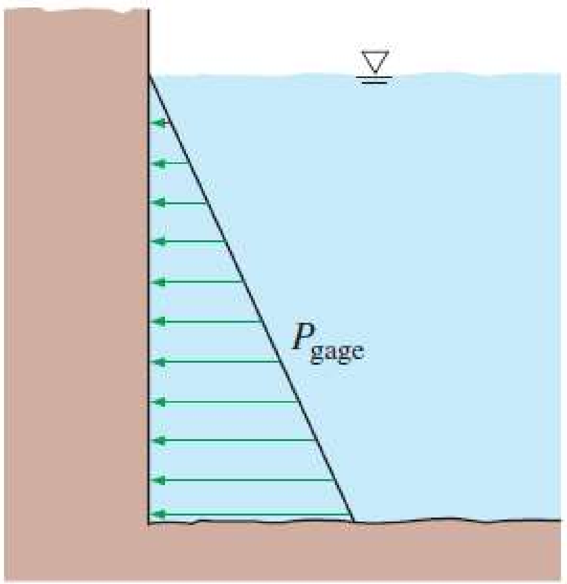
γ : Specific weight.

$$\Delta Z \to 0 \quad \Rightarrow \quad P_1 = P_2 = P_3 = P$$

Content

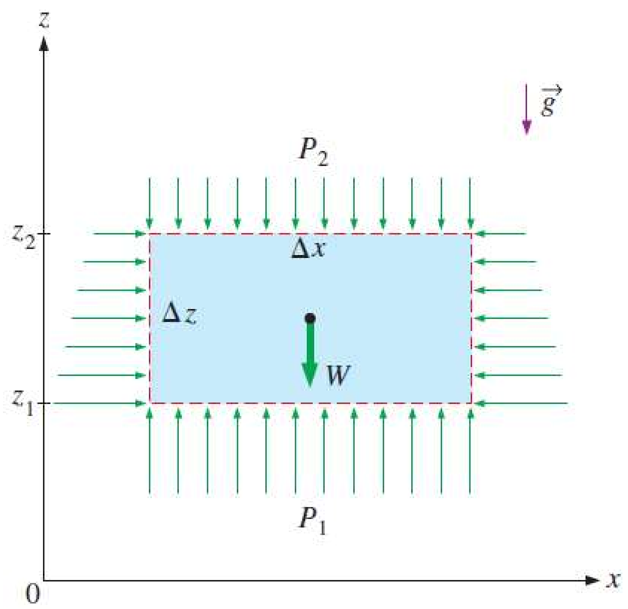
- Pressure
- **Variation of Pressure with Depth**

Variation of Pressure with Depth



The pressure of a fluid at rest increases linearly with depth.

γ : specific weight.



$$\sum F_z = 0$$

$$P_2 - P_1 = -\gamma \Delta z$$

$$P_{below} = P_{above} + \gamma\, h$$

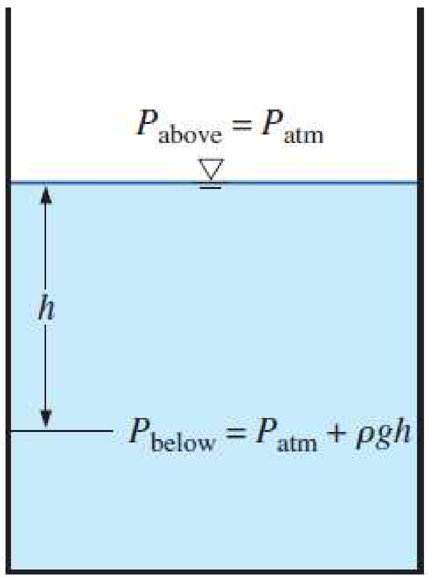
Pressure head

$$h = \Delta z$$

$$= z_2 - z_1$$

$$= \frac{P_1 - P_2}{\gamma}$$

Variation of Pressure with Depth



Pressure in a liquid at rest increases linearly with distance from the free surface.

$$P_{below} = P_{atm} + \rho g h$$

$$P_{gage} = \rho g h$$

When the variation of density ρ with elevation is known

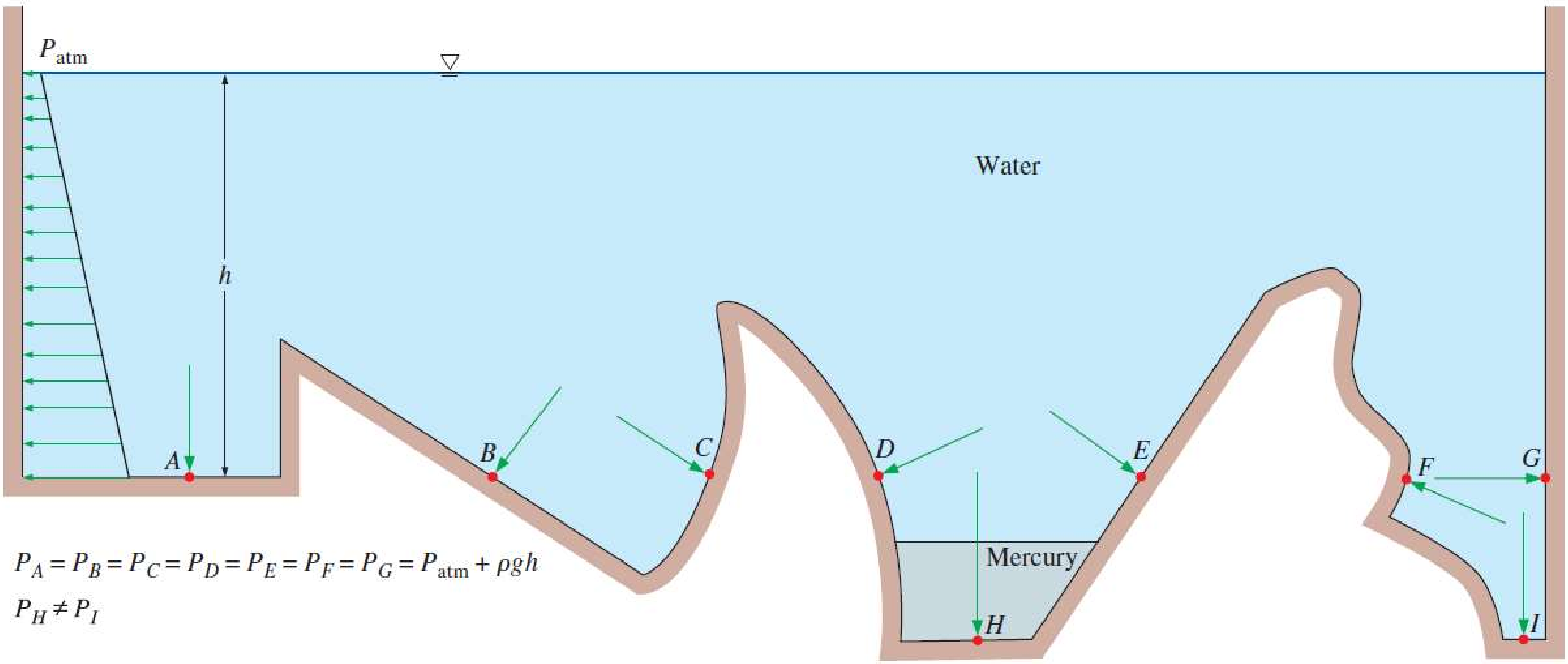
$$\Delta P = -\gamma \Delta z$$

$$\frac{dP}{dz} = -\gamma$$

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

Variation of Pressure with Depth

Pressure in a fluid at rest is independent of the shape or cross section of the container.

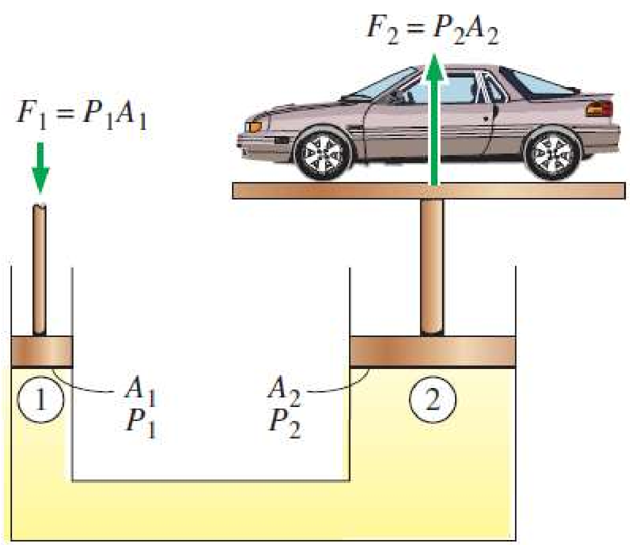


Variation of Pressure with Depth

Pascal's law

It states that the pressure applied to a confined fluid increases the pressure throughout by the same amount.

$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2}$$



Lifting of a large weight by a small force by the application of Pascal's law.

Variation of Pressure with Depth

Example 2.2

The gage pressure in a liquid at a depth of 3 m is read to be 28 kPa. Determine the gage pressure in the same liquid at a depth of 12 m.

Variation of Pressure with Depth

Example 2.3

A closed, 5-m-tall tank is filled with water to a depth of 4 m. The top portion of the tank is filled with air which, as indicated by a pressure gage at the top of the tank, is at a pressure of 20 kPa. Determine the pressure that the water exerts on the bottom of the tank.

Variation of Pressure with Depth

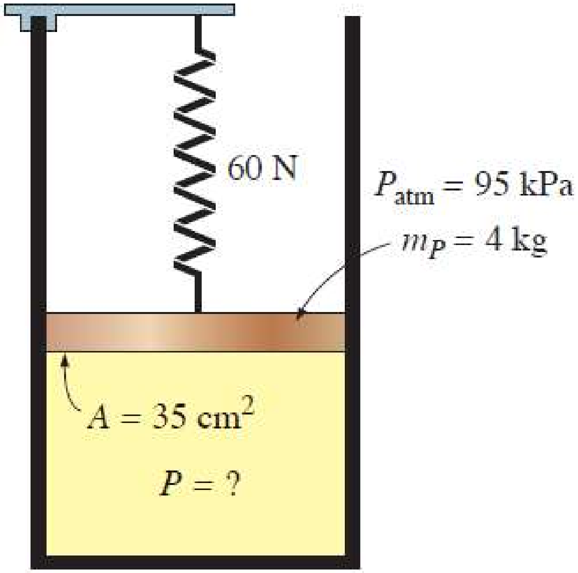
Example 2.4

If the pressure in a tank is 50 psi, find the equivalent pressure head of a) water, b) mercury (γ = 847.3 lbf/ft^3) and c) heavy fuel oil (SG=0.92).

Variation of Pressure with Depth

Example 2.5

A gas is contained in a vertical, frictionless piston–cylinder device. The piston has a mass of 4 kg and a cross sectional area of 35 cm^2. A compressed spring above the piston exerts a force of 60 N on the piston. If the atmospheric pressure is 95 kPa, determine the pressure inside the cylinder. *Answer:* 123.4 kPa



Content

- Pressure
- **Pressure Measurement Devices**

Pressure Measurement Devices

The Barometer - It is a device that measures atmospheric pressure; thus, atmospheric pressure is also called barometric pressure.

$$P_{atm} = \rho g h$$

ρ : Density.

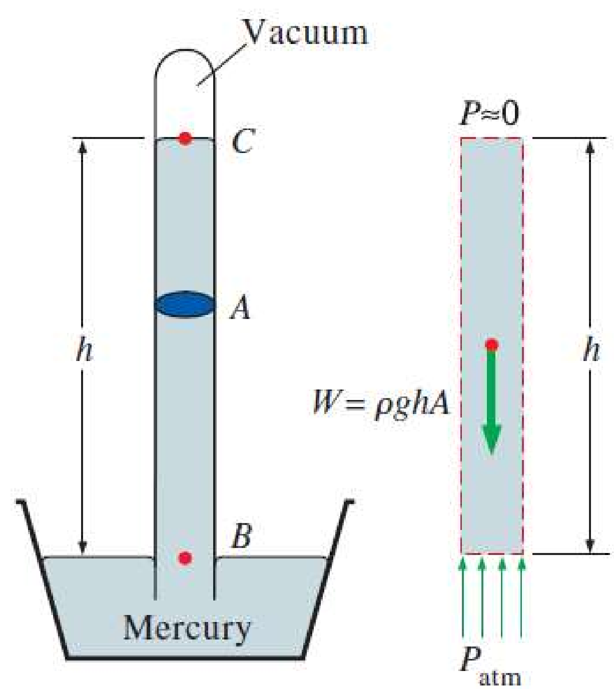
g : Gravitational acceleration.

h : Height of the mercury.

At sea level

$$1atm = 760mmHg$$
$$= 101.325kPa$$
$$= 14.7\,psi$$

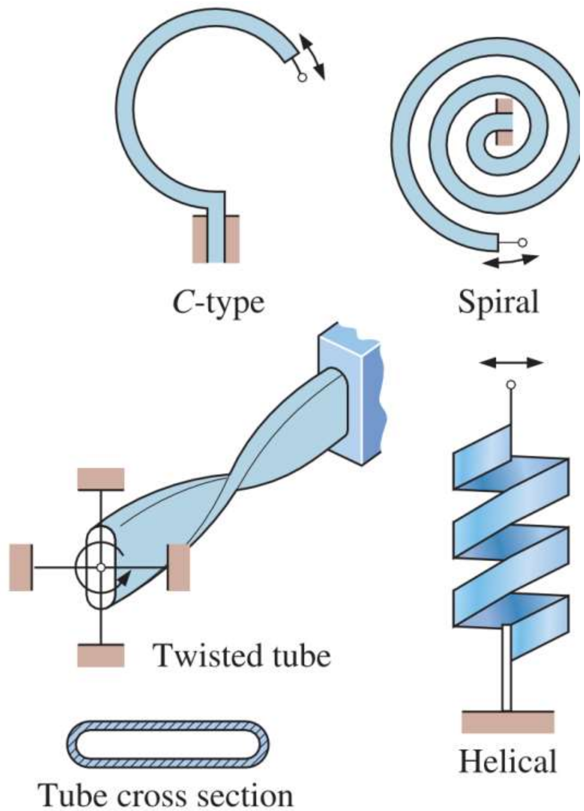
Remember $psi = \dfrac{lbf}{in^2}$



The basic barometer.

Pressure Measurement Devices

Bourdon tube - consist of a bent, coiled, or twisted hollow metal tube whose end is closed and connected to a dial indicator needle.



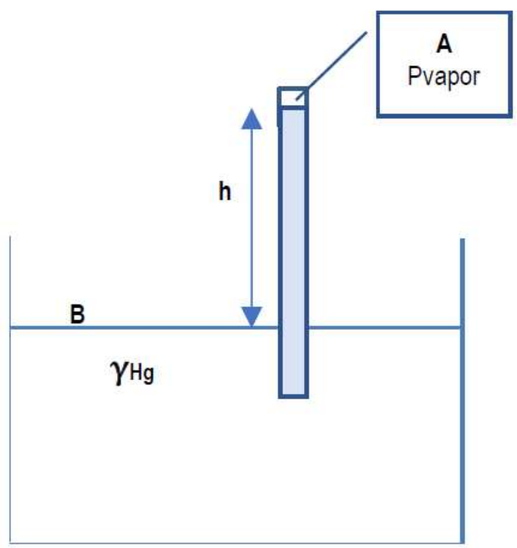
Pressure Measurement Devices

Pressure transducers – use various techniques to convert the pressure effect to an electrical effect such as a change in voltage, resistance, or capacitance.

Pressure Measurement Devices

Example 2.6

A simple mercury barometer consists of a glass tube closed at one end with the open end immersed in a container of mercury as shown in the Figure below. a) For a mercury column height h = 30.1 in, determine the atmospheric pressure (neglect P_{vapor}). b) A gage attached to a pressurized air tank located near the barometer reads 18 psi. What is the absolute pressure of the air in the tank? (γ_{Hg} = 847.3 lbf/ft^3)



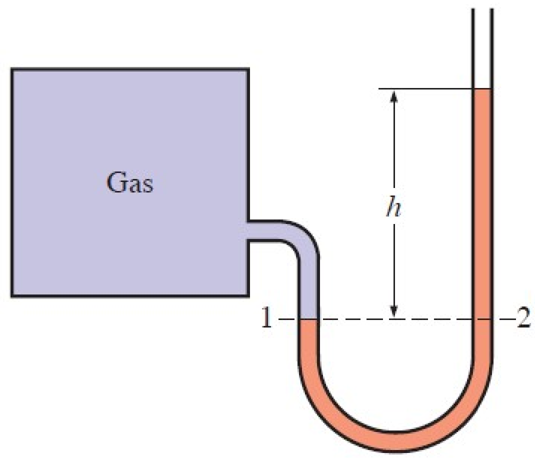
Pressure Measurement Devices

The Manometer

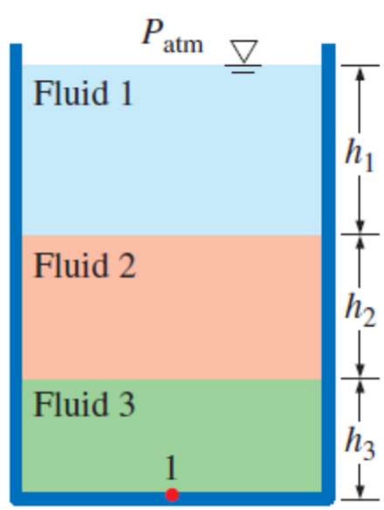
It is a device in which vertical or inclined fluid columns can be used to measure pressure differences.

$$P_1 = P_2$$

$$P_2 = P_{atm} + \rho g h$$



The basic manometer.



Stacked-up fluid layers at rest.

$$P_1 = P_{atm} + \rho_1 g h_1 + \rho_2 g h_2 + \rho_3 g h_3$$

Pressure Measurement Devices: The Manometer

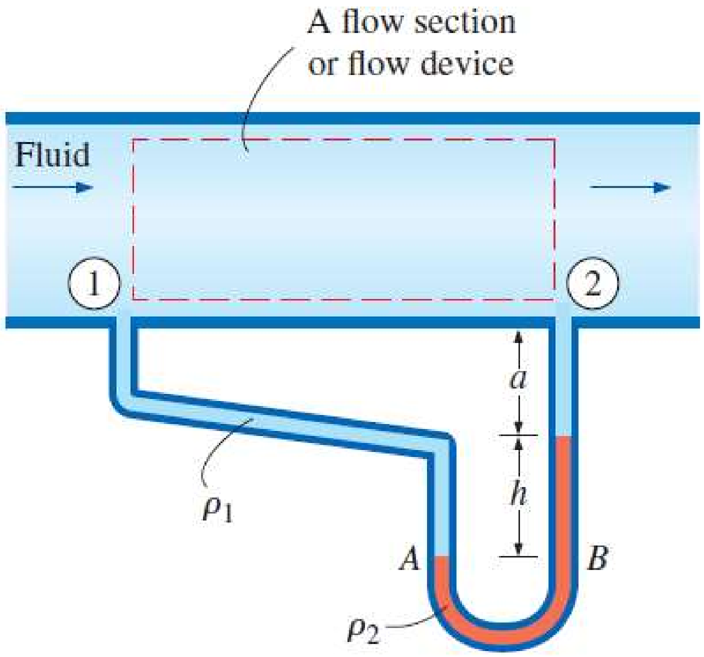
Measuring pressure drops across a horizontal flow section between two specified points.

$$P_1 - P_2 = (\rho_2 - \rho_1)gh$$

When the fluid flowing in the pipe is a gas,

$$\rho_1 << \rho_2$$

$$\Rightarrow \quad P_1 - P_2 \cong \rho_2 gh$$

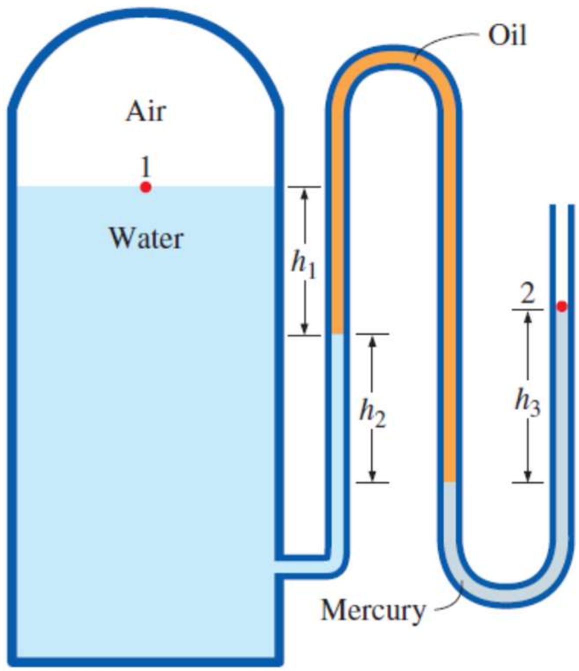


Measuring the pressure drop across a flow section.

Pressure Measurement Devices:
The Manometer

Example 2.7

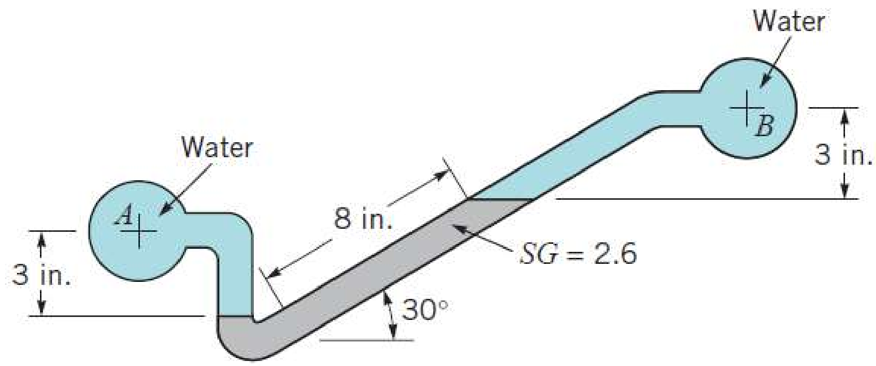
The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in the Figure below. Determine the gage pressure of air in the tank if h_1 = 0.4 m, h_2 = 0.6 m, and h_3 = 0.8 m. Take the densities of water, oil, and mercury to be 1000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively. *Answer* : 97.8 kPa



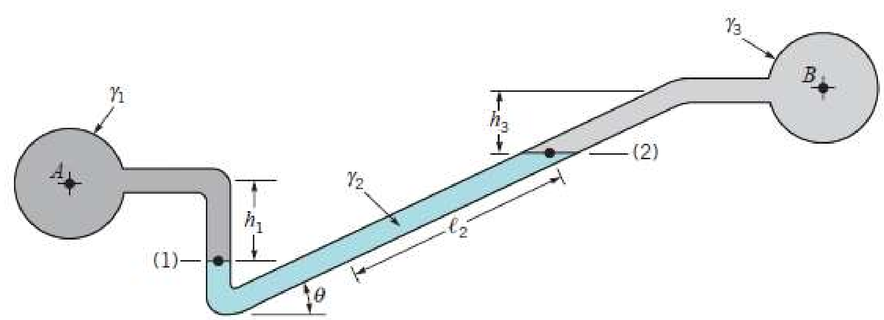
Pressure Measurement Devices:
The Manometer

Example 2.8

For the inclined-tube manometer of the Figure below the pressure in pipe A is 0.6 psi. The fluid in both pipes A and B is water, and the gage fluid in the manometer has a specific gravity of 2.6. What is the pressure in pipe B corresponding to the differential reading Shown? Answer: 0.224 psi



Hint:

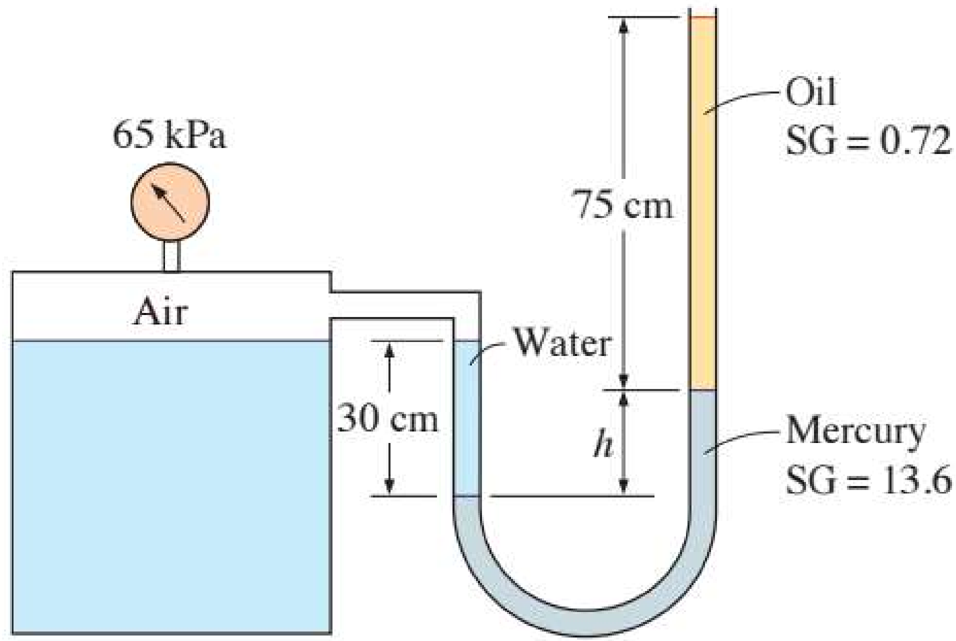


$$P_A - P_B = \gamma_2 l_2 \sin\theta + \gamma_3 h_3 - \gamma_1 h_1$$

Pressure Measurement Devices: The Manometer

Example 2.9

The gage pressure of the air in the tank shown in the Figure below is measured to be 65 kPa. Determine the differential height h of the mercury column.

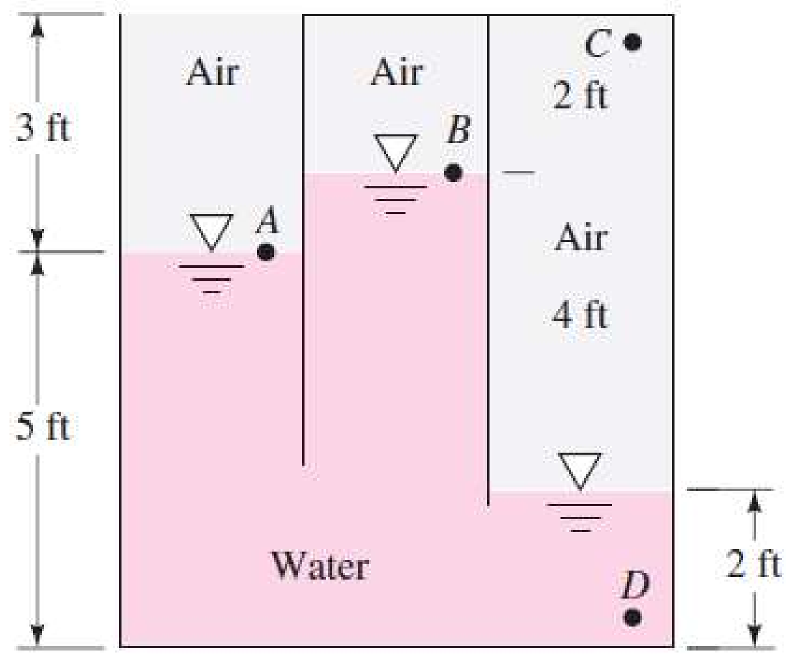


Pressure Measurement Devices:

The Manometer

Example 2.10

The system in the Figure below is at 20°C. If the pressure at point A is 1900 lbf/ft^2, determine the pressures at points B, C, and D in lbf/ft^2.



References

[1] Cengel Y., Cimbala, J. (2014). Fluid Mechanics: Fundamentals and Applications (3th Edition). New York: NY: McGraw-Hill Co.

[2] Munson, B.R., Young, D.F., Okiishi, T.H., and Huebsch, W.W. (2016). Fundamentals of Fluid Mechanics (8th Edition). John Wiley & Sons. ISBN 1119080703.