Pressure:

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

We speak of pressure only when we deal with a gas or a liquid. The counterpart of pressure in solids is normal stress.

The unit of pressure is: (**N/m^2**), *which is called* a **pascal (Pa).**

$$1\ kPa = 10^3\ Pa$$

$$1\ bar = 10^5\ Pa$$

$$1\ atm. = 101325\ Pa$$

The absolute pressure (P_{abs}): the actual pressure at a given position, and it is measured relative to absolute vacuum (i.e., absolute zero pressure).

Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere.

The gage pressure (P_{gage}): the difference between the absolute pressure and the local atmospheric pressure.
The gage pressure can be positive or negative.

Vacuum pressures (P_{vac}): the pressures below atmospheric pressure.
Measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure.

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

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

Where:

P_{gage}: Gage pressure.

P_{abs}: Absolute pressure.

P_{atm}: Atmospheric pressure.

P_{vac}: Vacuum pressures

The absolute pressure, gage pressure, atmospheric pressure, and vacuum pressures illustrated in figure (16).

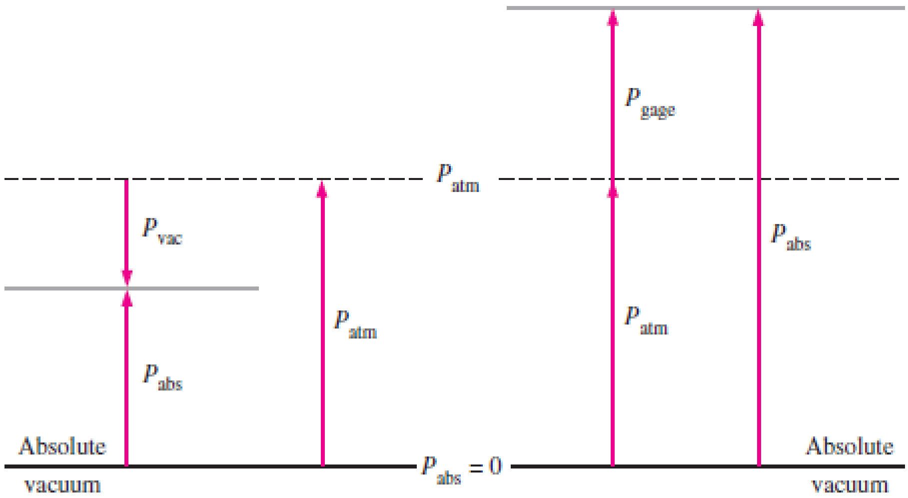


Figure (16) illustrated the absolute pressure, gage pressure, atmospheric pressure, and vacuum pressures

Example: A vacuum gage connected to a chamber reads (39989.59 Pa) at a location where the atmospheric pressure is (99973.98 Pa). Determine the absolute pressure in the chamber.

Solution:

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

$$P_{abs} = 99973.98 - 39989.59$$

$$P_{abs} = 59984.39 \text{ Pa}$$

Variation of Pressure with Depth:

Pressure in a fluid increases with depth because more fluid rests on deeper layers, and the effect of this "extra weight" on a deeper layer is balanced by an increase in pressure as shown in figure (17).

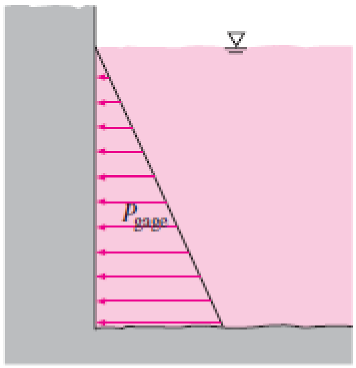


Figure (17) illustrated The pressure of a fluid at rest increases with depth (as a result of added weight).

If we take the (*above*) point to be at the free surface of a liquid open to the atmosphere as shown in figure (18), where the pressure is the atmospheric pressure (P_{atm}), then the pressure at a depth h below the free surface becomes:

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

Where:

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

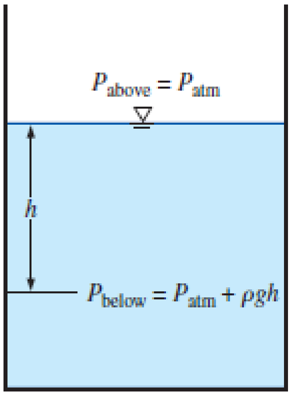


Figure (18) illustrated Pressure in a liquid at rest increases linearly with distance from the free surface

Pressure measurement devices:

- **The manometer:** is device used to measure small and moderate pressure differences. A manometer mainly consists of a glass or plastic U-tube containing one or more fluids such as mercury, water, alcohol, or oil.

To keep the size of the manometer to a manageable level, heavy fluids such as mercury are used if large pressure differences are anticipated.

Consider the manometer shown in figure (19) that is used to measure the pressure in the tank. Since the gravitational effects of gases are negligible, the pressure anywhere in the tank and at position 1 has the same value. Furthermore, since pressure in a fluid does not vary in the horizontal direction within a fluid, the pressure at point 2 is the same as the pressure at point 1, $P_2 = P_1$.

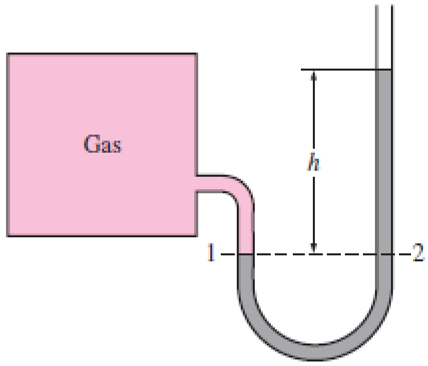


Figure (19) The basic manometer

The differential fluid column of height h is in static equilibrium, and it is open to the atmosphere. Then the pressure at point 2 is determined directly from the following equation:

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

Where:

ρ: the density of the fluid in the tube

Many engineering problems and some manometers involve multiple immiscible fluids of different densities stacked on top of each other. Such systems can be analyzed easily by remembering that

- The pressure change across a fluid column of height (h) is $\Delta P = \rho g h$
- Pressure increases downward in a given fluid and decreases upward (i.e., $P_{bottom} > P_{top}$).
- Two points at the same elevation in a continuous fluid at rest are at the same pressure.

The last principle, which is a result of **Pascal's law**, allows us to "jump" from one fluid column to the next in manometers without worrying about pressure change as long as we don't jump over a different fluid, and the fluid is at rest. Then the pressure at any point can be determined by starting with a point of known pressure and adding or subtracting ($\rho g h$) terms as we advance toward the point of interest. For example, the pressure at the bottom of the tank in figure (20) can be determined by starting at the free surface where the pressure is (P_{atm}), moving downward until we reach point 1 at the bottom, and setting the result equal to (P_1). It gives:

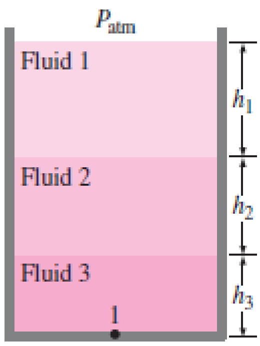
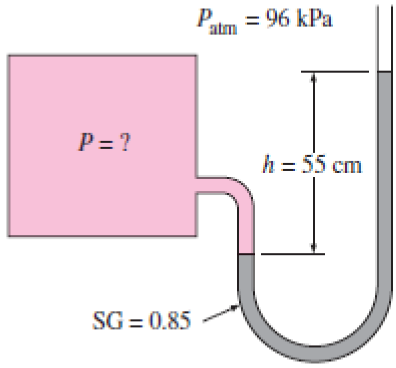


Figure (20) In stacked-up fluid layers, the pressure change across a fluid layer of density ρ and height h is $\rho g h$.

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

Example: A manometer is used to measure the pressure in a tank. The fluid used has a specific gravity of **(0.85)**, and the manometer column height is **(55 cm)**, as shown in Figure. If the atmospheric pressure is **(96 kPa)**. **Determine the absolute pressure within the tank.**



Solution:

$$SG = \frac{\rho}{\rho_{H_2O}} \Rightarrow \rho = SG(\rho_{H_2O}) \Rightarrow \rho = (0.85)(1000) = 850 \text{ kg/m}^3$$

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

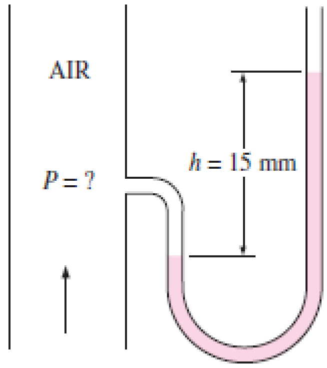
$$P = 96000 + (850)(9.81)(0.55)$$

$$P = 96000 + 4586.175$$

$$P = 100586.175 \text{ Pa}$$

$$P = 100.586 \text{ kPa}$$

Example: A mercury manometer ($\rho = 13600 \text{kg/m}^3$) is connected to an air duct to measure the pressure inside as shown in figure. The difference in the manometer levels is **(15 mm)**, and the atmospheric pressure is **(100 kPa)**. **Determine the absolute pressure in the duct.**



Solution:

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

$$P = 100000 + (13600)(9.81)(0.015)$$

$$P = 100000 + 2001.24$$

$$P = 102001.24 \text{ Pa}$$

Example: Repeat the previous example with a differential mercury height of **(45 mm)**.

Solution:

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

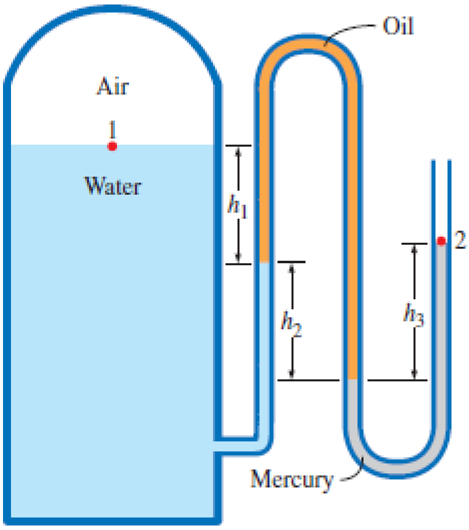
$$P = 100000 + (13600)(9.81)(0.045)$$

$$P = 100000 + 6003.72$$

$$P = 106003.72 \text{ Pa}$$

Example: The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in figure. The tank is located on a mountain at an altitude of 1400 m where the atmospheric pressure is **85.6 kPa**.

Determine the air pressure in the tank if h_1**= 0.1 m**, h_2**= 0.2 m**, and h_3**= 0.35 m**. Take the densities of water, oil, and mercury to be **1000 kg/m³**, **850 kg/m³**, and **13600 kg/m³**, respectively.



Solution:

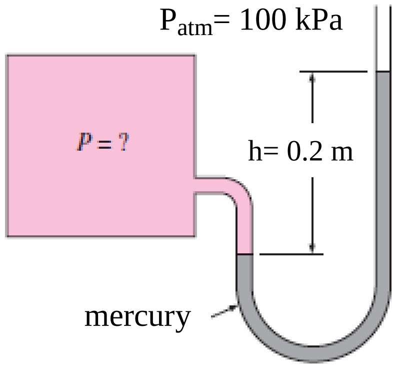
$$P_1 = P_{atm} - \rho_w g h_1 - \rho_{oil} g h_2 + \rho_{mercury} g h_3$$

$$P_1 = 85600 - [(1000)(9.81)(0.1)] - [(850)(9.81)(0.2)] + [(13600)(9.81)(0.35)]$$

$$P_1 = 85600 - 981 - 1667.2 + 46695.6$$

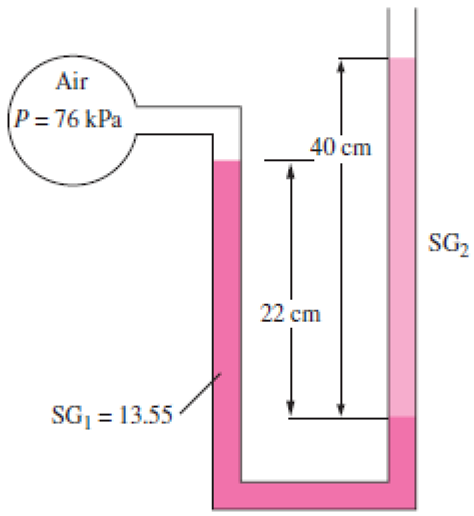
$$P_1 = 129647.4 \text{ Pa}$$

H.W: A manometer is used to measure the pressure in a tank. The fluid used is (mercury) with density **(13600 kg/m^3)**, and the manometer column height is **(0.2 m)**, as shown in Figure. If the atmospheric pressure is **(100 kPa)**. **Determine the absolute pressure within the tank.**



Answer: 126683.2 Pa

H.W: Consider a double-fluid manometer attached to an air pipe shown in figure. If the specific gravity of one fluid is **(13.55)**. **Determine the specific gravity of the other fluid for the indicated absolute pressure of air**. Take the atmospheric pressure to be **(100 kPa).**



Answer: 1.336

- **The Barometer:** atmospheric pressure is measured by a device called a barometer; thus, the atmospheric pressure is often referred to as *the barometric pressure*.

The Italian Evangelista Torricelli (1608–1647) was the first to prove that the atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere, as shown in Figure (21).

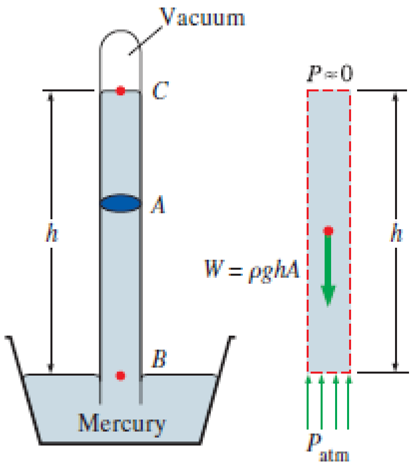


Figure (21) The basic barometer