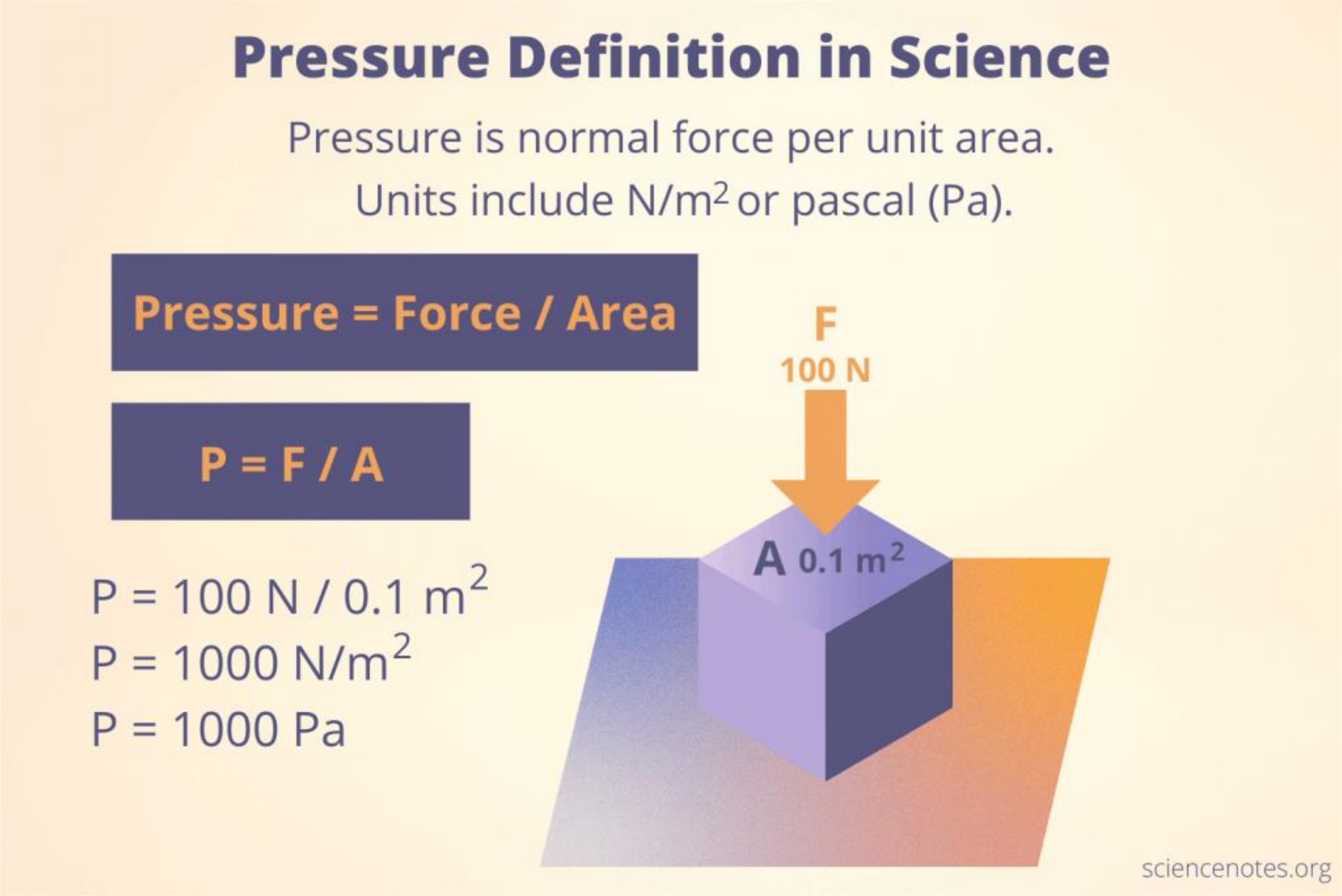
Instrumentation-Sensors (what)

- Introduction: principles and fundamentals of Process Measurement and Instrumentation
- **Pressure Measurement**
- Flow Measurement
- Level Measurement
- Temperature Measurement
- Sensors

Pressure Measurement

What is pressure?



What is pressure?

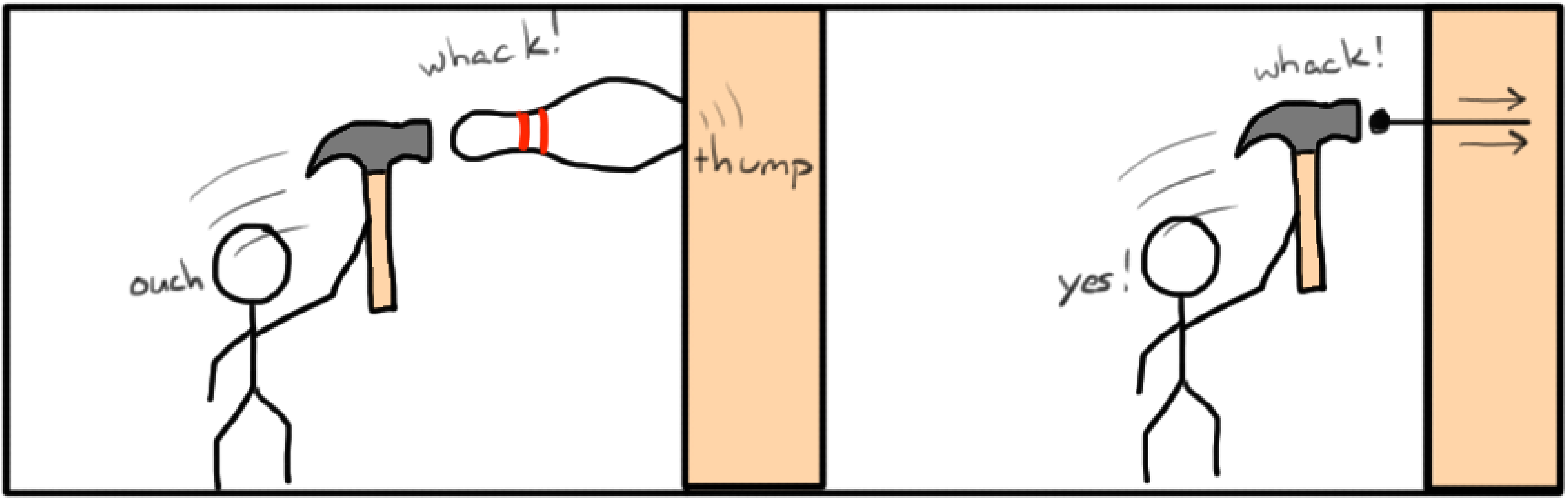
Example:

The liquid in a container has a total weight of 152 kN, and the container has a $8.9\ m^2$ base. What is the pressure on the base?

Solution

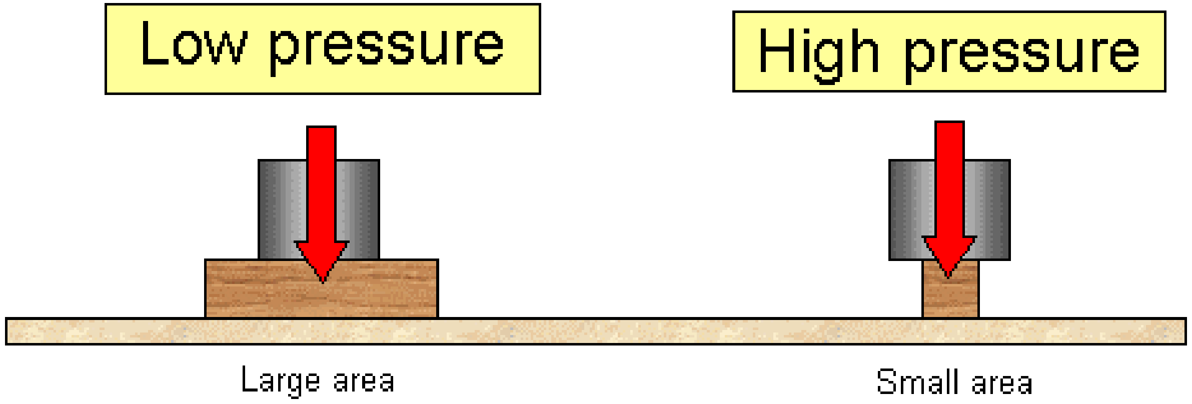
$$Pressure = \frac{152}{8.9} kPa = 17.1 kPa$$

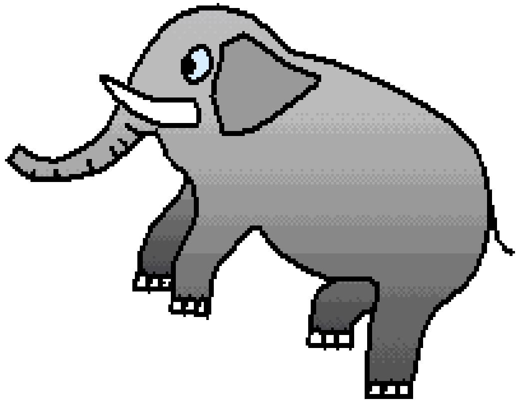
What is pressure?



Pressure depends on two factors

- *1.force* -more force more pressure
- 2.*area* -more area less pressure





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

Units of Pressure

Unit	unitsymbol	corresponds to	Country/Region
Pascal	Pa	1 bar = 100,000 Pa	-
Bar	bar	1 bar = 1 bar	Western Europe
Kilopascal	kPa	1 bar = 100 kPa	Australia
Megapascal	MPa	1 bar = 0.1 MPa	China
Pound per square inch	psi	1 bar = 14.5 psi	North America
Kilogram per square centimetres	kg/cm^2 or $kg(f)/cm^2$	1 bar = 1.02 kg/cm^2	India, Korea
Inch of mercury column	inHg	1 bar = 29.53 inHg	North America

Units of Pressure

Example 2:

What pressure in psi corresponds to 98.5 kPa?

Solution:

$$p = 98.5 \text{ kPa } (6.895 \text{ kPa/psi}) = 98.5/6.895 \text{ psi} = 14.3 \text{ psi}$$

Fluid Pressure

The pressure exerted by a static fluid depends only upon the **depth of the fluid**, the **density** of the fluid, and the **acceleration of gravity**.

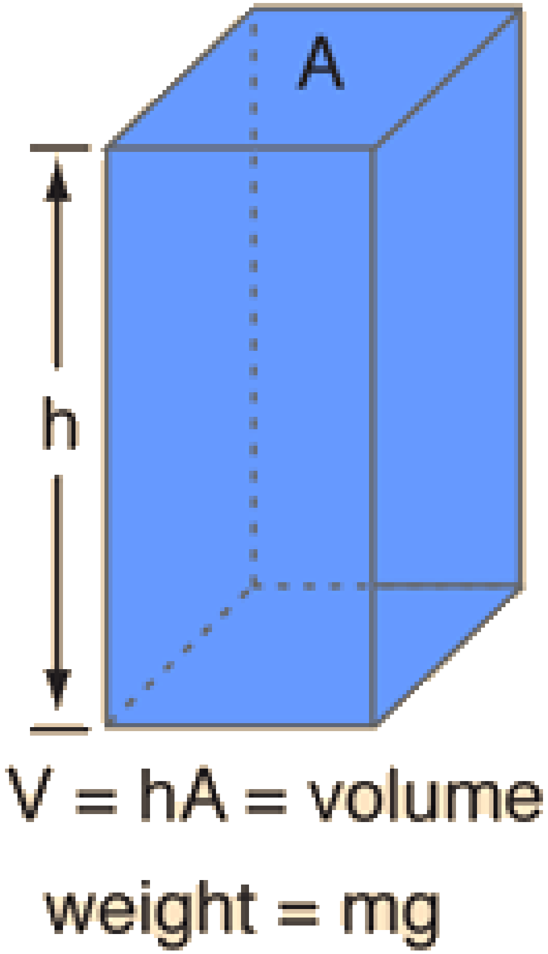
$$P_{\text{static fluid}} = \rho g h$$

where $\rho = m/V$ = fluid density

g = acceleration of gravity

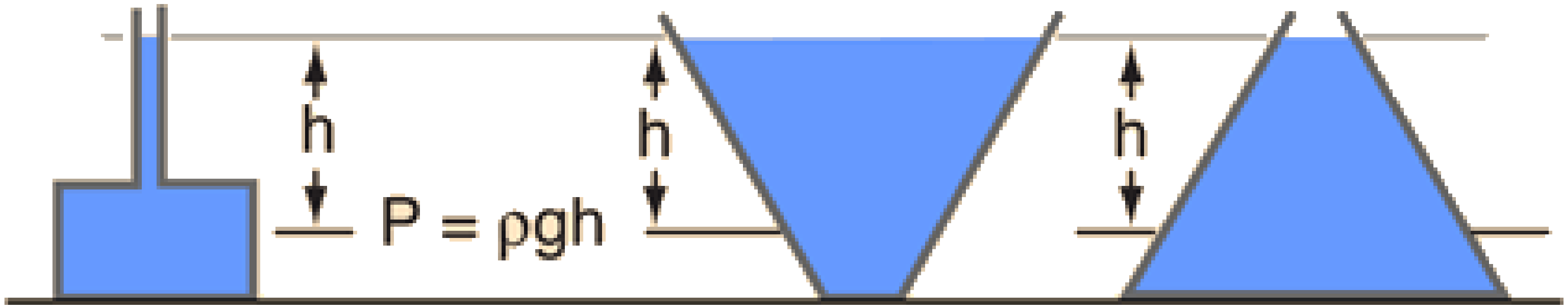
h = depth of fluid

Fluid Pressure



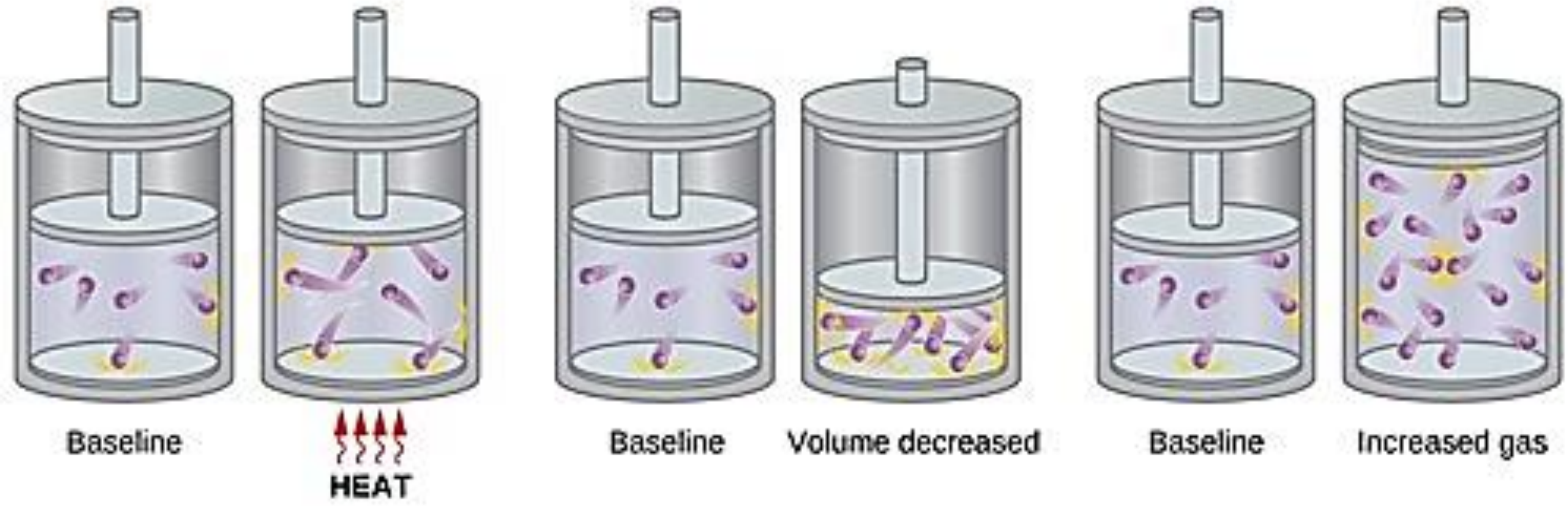
Static fluid pressure does not depend on the shape, total mass, or surface area of the liquid.

$$\text{Pressure} = \frac{\text{weight}}{\text{area}} = \frac{mg}{A} = \frac{\rho V g}{A} = \rho g h$$

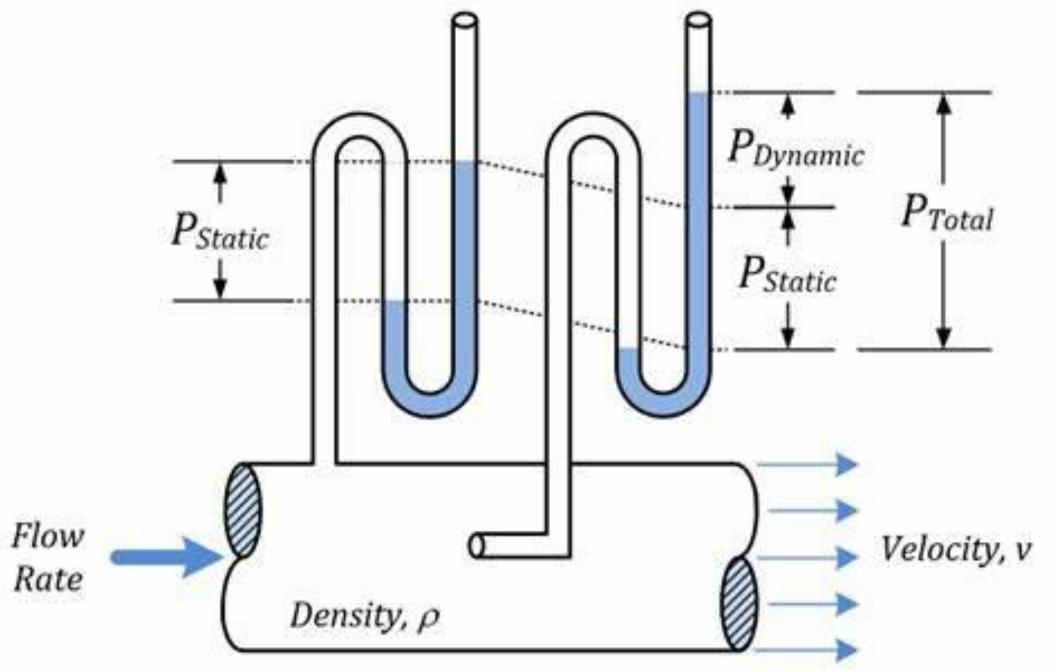


How is pressure generated

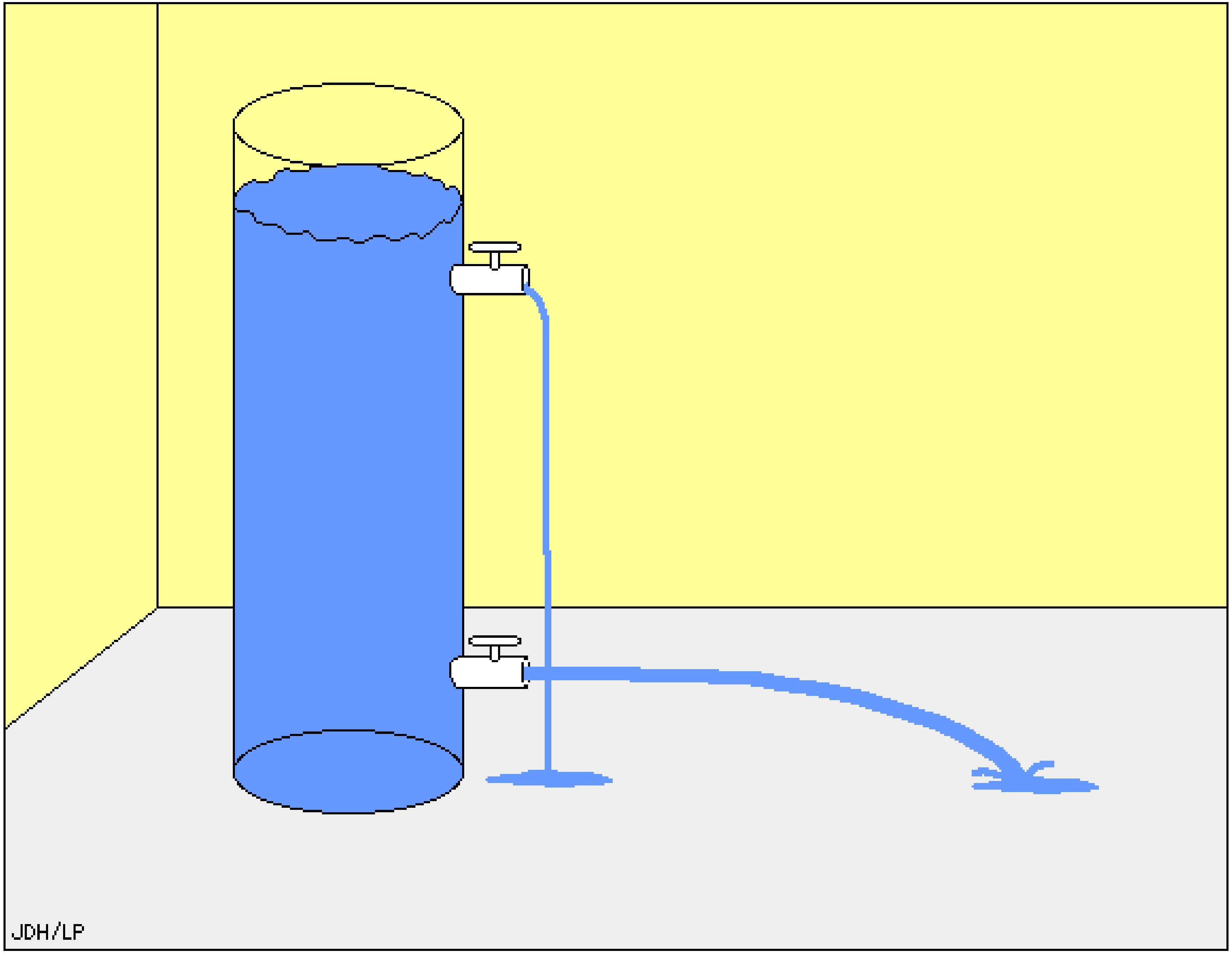
Pressure is caused by the collision of the molecules/particles with the walls of a container or a surface.
If the molecules/particles are moving in the same way in **all directions**, it will result in **equal** forces on **equal** areas of the surface, regardless of the **direction** in which they face.



Static, dynamic and total pressure



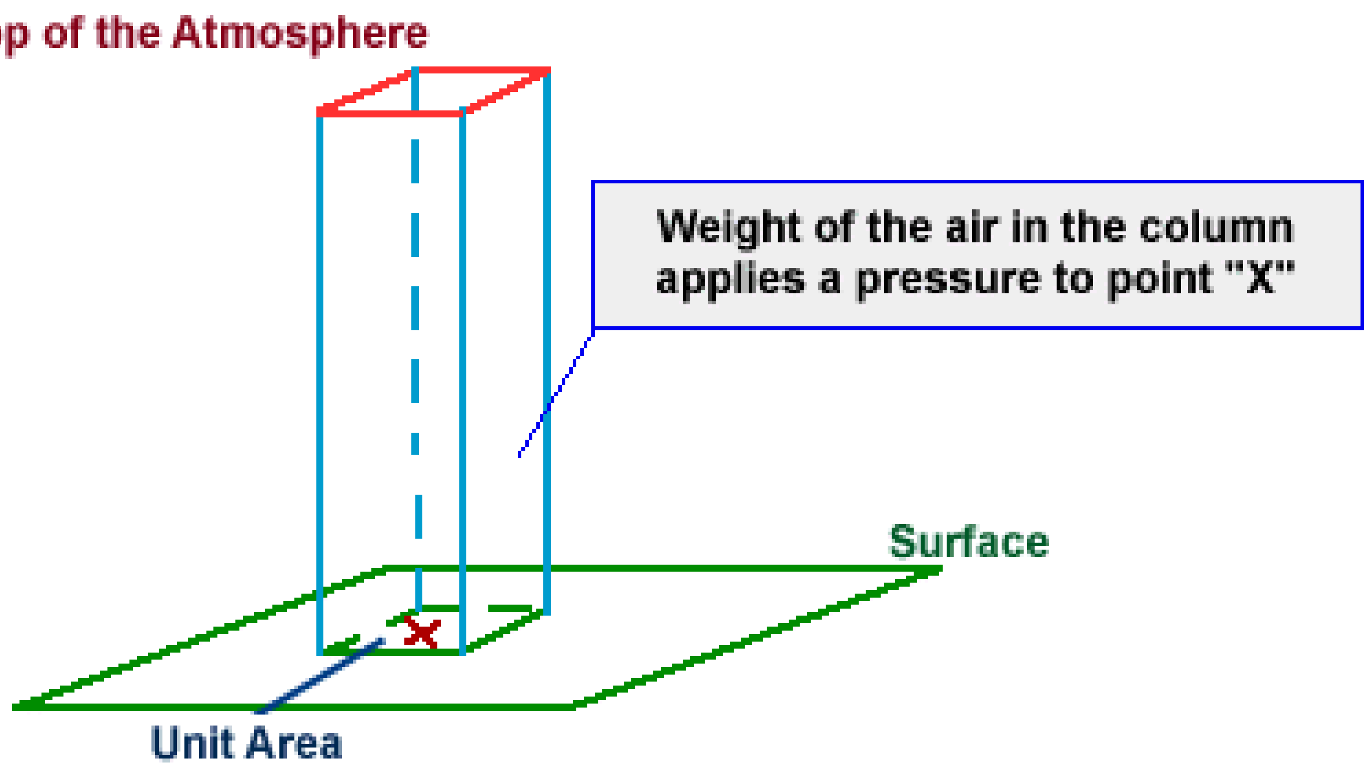
- **Static pressure** is the pressure of fluids of gazes that are stationary or not in motion.
- **Dynamic pressure** is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow
- **Impact pressure (Total pressure)** is the sum of static and dynamic pressure on a surface


JDH/LP

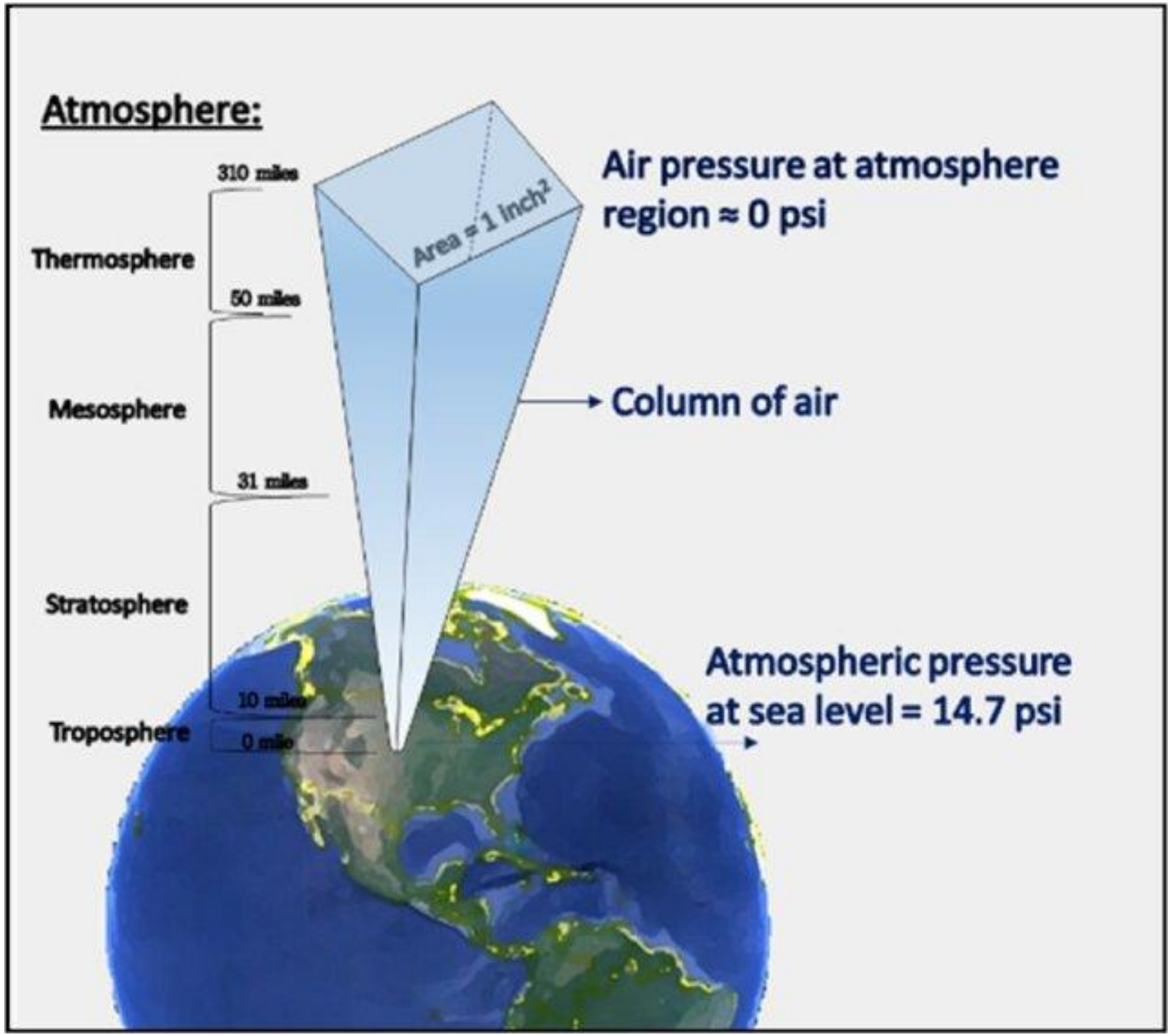
What is the Difference Between Gauge, Absolute and Differential Pressure?

Atmospheric pressure

Atmospheric pressure is the pressure on the Earth's surface due to the weight of the gases in the Earth's atmosphere, and is normally expressed at sea level as 14.7 psi or 101.36 kPa.



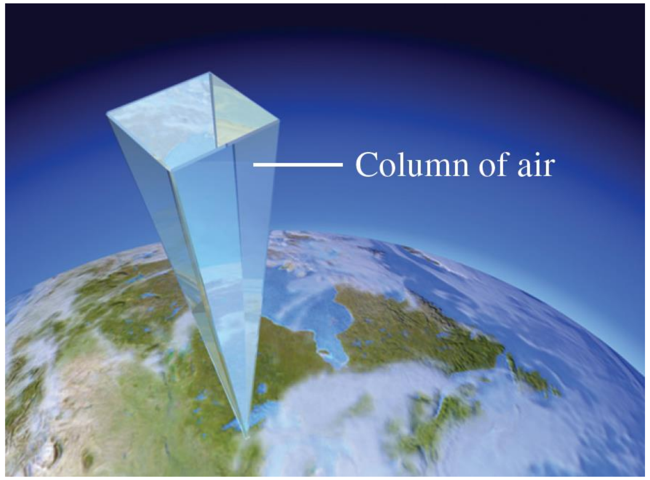
Atmospheric pressure



Atmospheric pressure

- Calculation of atmospheric pressure

Area
1 cm x 1 cm
or
0.0001 m^2



Mass: 1 kg

$$1\ \mathrm{kg} \times \frac{9.80665\ \mathrm{m}}{\mathrm{s}^2} \approx 10\ \mathrm{kg} \cdot \mathrm{m/s}^2 = 10\ \mathrm{N}$$

where 9.80 m/s^2 is the gravitational constant.

$$\frac{10\ \mathrm{N}}{0.0001\ \mathrm{m}^2} = 1 \times 10^5\ \mathrm{Pa}$$

Gauge pressure

Gauge pressure is the pressure measured with respect to atmospheric pressure, and is normally expressed as psig or kPa(g).

$$P_g = P_s - P_{atm}$$

Where:

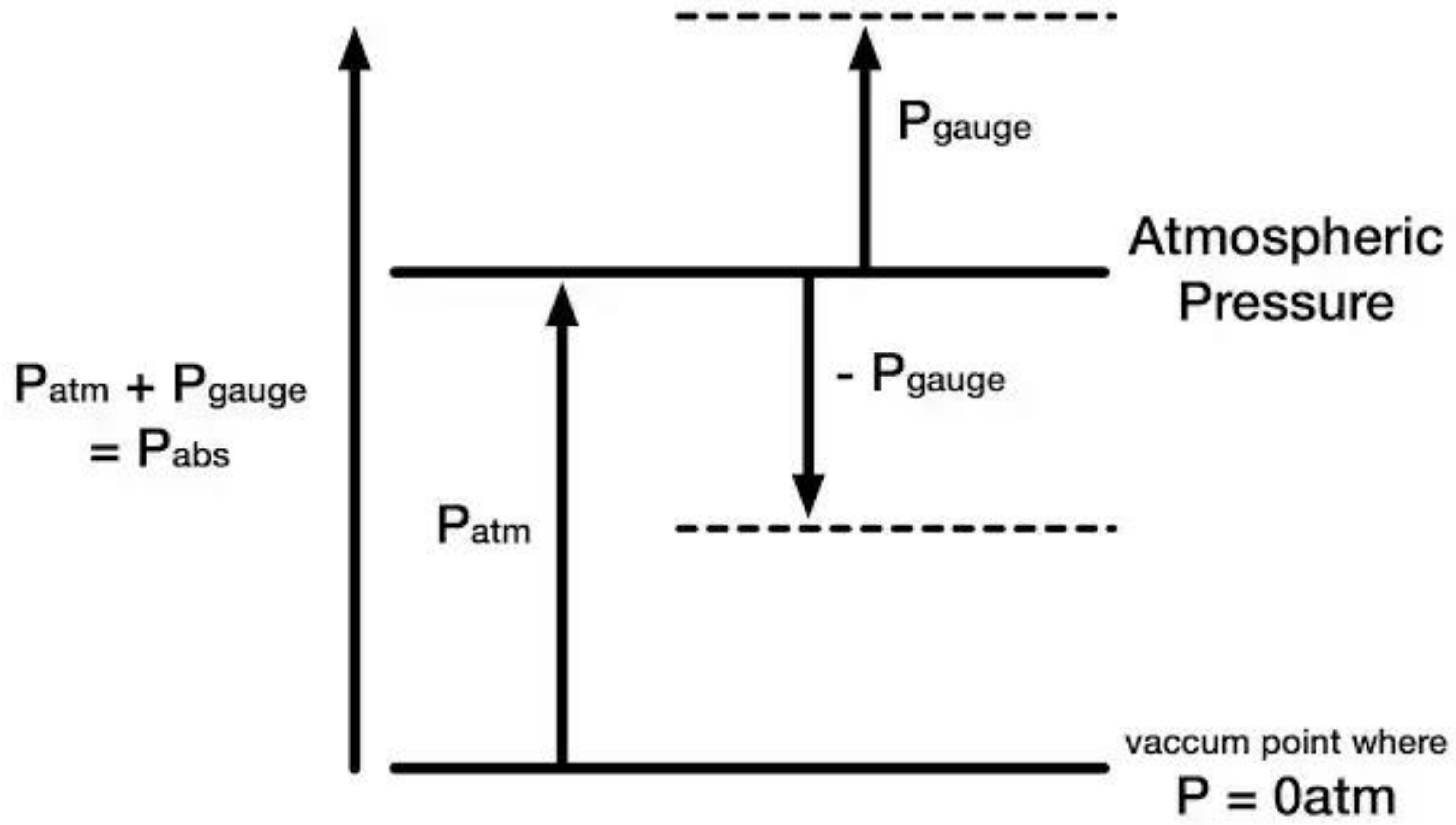
P_s is the system's pressure (or absolute pressure),

P_{atm} is atmospheric pressure and

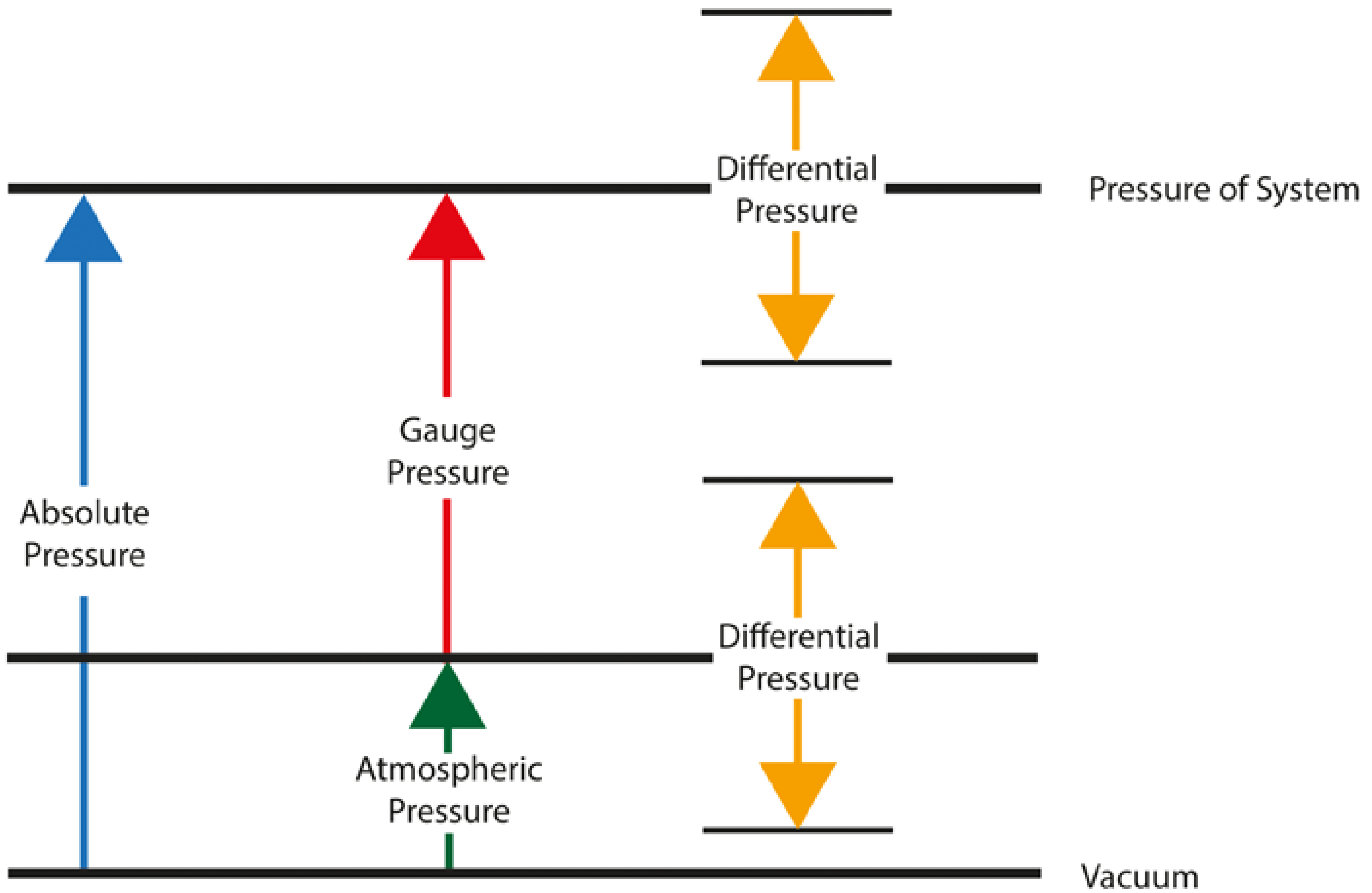
P_g is the gauge pressure.

Absolute pressure

Absolute pressure is the pressure measured with respect to a vacuum, and is expressed in psia or kPa(a).



Gauge, Absolute and Differential Pressure



Pabs = Absolute Pressure

Patm= Atmospheric Pressure

Pg= Gauge Pressure

DP or ΔP = Differential Pressure

Gauge, Absolute and Differential Pressure

Exemple

Problem: Find the absolute pressure if a vacuum gauge reads 11.5 psi and the atmospheric pressure is 14.6 psi.

Solution: When dealing with pressure below atmospheric pressure, you must use Equation 5-13:

$$P_a = P_g - P_{atm}$$

$$P_a = 11.5 \text{ psi} - 14.6 \text{ psi}$$

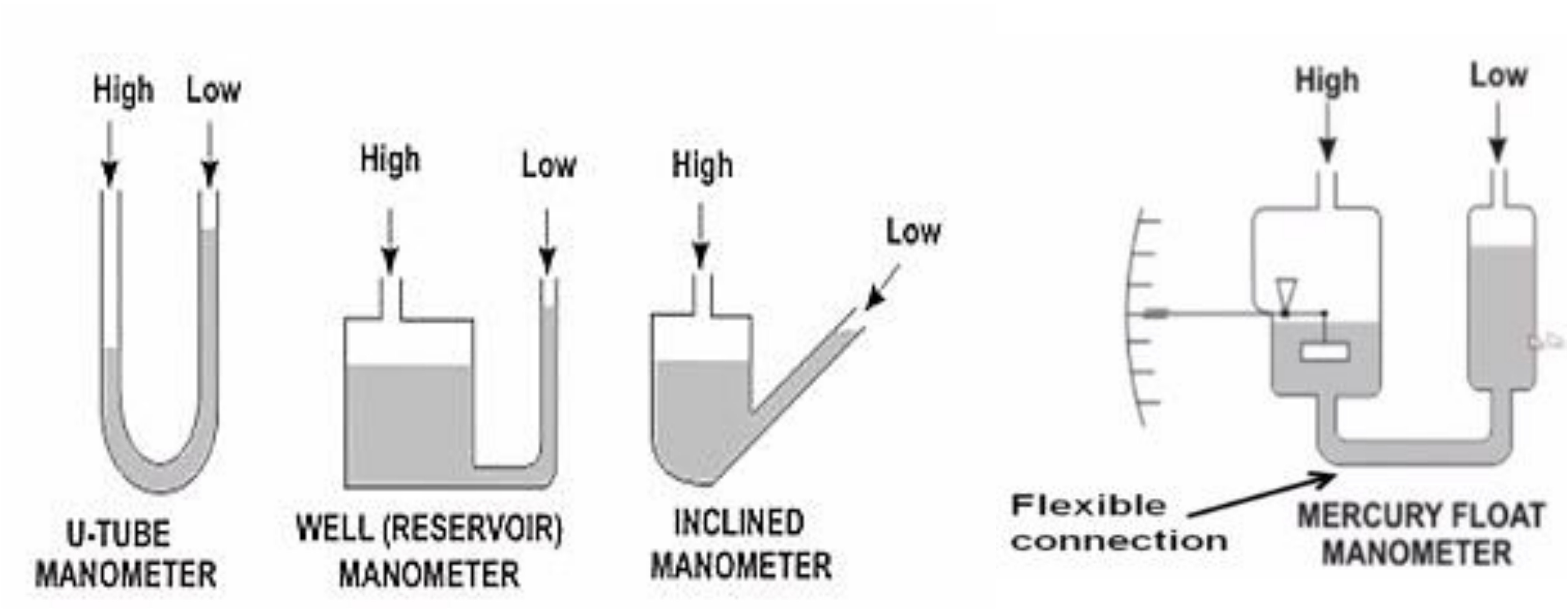
$$P_a = -3.1 \text{ psi}$$

Video Link: https://youtu.be/Gd648AoNcYk

Mechanical Pressure Instruments

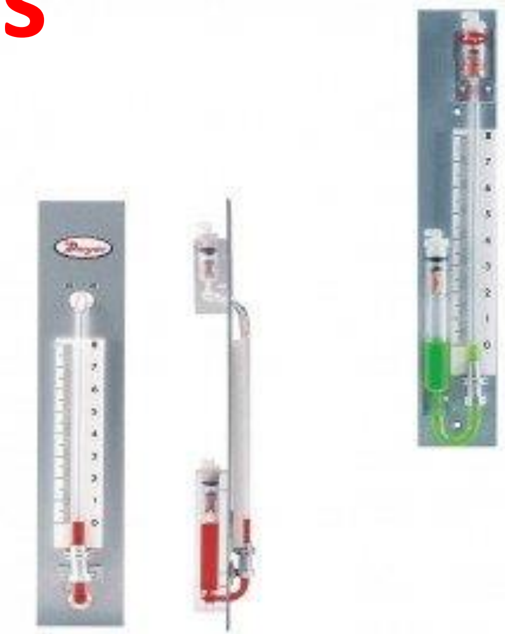
Manometers

Manometers


High
Low
U-TUBE MANOMETER
High
Low
WELL (RESERVOIR) MANOMETER
High
Low
INCLINED MANOMETER
High
Low
Flexible connection
MERCURY FLOAT MANOMETER

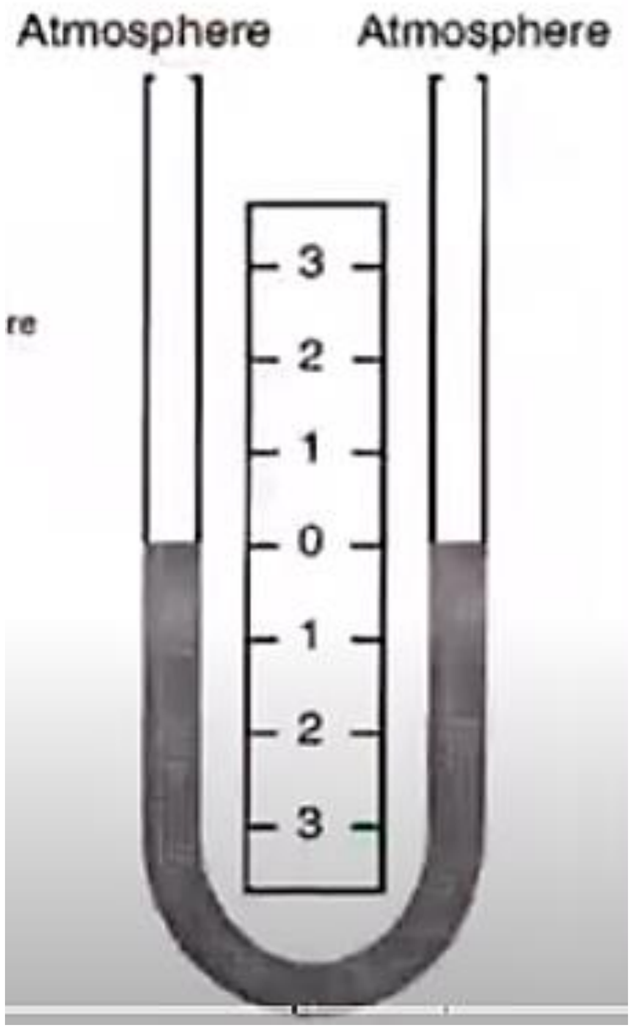
Manometers basics

- ✓ Characterized by its inherent accuracy and simplicity of operation
- ✓ It's the U-tube manometer, which is a U-shaped glass tube partially filled with liquid
- ✓ **U-tube manometer has no moving parts and requires no calibration**
- ✓ **Manometer measurement are functions of gravity and the liquid's density, both physical properties that make the U-tube manometer a NIST standard for accuracy.**



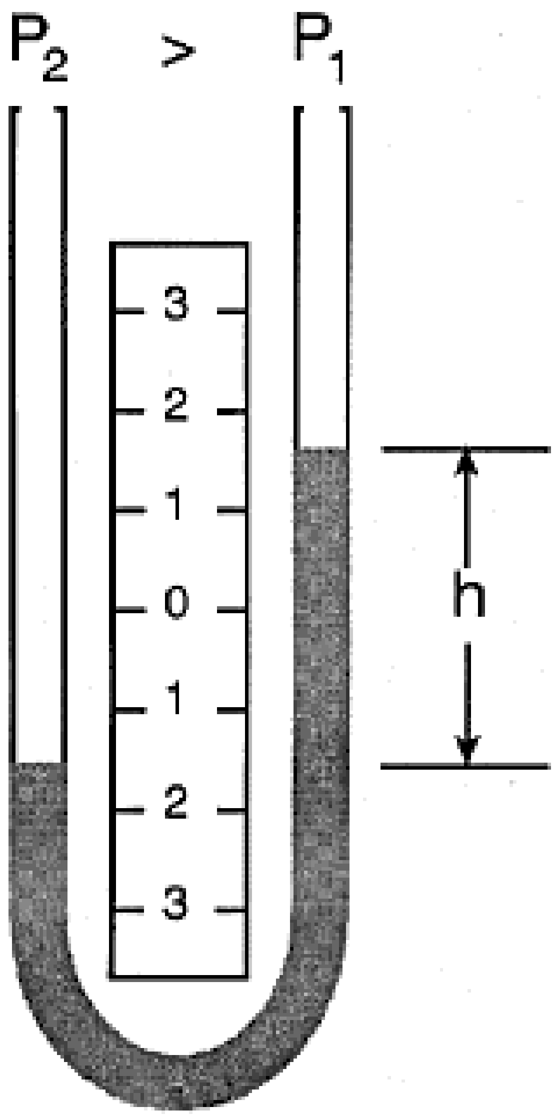
U-tube Manometers

With both legs of a U-tube manometer open to the atmosphere or subjected to the same pressure, the liquid maintains the same level in each leg, establishing a zero reference.



U-tube Manometers

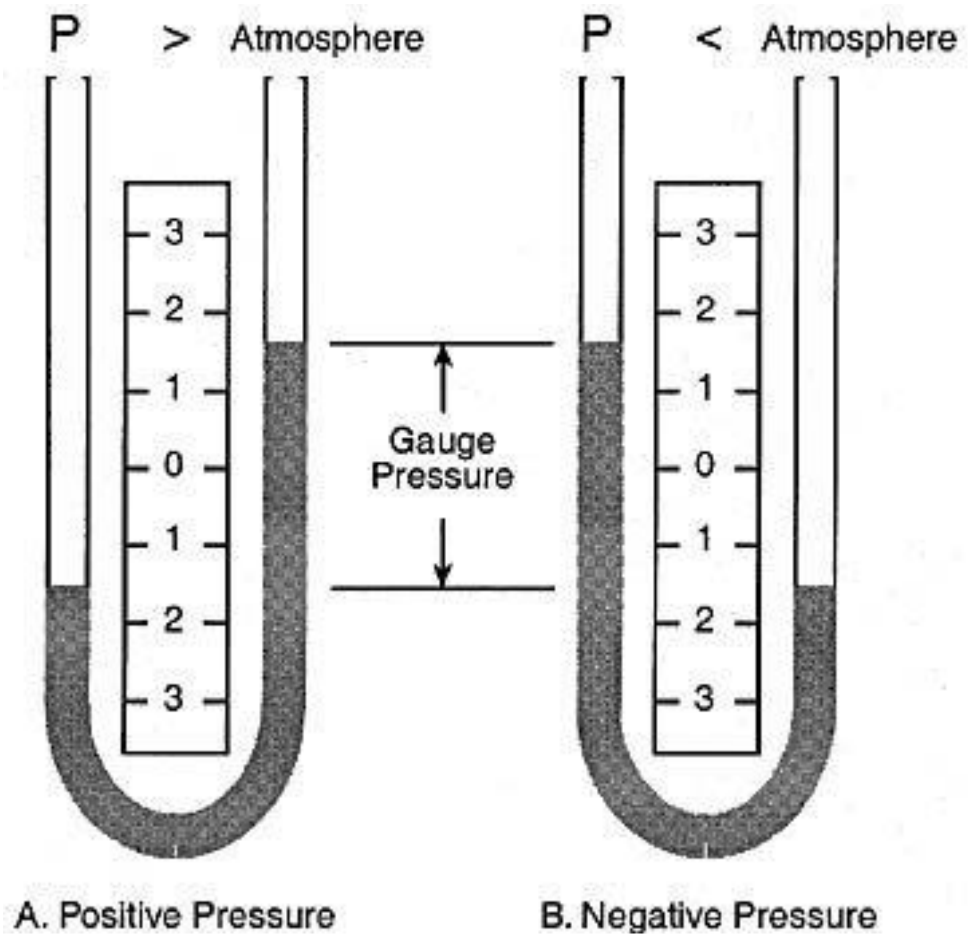
- With a **greater pressure applied to the left side of a U-tube manometer**, the liquid lowers in the left leg and rises in the right leg.
- The liquid moves until the unit weight of the liquid, **as indicated by h**, exactly balances the pressure.



U-tube Manometers

- Gauge pressure is a measurement relative to atmospheric pressure and it varies with the barometric reading.

- A gauge pressure measurement is **positive when the unknown pressure exceeds atmospheric pressure (A)**, and is **negative when the unknown pressure is less than atmospheric pressure (B)**.



U-tube Manometers

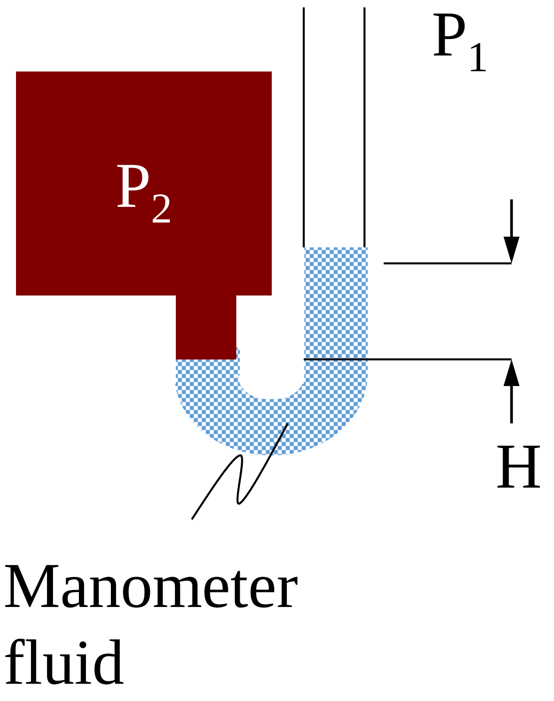
- Pressure varies with depth for constant density fluid

$$P_2 - P_1 = \rho g H$$

ρ=density

g=gravitational constant

h=difference in height



U-tube Manometers

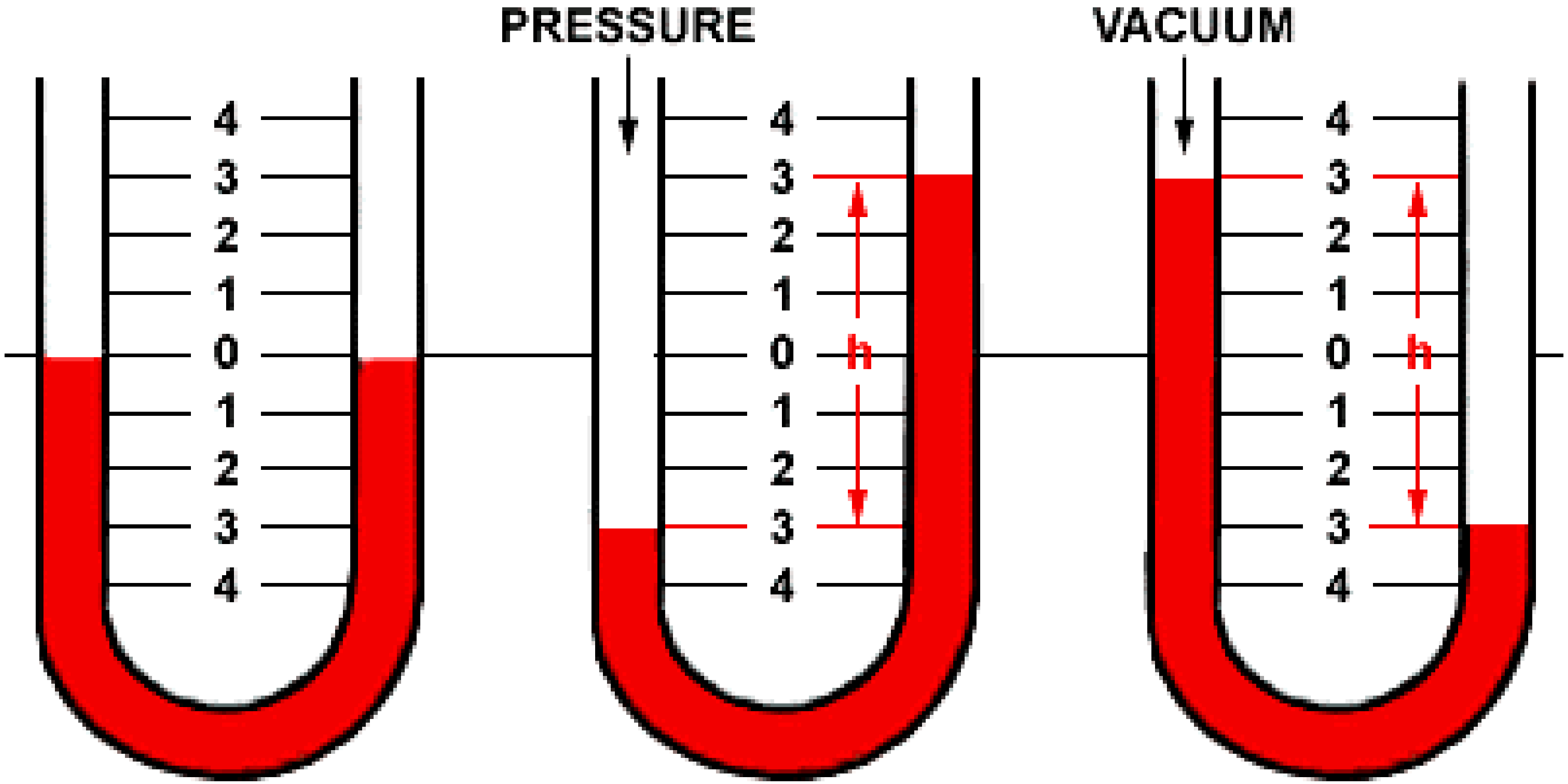
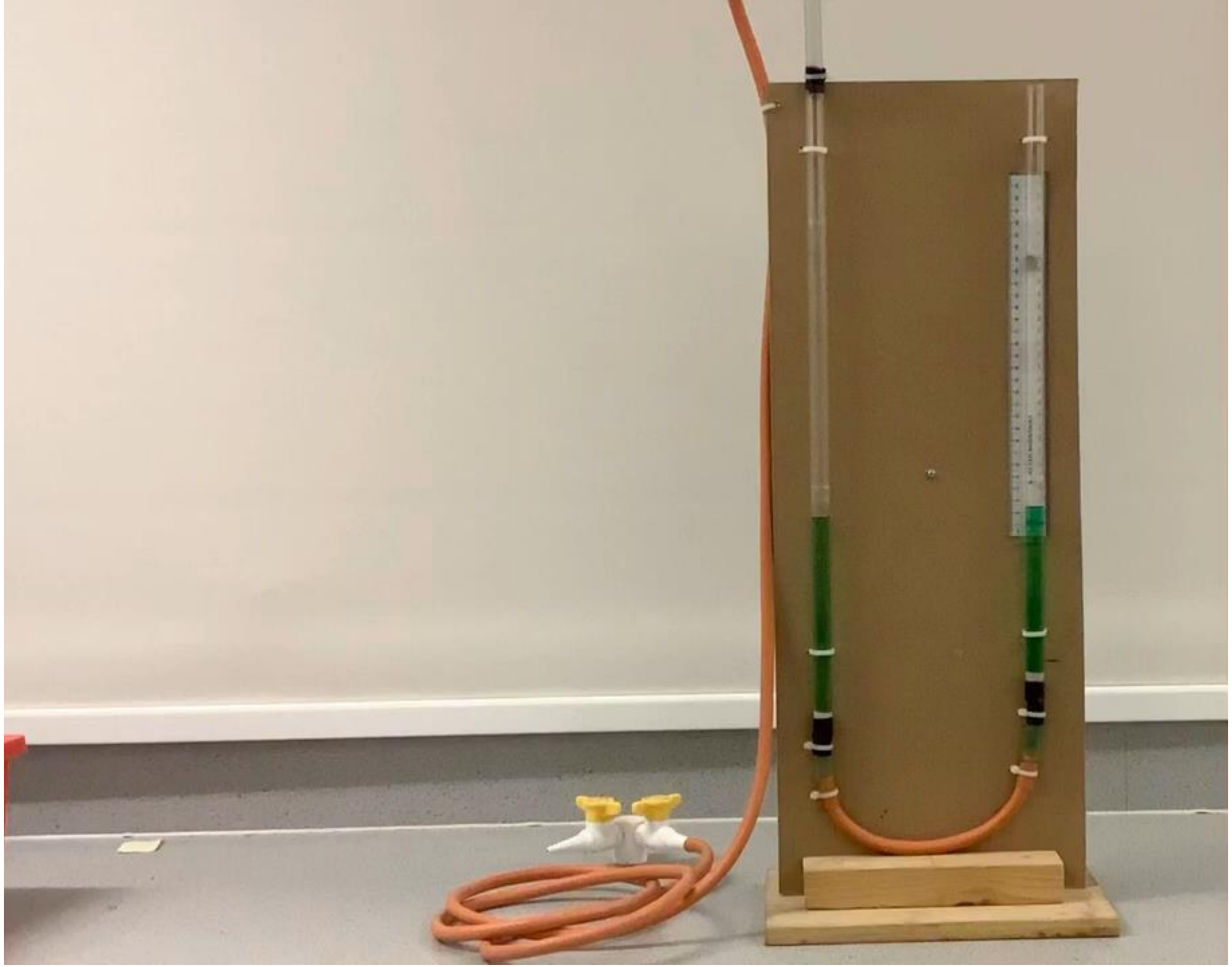


Fig. 2-1

Fig. 2-2

Fig. 2-3



$$P_2 - P_1 = \rho g H$$

ρ=density

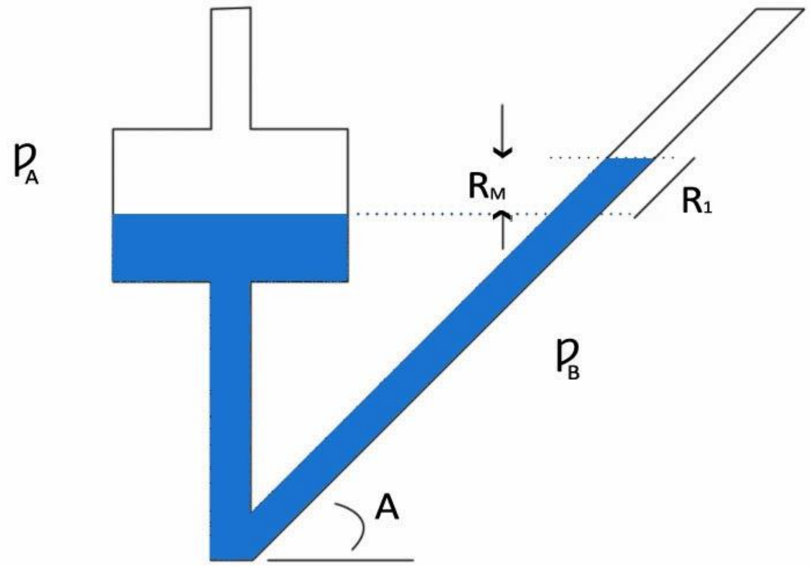
g=gravitational constant

h=difference in height

Video Link: https://youtu.be/Uw9TMnSfPLo

Inclined Manometers

- Inclined type manometer is best for measuring low pressure

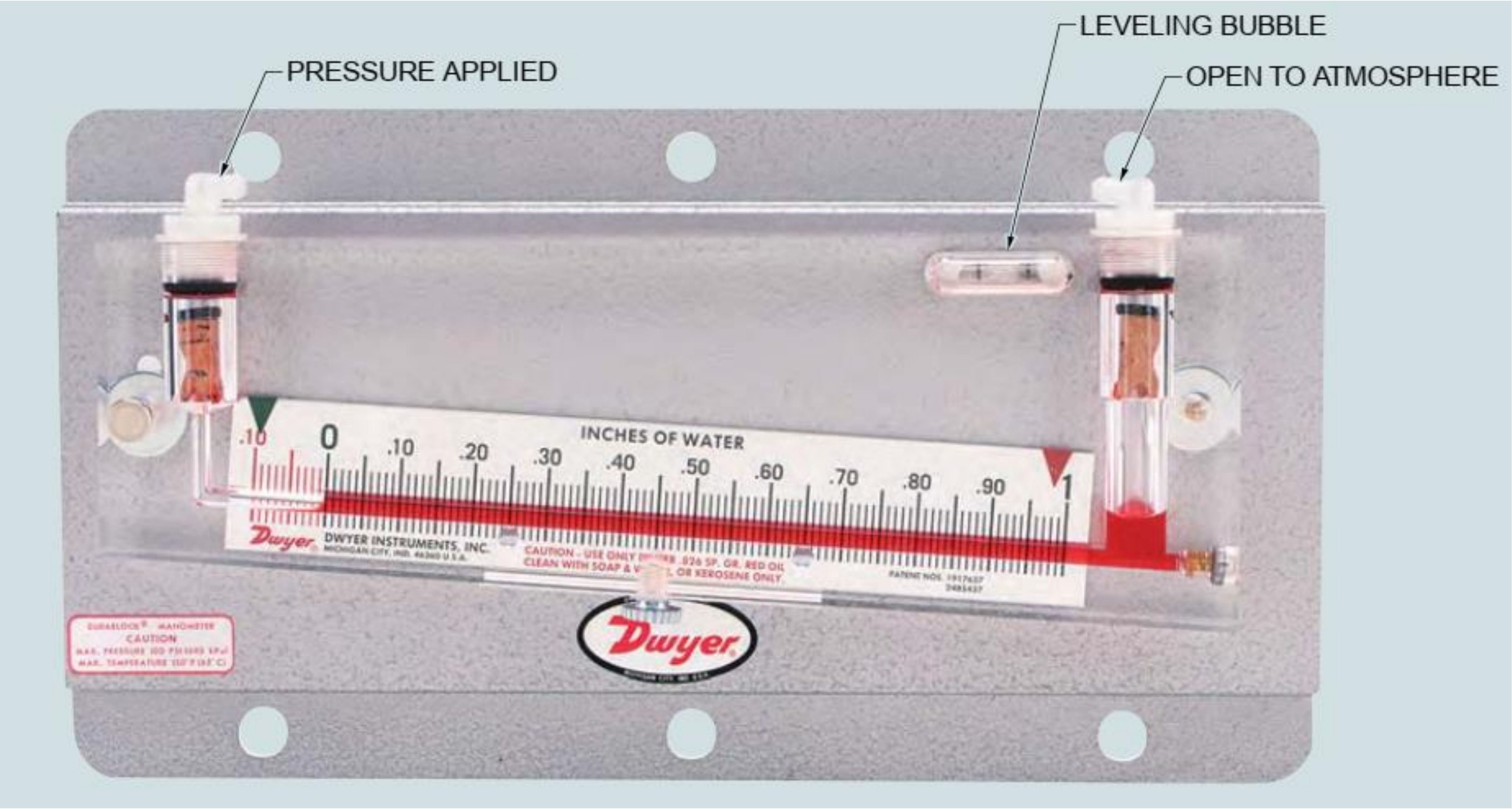


$$P_A - P_B = R_1.\mathrm{Sin}(A).g\,.(\rho_B - \rho_A)$$

ρ_A DENSITY OF FLUID A

ρ_B DENSITY OF MANOMETRIC FLUID B

Inclined Manometers



Reservoir (Well) Manometers

In this design, one le gis replaced by a large diameter well so that the pressure differential is indicated only by the height of the column in the single leg.

The pressure difference can be read directly on a single scale.

For static balance,

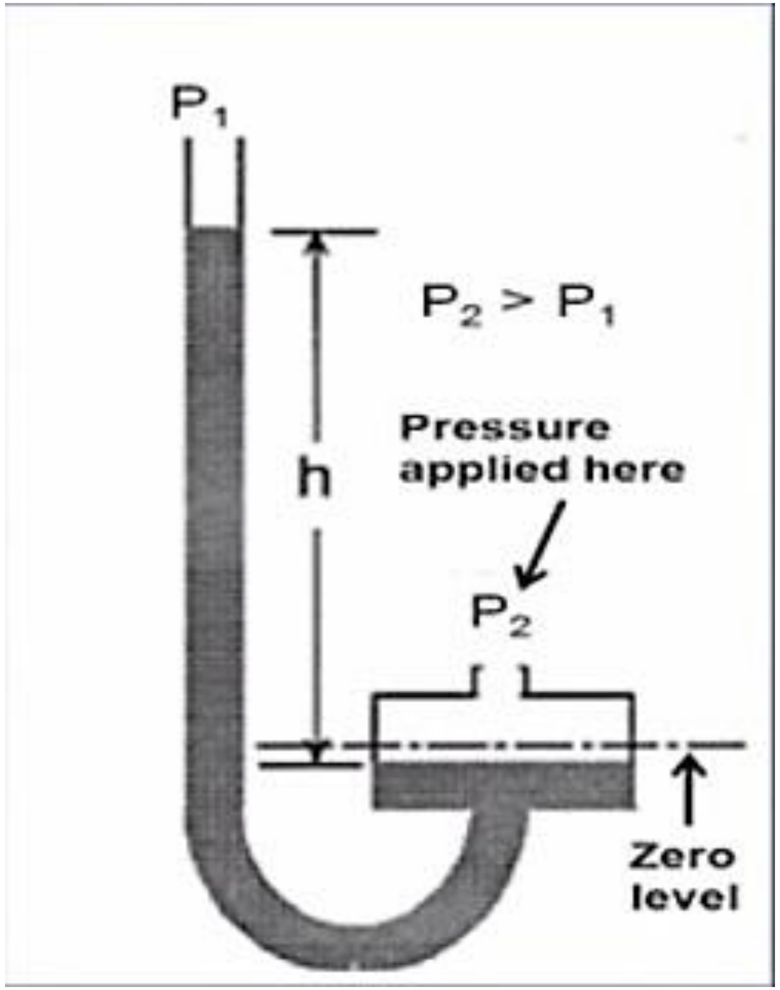
$$P_2 - P_1 = \rho(1+A_1/A_2)hg$$

Where

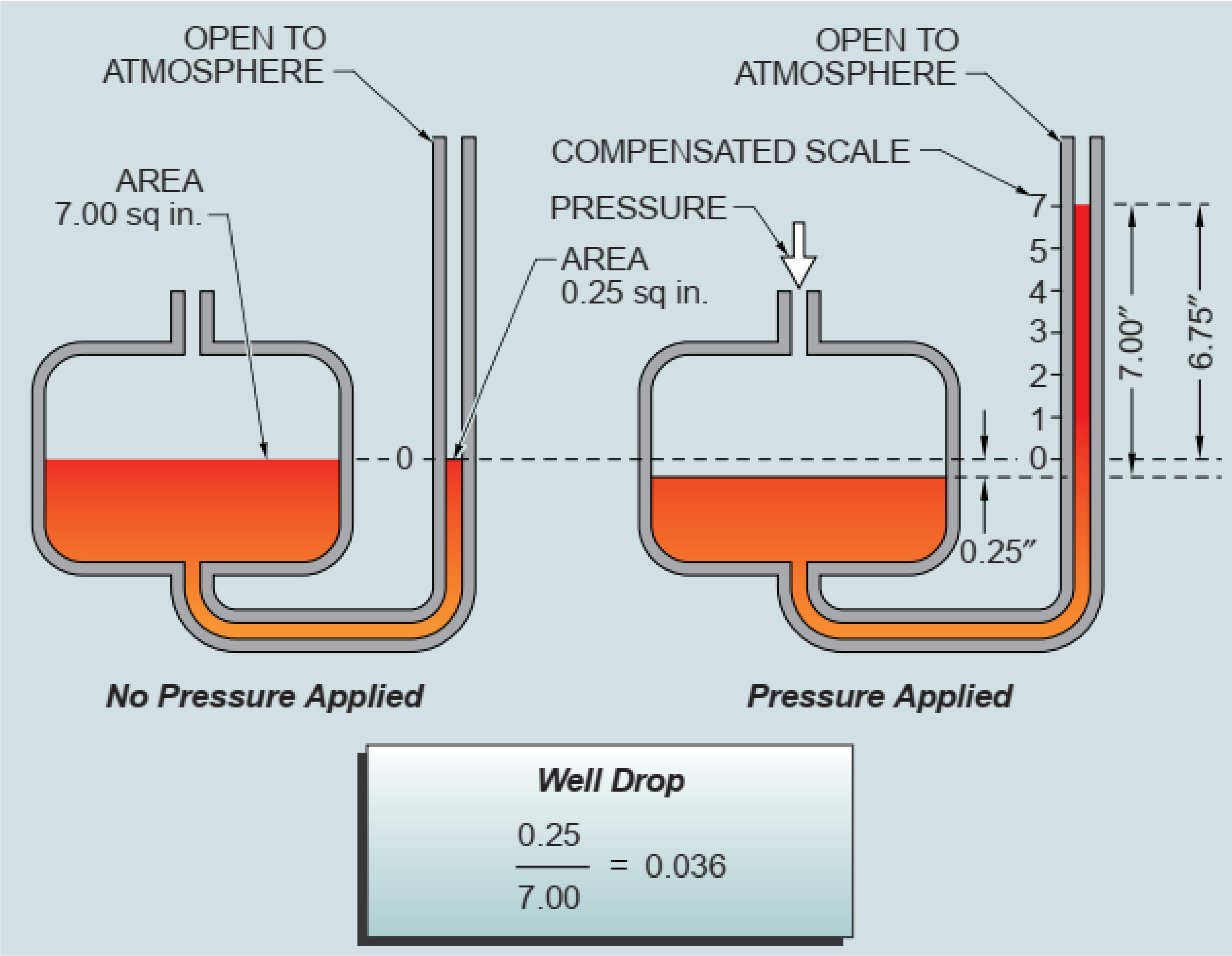
A_1= area of smaller diameter leg

A_2= area of well

If the ratio of A_1/A_2 is smaller compared with unity, them the error in neglecting this term becomes negligible, and the static balance relation becomes $\mathbf{P_2 - P_1 = \rho gh}$



Reservoir (Well) Manometers

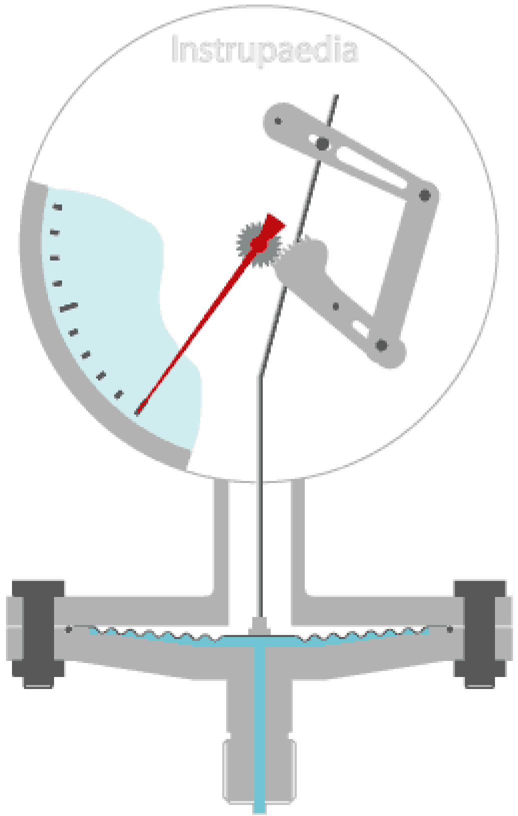


Advantages and disadvantages of manometer

Advantages of manometer	Disadvantages of manometer
✓ Relatively inexpensive. ✓ Easy to fabricate. ✓ Requires very little maintenance. ✓ Good accuracy and sensitivity. ✓ Their sensitivity can be changed by changing manometric fluids. ✓ Particularly suitable to low pressures and low differential pressures.	✓ Large and bulky ✓ Levelling is required ✓ Compatibility required between manometer fluid and measured fluid ✓ No over – range protection ✓ Very sensitive to temperature changes

Diaphragms

- A ***diaphragm*** is a mechanical pressure sensor consisting of a **thin**, **flexible** disc that flexes in response to a **change in pressure**.
- Pressure-sensing diaphragms are commonly made of **steel**, **stainless steel**, **titanium**, **beryllium copper**, **bronze**, **rubber**, or other materials.
- A diaphragm is usually **secured** at its outer edges between matching base plates resembling flanges.
- A spring acting on the center of the diaphragm may be used to provide the counteracting force to the applied pressure.



Diaphragms

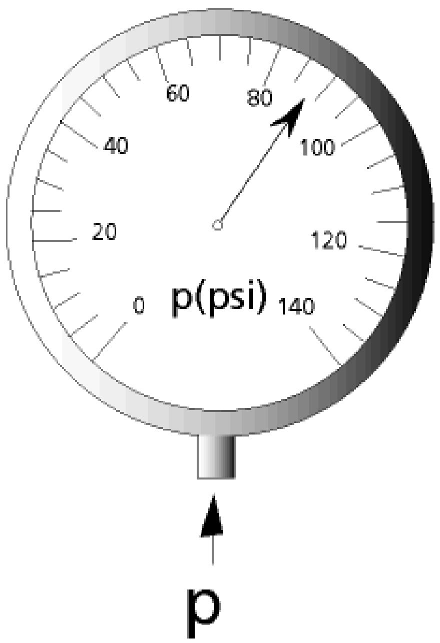
Video Link: https://youtu.be/5ScB2nEcfOs

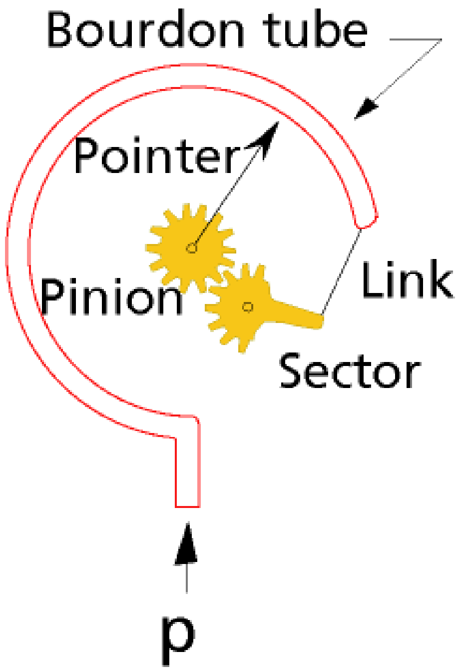
Diaphragms

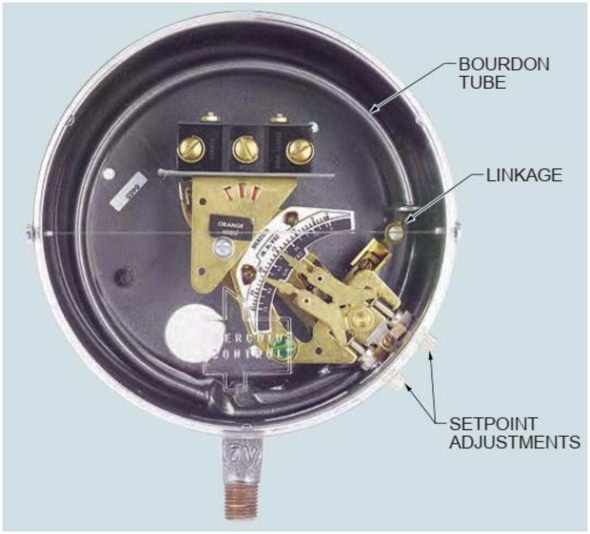
Video Link: https://youtu.be/nWWG3tQEwYY

Bourdon Tubes

- **Bourdon tubes** are a mechanical pressure sensor consisting of a **hollow tube** formed into a **helical**, **spiral**, or **C shape**. To construct a pressure spring, a tube made from flattened, seamless metal tubing is formed into the desired shape.
- Beryllium copper, steel, and stainless steel are commonly used materials. The spring is welded, brazed, or flanged to metal tubing that admits the pressurized fluid from the process.
- The wall thickness determines the maximum pressure for a pressure spring.



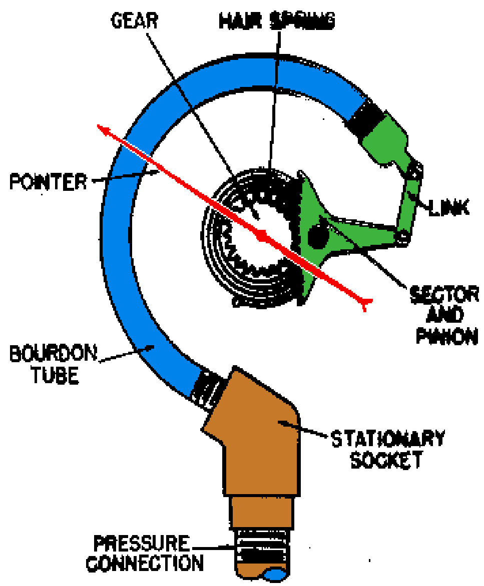


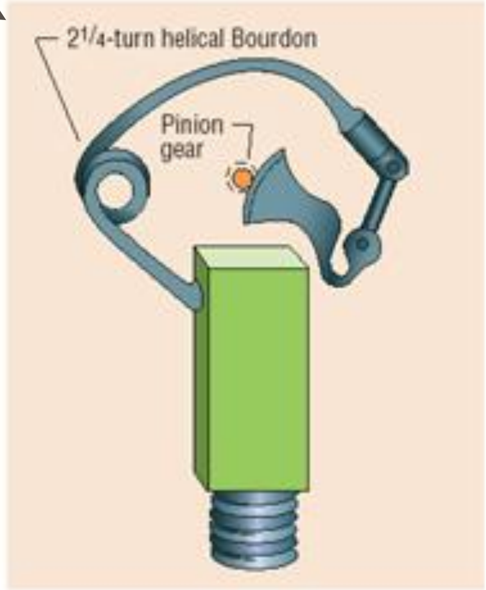


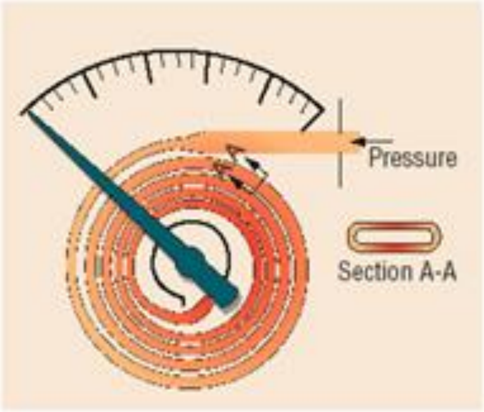
Bourdon Tubes

Bourdon tubes are generally are of three types

1. **C-type**
2. Helical type
3. Spiral type







Bourdon Tubes

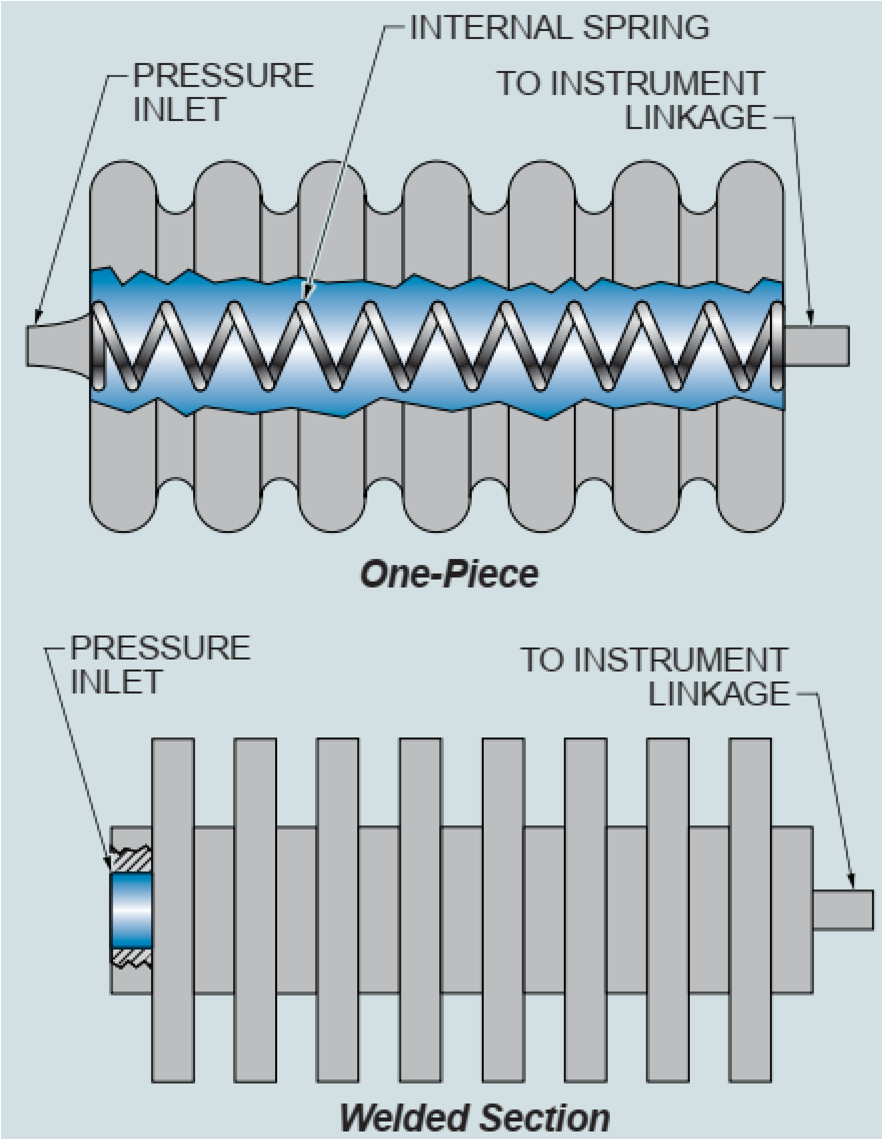
Video Link: https://youtu.be/fmOnrEZ_z6k

Bourdon tube vs. diaphragm

Video Link: https://youtu.be/JnPSeEW-EeA

Bellows

A ***bellows*** is a mechanical pressure sensor consisting of a **one-piece**, **collapsible**, **seamless metallic unit** with deep folds formed from thin-wall tubing with an enclosed spring to provide stability, or with an assembled unit of welded sections.

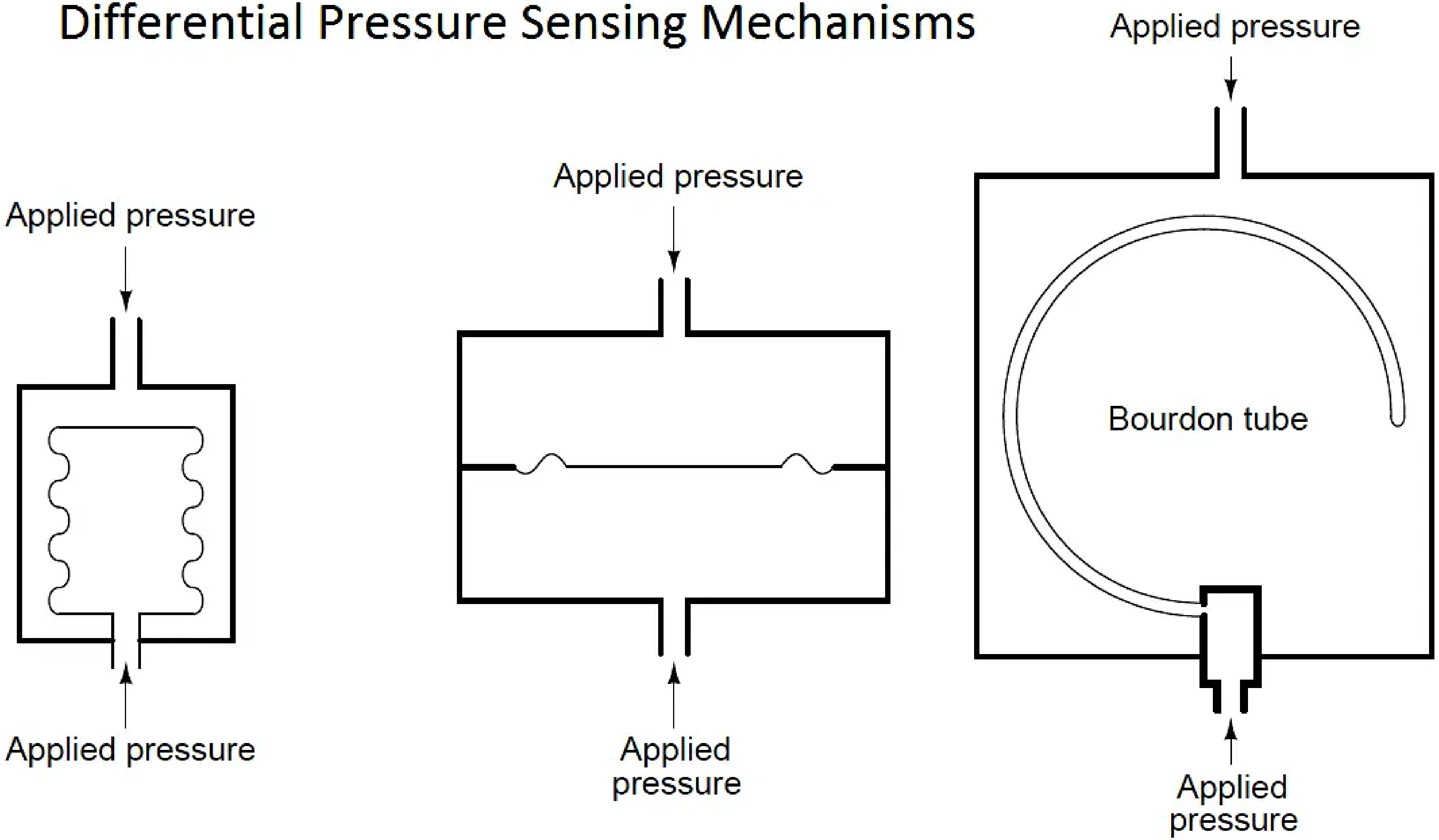


Bellows Vs Bourdon Tube

Video Link: https://youtu.be/_T_fvlH_Gxg

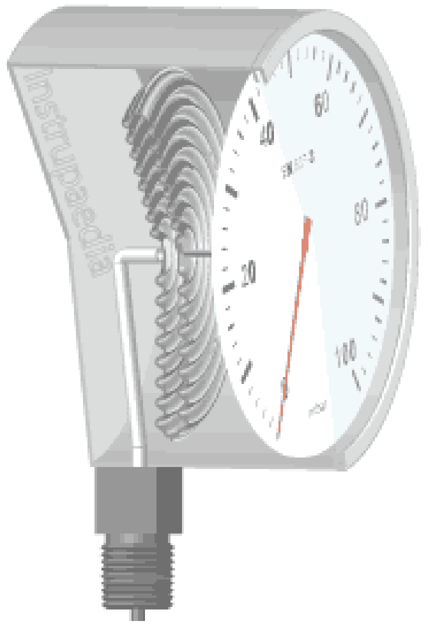
Bellows, Diaphragms and Bourdon Tubes

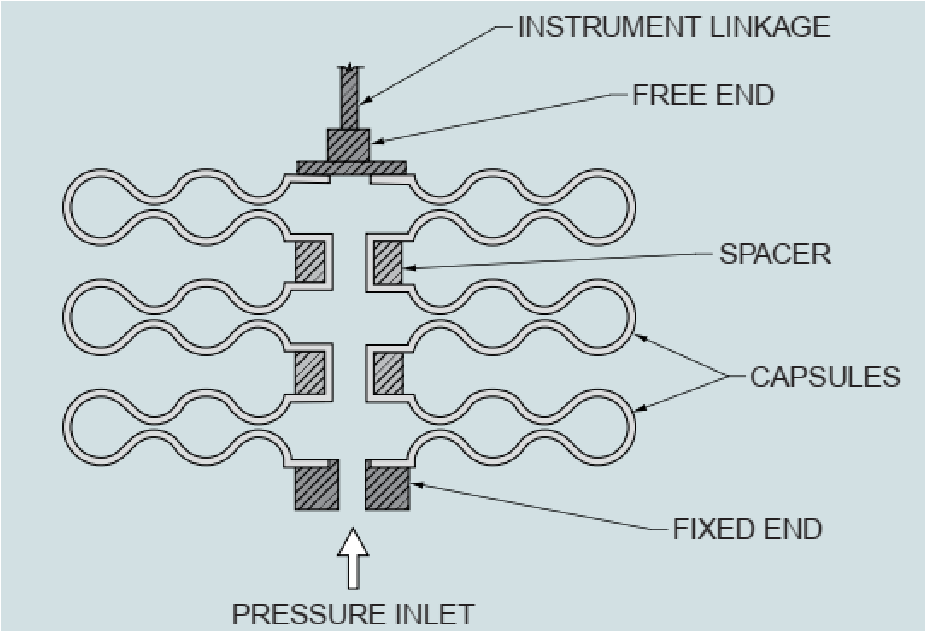
Differential Pressure Sensing Mechanisms



Capsules

- A ***capsule*** is a mechanical pressure sensor consisting of **two convoluted metal diaphragms** with their outer edges welded, brazed, or soldered together to provide an empty chamber between them.
- One of the diaphragms is connected at its center to metal tubing that admits fluid to the chamber. The other diaphragm is fitted with a mechanical connection to the indicator, or fitted with a transducer.





MCQ questions

1. Normal force acting per unit cross sectional area is called:

a) Weight

b) Volume

c) Pressure

d) Friction

MCQ questions

2. Pressure in fluid depends on:

a) depth below the surface

b) density of fluid

c) the value of g

d) all of the above

MCQ questions

3. Which of the following conversion takes place in bourdon tube

a) Pressure to displacement

b) Pressure to voltage

c) Pressure to strain

d) Pressure to force

MCQ questions

4. In a U-tube manometer, one end is open to the atmosphere, the other end attached to a pressurized gas of gauge pressure 40 kPa. The height of the fluid column in the atmospheric side is 60 cm, and that on the gas side is 30 cm. The manometic fluid used is: (Take g = 9.8 m/s^2).

a) Water (ρ = 1000 kg/m^3)

b) Liquid ammonia (ρ = 682 kg/m^3)

c) Oil (ρ = 870 kg/m^3)

$\boxed{\text{d) Mercury } (\rho = 13605\ kg/m^3)}$

Explanation: Gauge pressure = 40000 Pa. Height difference = 60 – 30 = 30 cm = 0.3 m. ρ*g*(h2 – h1) = 40000. We get, ρ = 13605 kg/m^3 = Density of mercury.

MCQ questions

5. In a U-tube mercury manometer, one end is exposed to the atmosphere and the other end is connected to a pressurized gas. The gauge pressure of the gas is found to be 40 kPa. Now, we change the manometric fluid to water. The height difference changes by: ($\rho_{mercury}$ = 13600 kg/m^3, ρ_{water} = 1000 kg/m^3).

a) 1260%

b) 92.64 %

c) Remains unchanged (0%)

d) 13.6%

MCQ questions

6. A manometric liquid should suitably have ________

a) Low density & Low Vapour pressure

b) Low density & High Vapour pressure

c) High density & Low Vapour pressure

d) High density & High Vapour pressure

Explanation: A high density is favourable because the height of the column required for the manometer would be low. A liquid with high vapour pressure would be less sensitive to changes in pressure and may result in a slower rise of the manometric fluid. Thus, a fluid with low vapour pressure is favourable.

MCQ questions

7. A simple U-tube manometer can measure negative gauge pressures.

a) True

b) False

Explanation: The height of the manometric fluid in a U-tube manometer in the test column would fall if there is a positive gauge pressure. The height would increase if there is a negative gauge pressure. It is possible to measure negative gauge pressures with a U-tube manometer. However, the negative pressure cannot fall below -1 Bar.

MCQ questions

8. Both ends of a U-tube manometer are exposed to the atmosphere. There exists a possibility that the height difference of the manometer is non-zero. True or False?

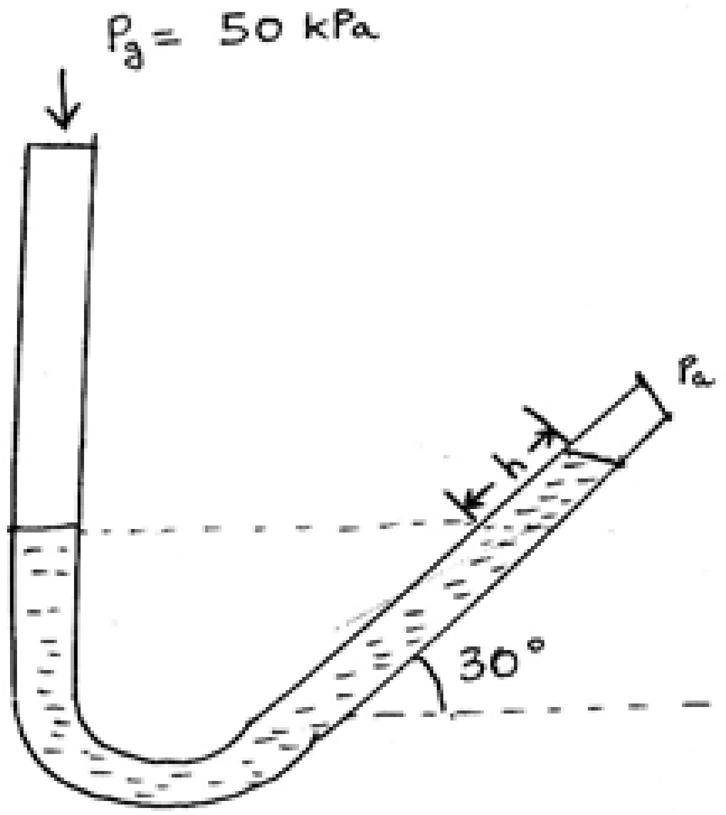
a) True

b) False

Explanation: The height difference may be non-zero when there are multiple immiscible fluids used in the same manometer. Even though the pressure is same on both surfaces, the height would be different as the fluid with higher density will be at a lower height.

MCQ questions

9. The below figure shows an inclined tube mercury manometer. The vertical end of the tube is exposed to a gas of gauge pressure 50 kPa and the inclined end is exposed to the atmosphere. The inclined part of the tube is at an angle of 30^o with the horizontal. Find the value of h (in cm) (take g = 9.8 m/s^2, $\rho_{mercury} = 13600\ kg/m^3$)



a) 60

b) 50

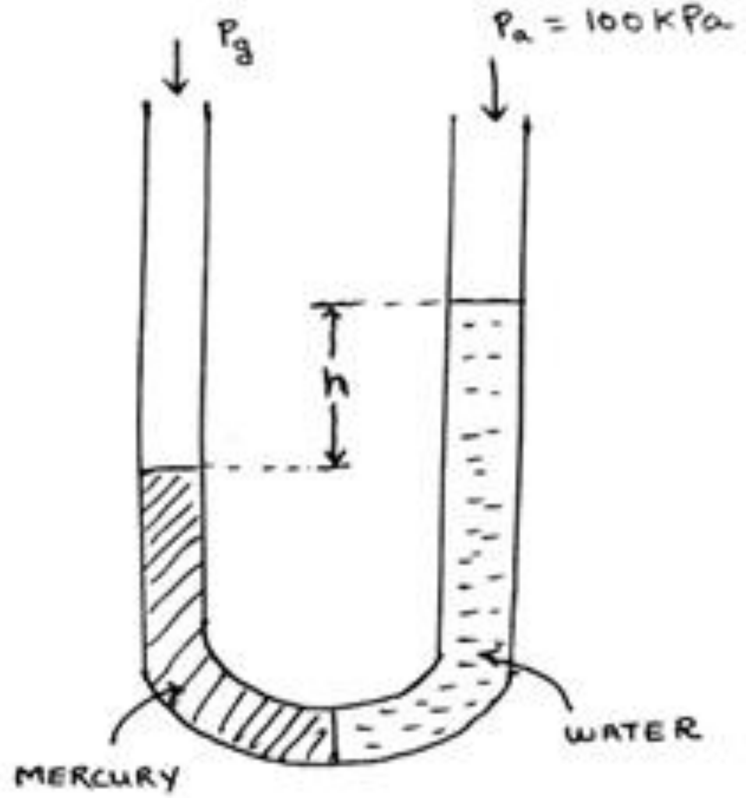
c) 75

d) 25

Explanation: Pressure along the dotted line will be 50 kPa. Gauge pressure in an inclined manometer is given by P = ρ.g.h.sin (ϴ). Substituting P, ρ and ϴ, we get the value of h as 0.75 m.

MCQ questions

10. In the manometer given above, 2 immiscible fluids mercury (ρ = 13600 kg/m^3) and water (ρ = 1000 kg/m^3) are used as manometric fluids. The water end is exposed to atmosphere (100 kPa) and the mercury end is exposed to a gas. At this position, the interface between the fluids is at the bottom most point of the manometer. Ignore the width of the manometer tube and the radius of curvature. The value of h is found to be 9.45 m. The height of the mercury column is given to be 75 cm. Find the gauge pressure of the gas. (g = 9.8 m/s^2)



a) 100 kPa

b) 50 kPa

c) 200 kPa

$\boxed{\text{d) 0 kPa}}$

MCQ questions

Explanation: Height of water column = 0.75 + 9.45 = 10.2 m. We equate the pressures at the bottom most point. $P_a + \rho_w.g.(10.2) = P_g + \rho_m.g.(0.75)$. We find, Pg = 100 kPa = Absolute pressure. Hence, gauge pressure will be 0.