# PRESSURE MEASUREMENT

## MEG 222 Week 3 Lecture

# Lecture Learning Outcomes

**At the end of this lecture, you will be able to,**

- Explain the concept of manometers
- Describe the different types of manometers
- Apply appropriate manometer equations to determine pressure

# Introduction

Numerous devices and techniques are used in the measurement of,

i. Absolute pressure
ii. Gauge pressure
iii. Vacuum pressure

**Absolute pressure**

Measured relative to a perfect vacuum i.e. absolute zero pressure

**Gauge pressure**

Measured relative to atmospheric pressure

**Vacuum pressure**

Negative gauge pressure which is also called suction pressure

# Introduction

In previous lectures, recall that pressure can be expressed as the height of a column of fluid (Pressure Head). For example, standard atmospheric pressure can be expressed as 760 mm of mercury Hg (abs)

Note that throughout this lecture, pressure will be assumed to be gauge pressure unless specifically designated absolute. For example 60 kPa will be assumed to be gauge pressure while 60 kPa (abs) will be absolute pressure

# Mercury Barometer

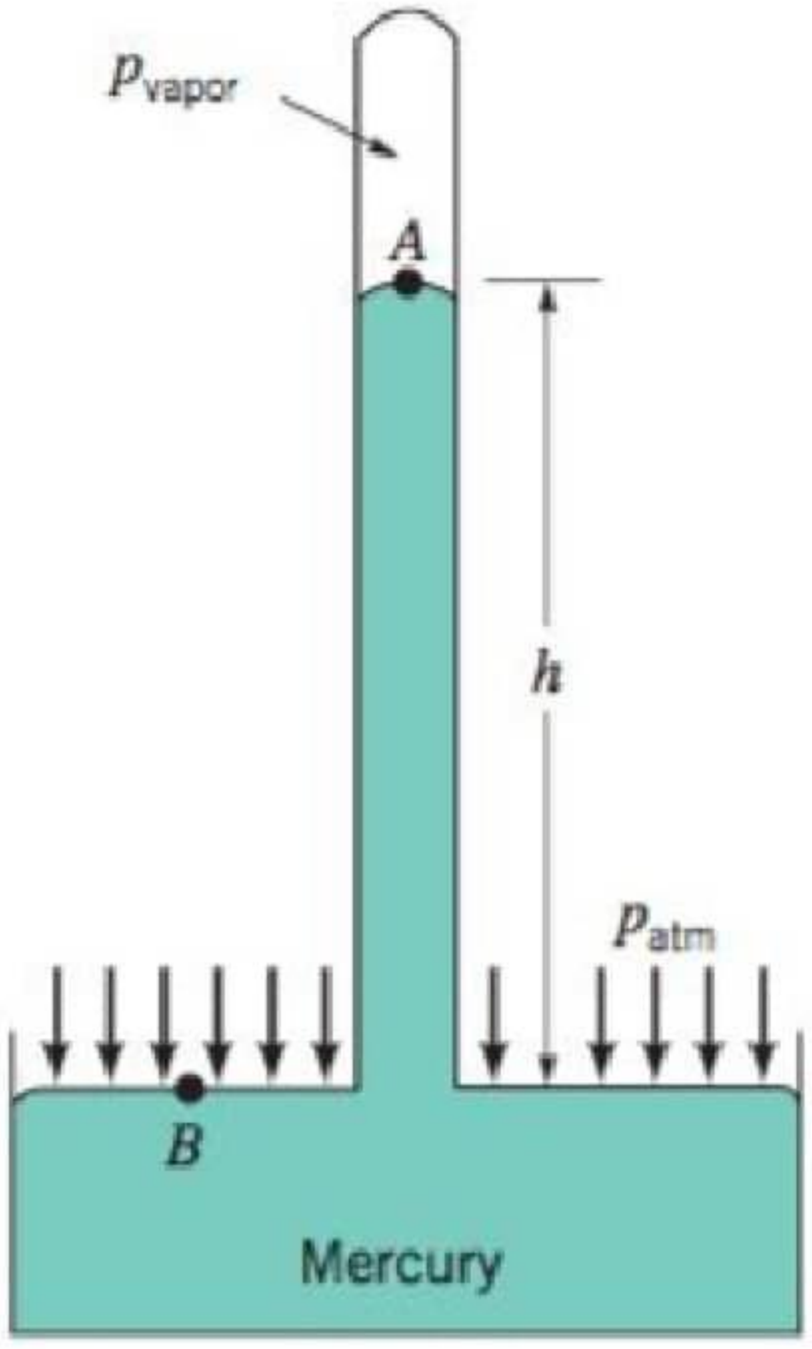



Fig. 1: Mercury Barometer

- **The mercury barometer is used to measure atmospheric pressure**
- **It consists of a glass tube closed at one end with the open end immersed in a container of mercury**
- **The tube (initially with the open end faced upwards) is filled with mercury and then turned upside down with the open end immersed in the container of mercury**

# Mercury Barometer

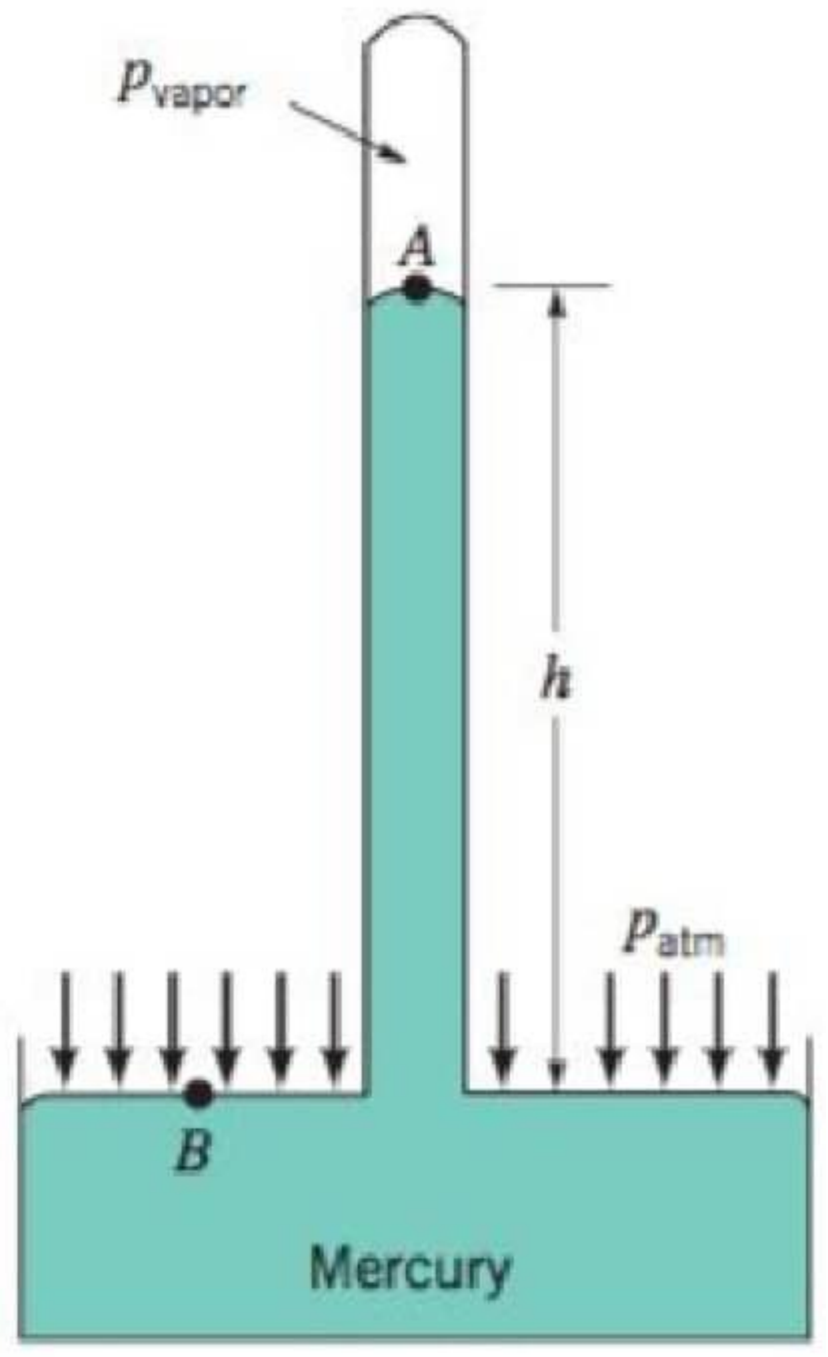



Fig. 1: Mercury Barometer

- **The column of mercury, after a while comes to an equilibrium position where its weight plus the force due to the vapor pressure (which develops in the space above the column) balances the force due to atmospheric pressure**

- **Thus,**

$$p_{atm} = \gamma h + p_{vapor}$$

# Mercury Barometer

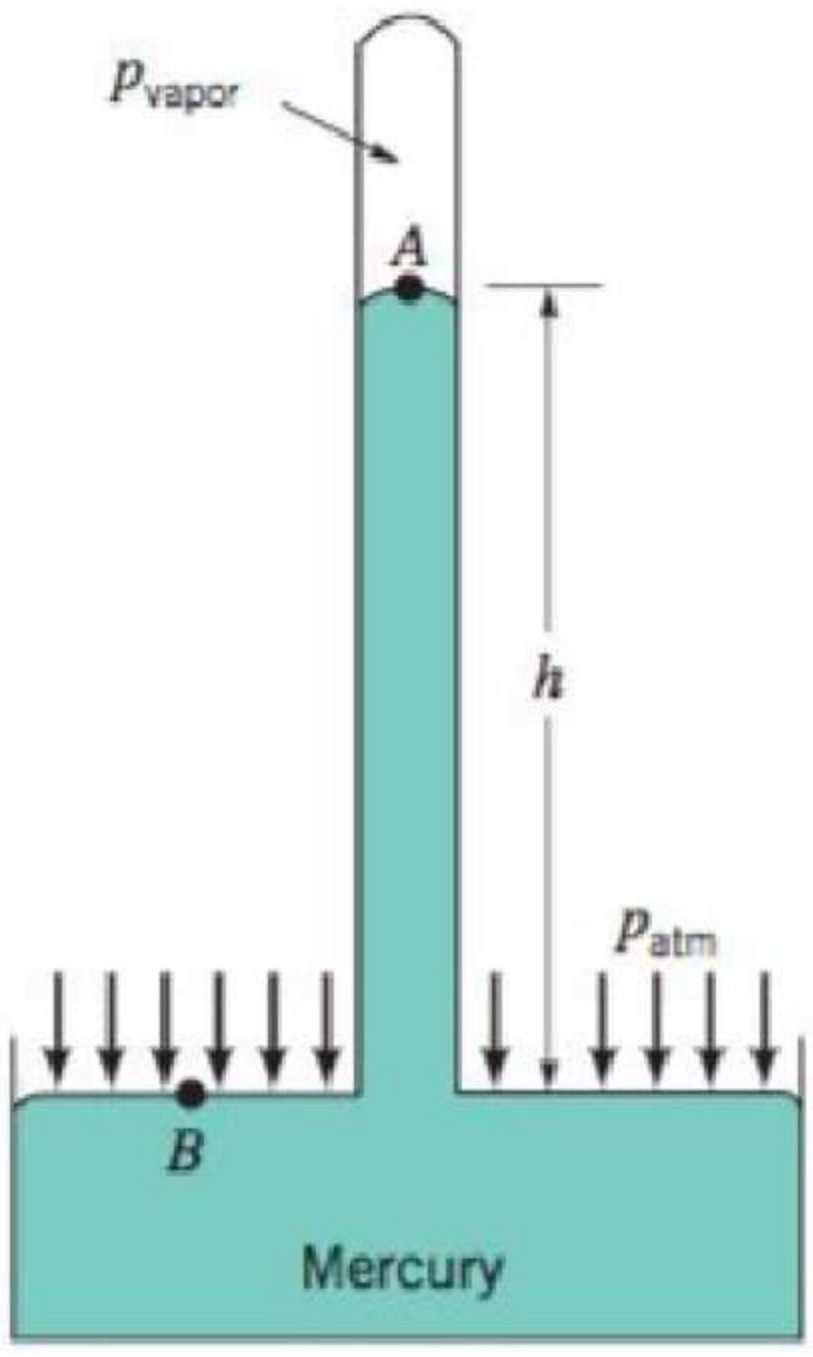



Fig. 1: Mercury Barometer

- Question for students: Why is water not used as a barometric liquid?

- Pressure measuring devices that involve the standard technique of using liquid columns in vertical or inclined tubes are called manometers

- The mercury barometer is an example of a manometer

# Manometers

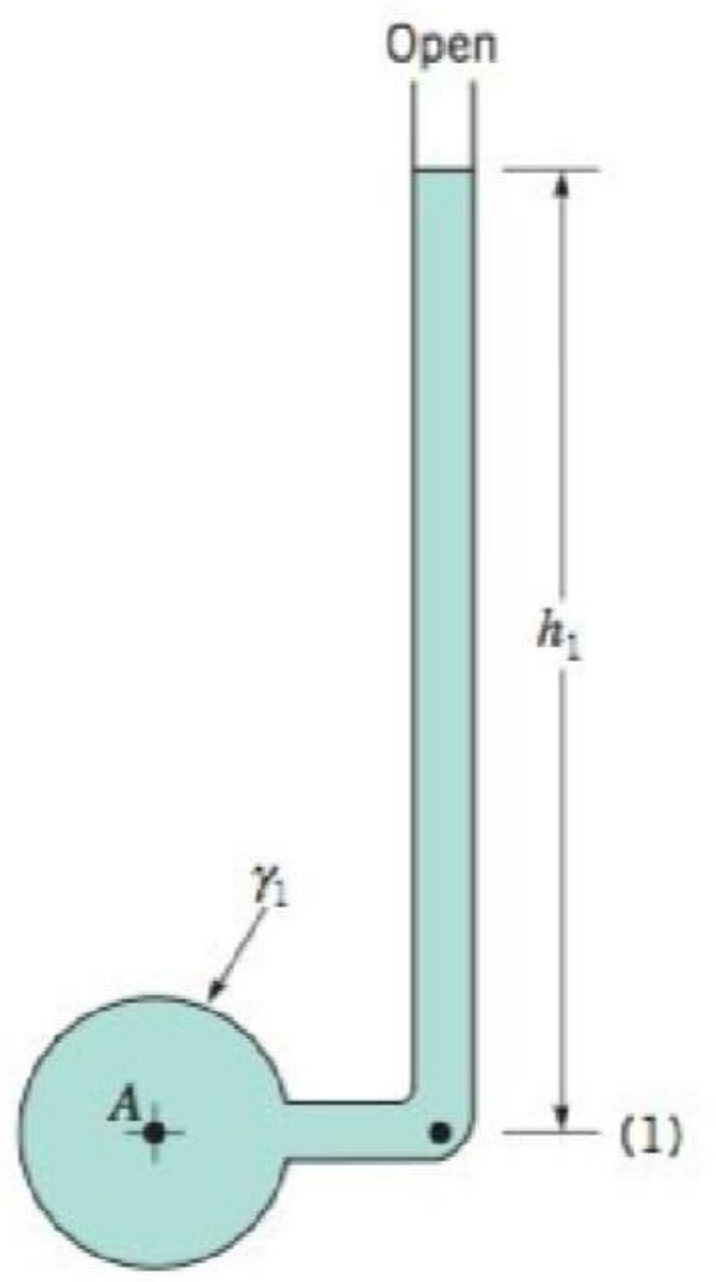



**Fig. 2: Piezometer Tube**

- **There are three common types of manometers**

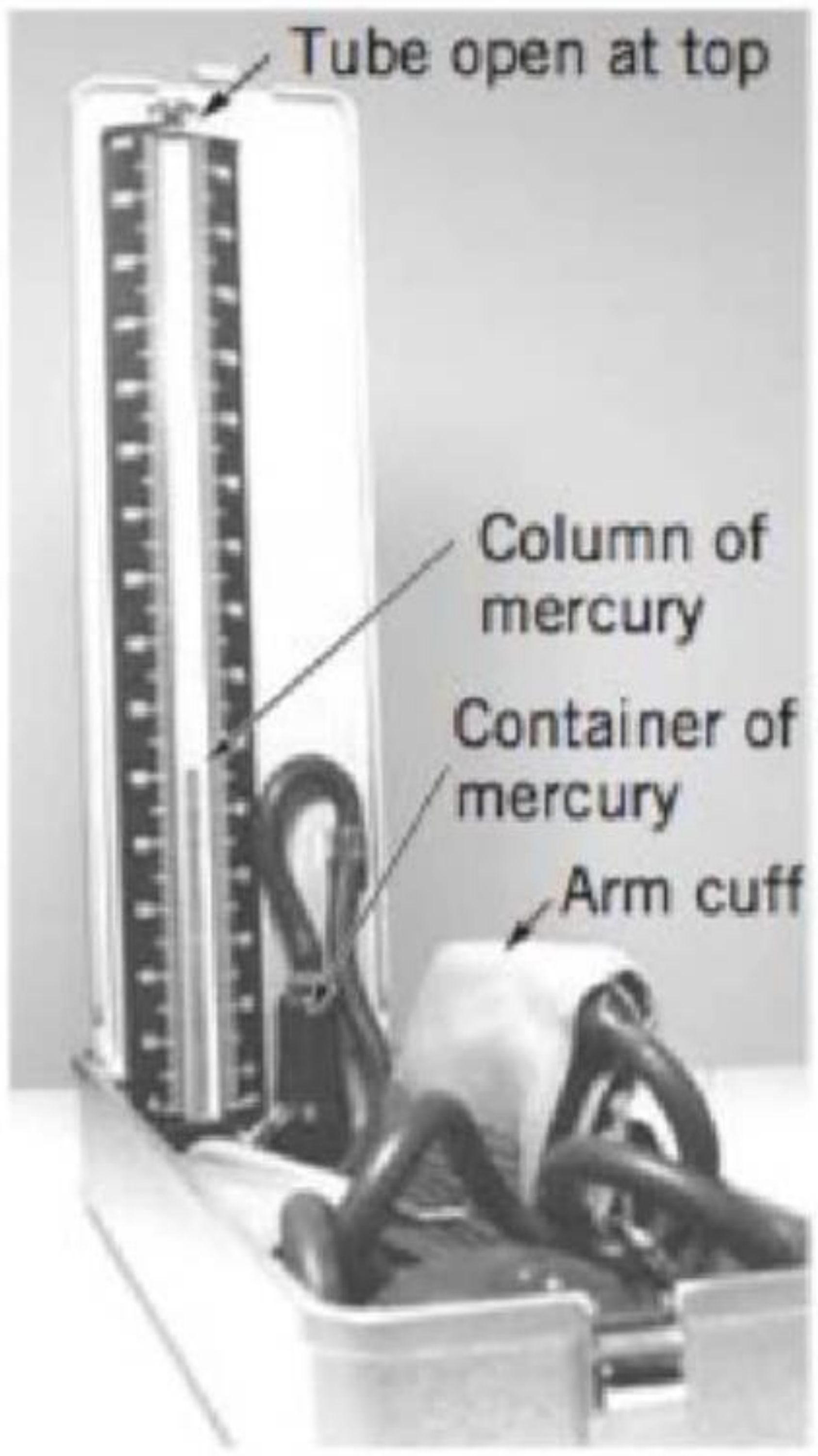
✓ **Piezometer tube**

✓ **U-tube manometer**

✓ **Inclined-tube manometer**

- **Piezometer Tube:** **Is the simplest type of manometer. It consists of a vertical tube, open at the top and attached to the container in which the pressure is desired.**

# Manometers



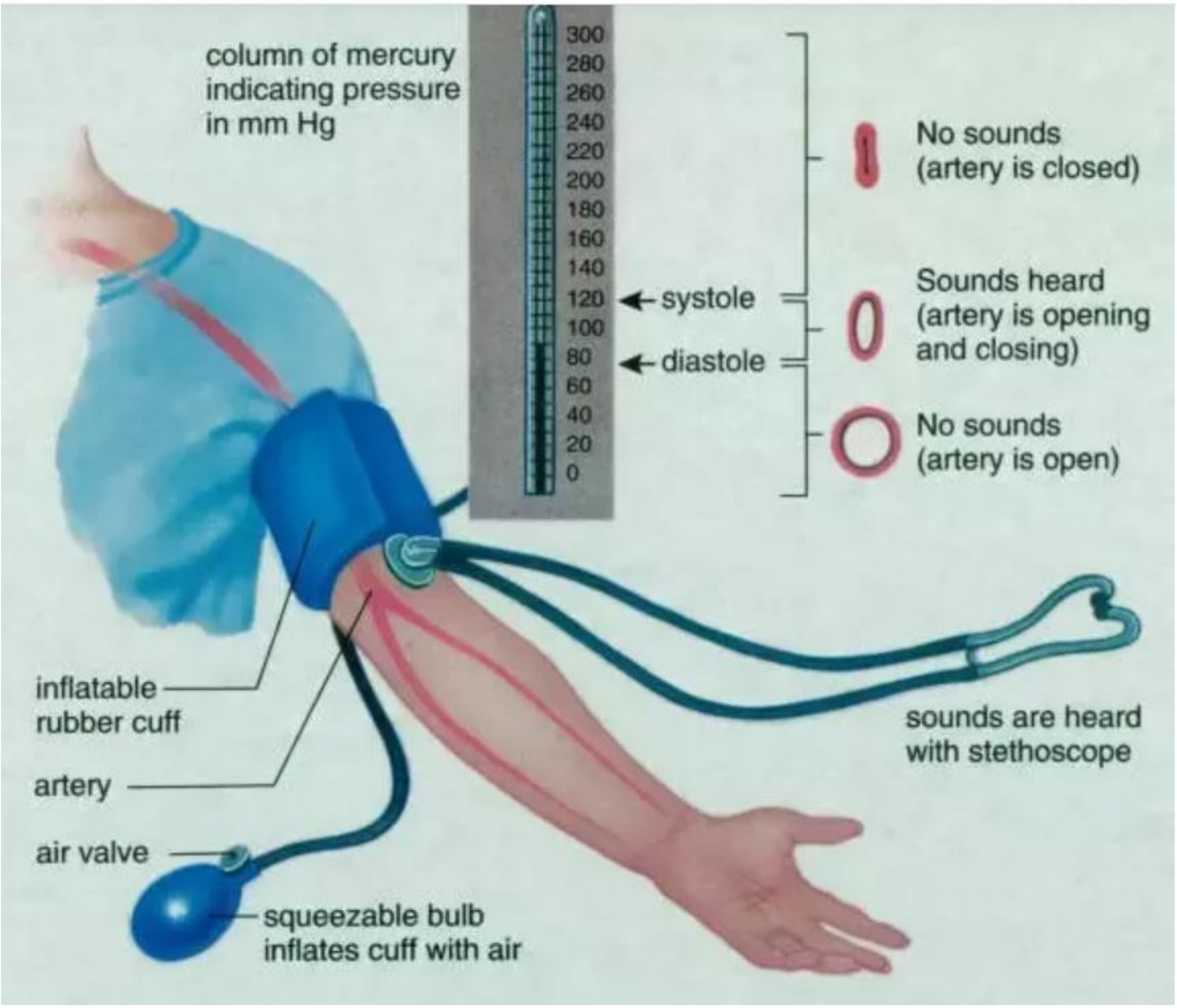




Fig. 3: Sphygmomanometer

- **The sphygmomanometer, used to measure blood pressure, operates based on the principle of a piezometer tube**

- **The cuff contains a hollow rubber air bladder wrapped around the arm. The cuff is inflated until the pressure in the air bladder is equal to the pressure on the artery under the cuff.**

# Manometers

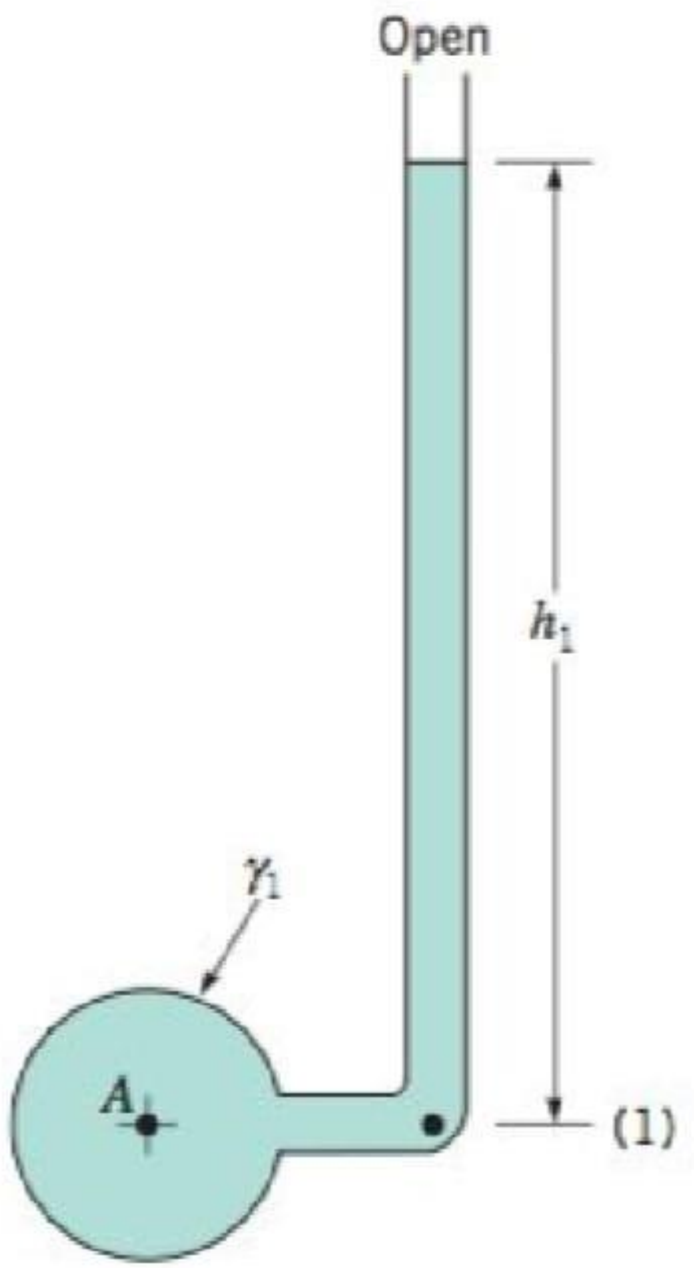



Fig. 2: Piezometer Tube

- **Because manometers involve columns of fluids at rest, the fundamental equation describing their use is,**

$$p = \gamma h + p_0$$

- **The equation above gives the pressure at any elevation within a homogeneous fluid in terms of a reference pressure $p_0$ and the vertical distance $h$ between $p$ and $p_0$.**

- **Recall that pressure increases as we move downward and decreases as we move upward**

# Manometers

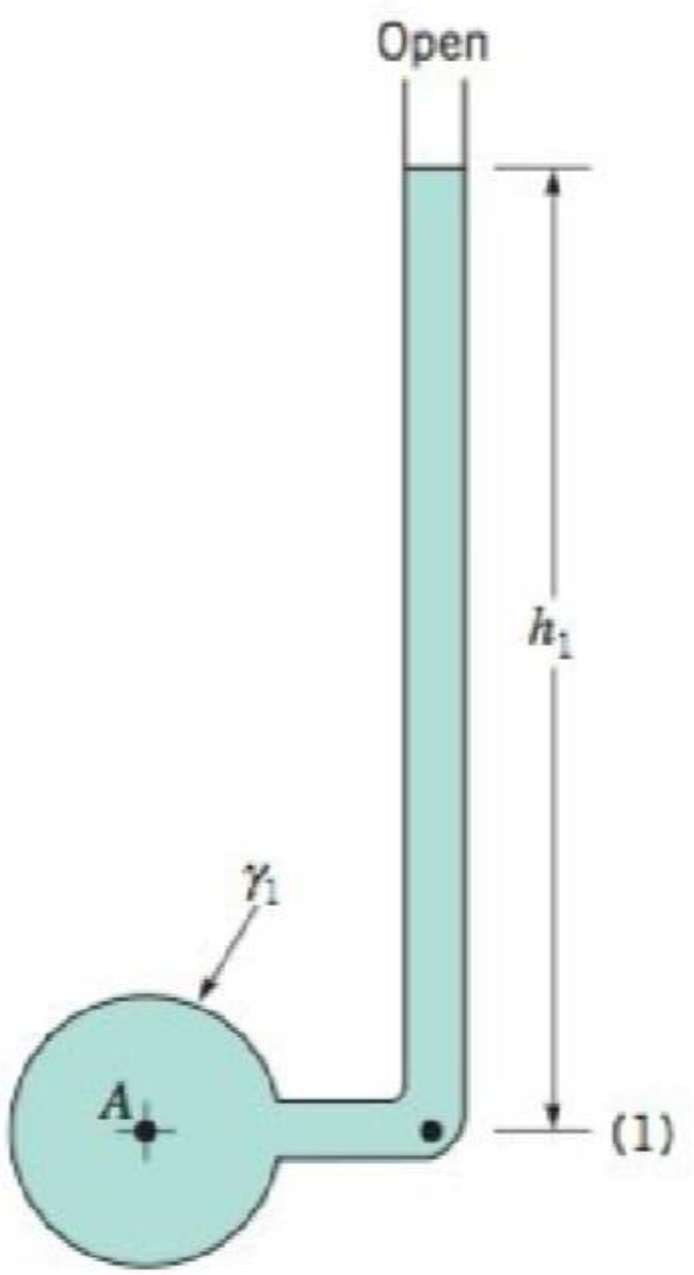



Fig. 2: Piezometer Tube

- **For the piezometer tube showed in Figure 2**

$$p_A = \gamma_1 h_1$$

**Can you confirm if this equation is correct by comparing it with the fundamental equation in the previous slide?**

- **Although the piezometer tube is very simple and accurate, it has some disadvantages.**

✓ It is only suitable if the pressure in the container is greater than atmospheric air

✓ If the pressure in the container is smaller than atmospheric air, air will be sucked into the system

✓ It can only measure relatively small pressures so that the required height of the column is reasonable

✓ The fluid in the container (requiring measurement of pressure) must be a liquid

# Manometers

- **U-Tube Manometer**
- To overcome the disadvantages of the piezometer tube, another type of manometer called the U-Tube manometer is widely used.
- It consists of a tube formed into the shape of a U as shown in Figure 3.
- The fluid in the manometer is called the gauge fluid.
- To find the pressure $p_A$ in terms of the various column heights, we start from one end of the system and work around to the other end of the system

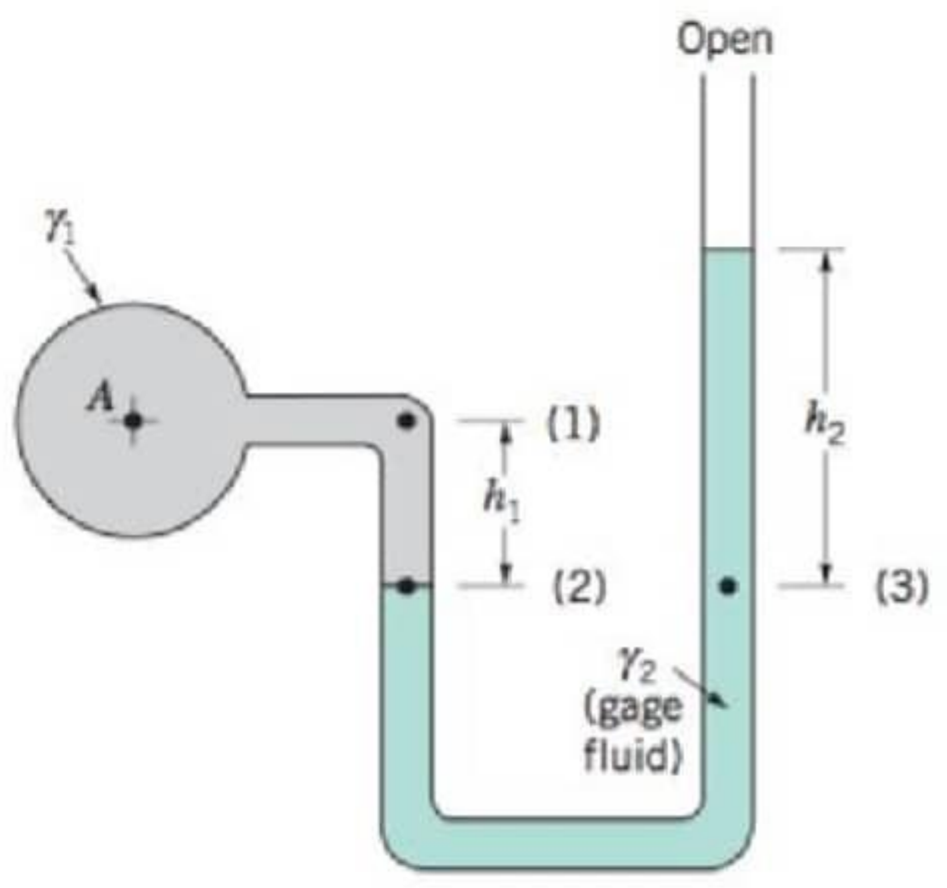



Fig. 3: Simple U-Tube Manometer

# Manometers

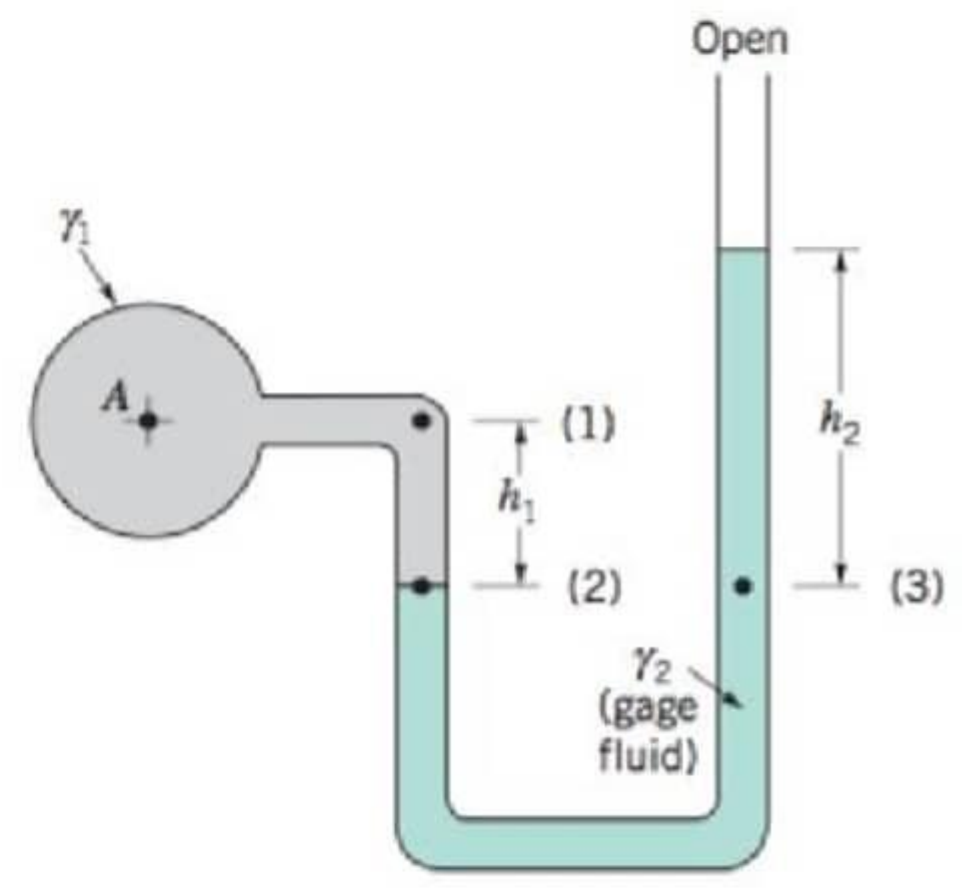



**Fig. 3: Simple U-Tube Manometer**

- **For the U-Tube manometer shown, we start from point A and work around to the open end**
- **Pressure at point A and point (1) are the same. Why?**
- **As we move from point (1) to (2), pressure will increase by $\gamma_1 h_1$. Why?**
- **The pressure at point (2) is the same as the pressure at point (3). Why?**
- **From point (3), as we move vertically upward to the open where pressure is zero, the pressure decreases by $\gamma_2 h_2$**

# Manometers

- **We can obtain the equation form of the various steps in the previous slides by**

$$p_2 = p_3$$

$$p_2 = p_A + \gamma_1 h_1; \quad p_3 = 0 + \gamma_2 h_2$$

$$p_A + \gamma_1 h_1 = \gamma_2 h_2$$

**Therefore,**

$$p_A = \gamma_2 h_2 - \gamma_1 h_1$$

- **Observe that the pressure at A is in terms of the column heights**

- **One major advantage of the U-tube manometer is the fact that the gauge fluid can be different from the fluid in the container**

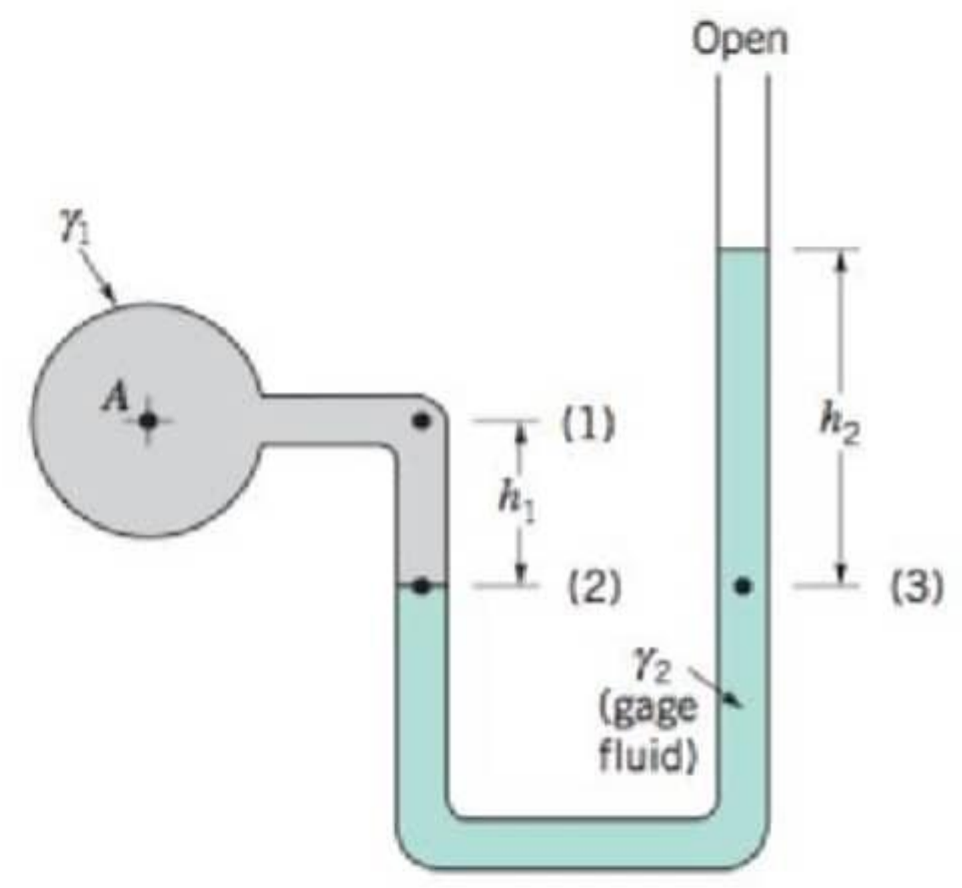



**Fig. 3: Simple U-Tube Manometer**

# Manometers

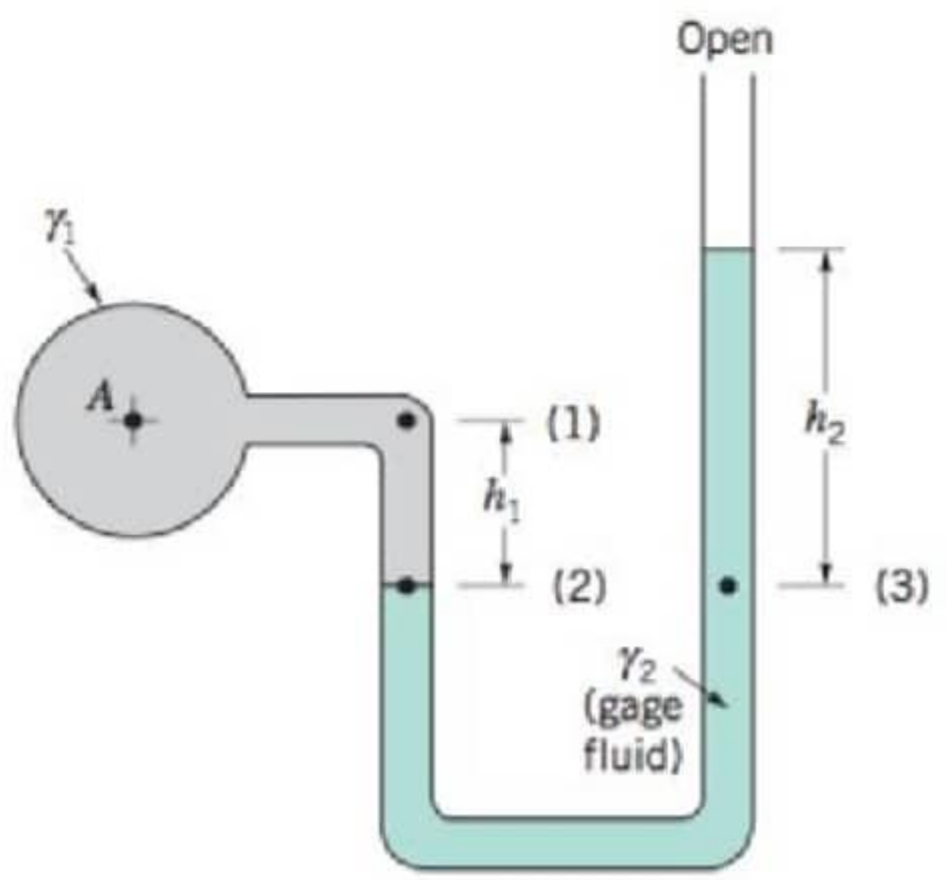



Fig. 3: Simple U-Tube Manometer

- **If the fluid in the container is a gas, the contribution of the gas column $\gamma_1 h_1$ is almost always negligible because of the low specific weight of gases (Check and compare the specific weight of air with that of water)**

- **Therefore, $p_2 = p_A + \gamma_1 h_1$ becomes $p_A \approx p_2$ and $p_A \approx \gamma_2 h_2$**

# Manometers

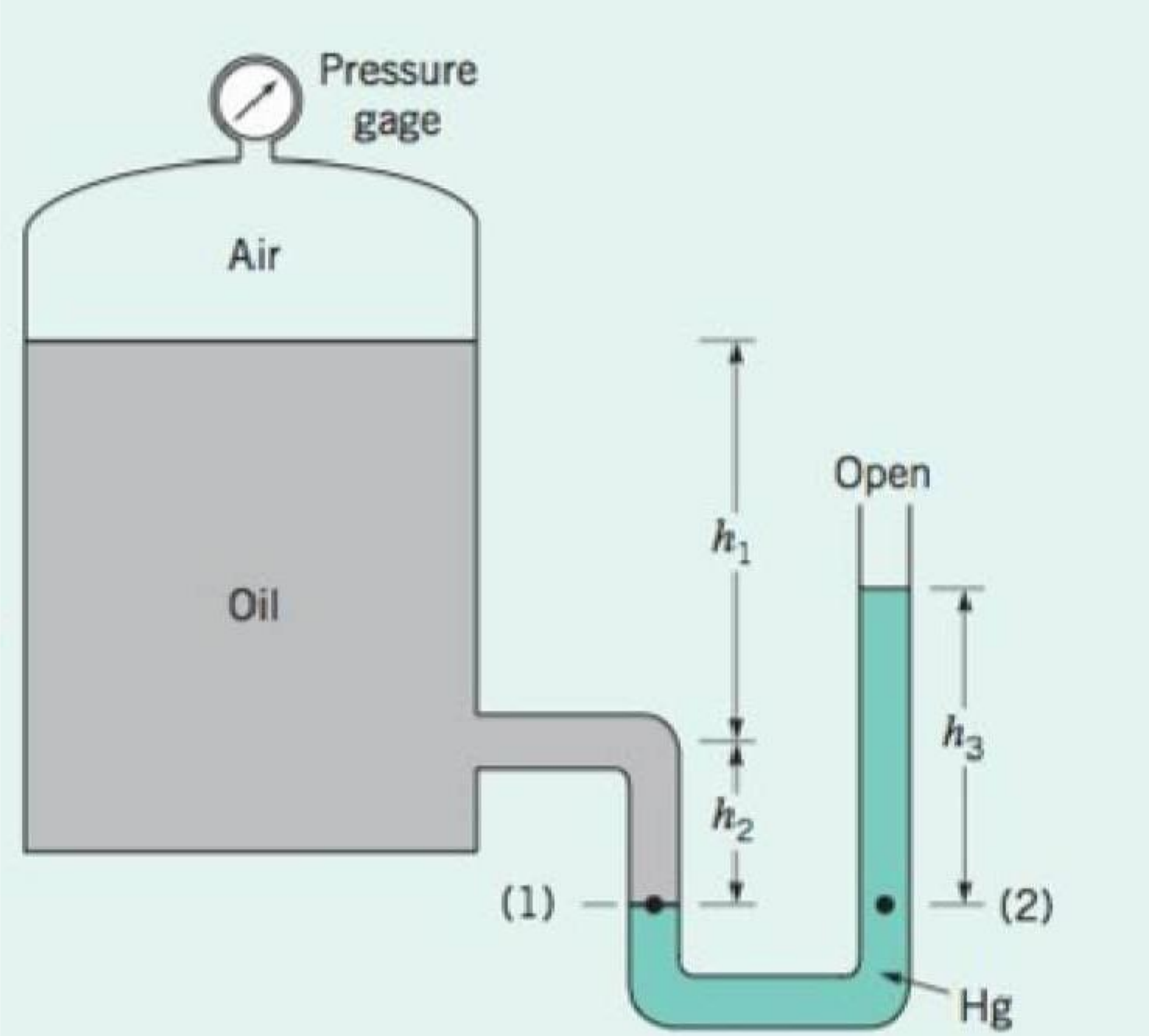



**Fig. 4: Class Activity 1**

**Class Activity 1**

**A closed tank contains compressed air and oil $(SG_{oil} = 0.90)$. A U-Tube manometer using mercury $(SG_{Hg} = 13.6)$ is connected to the tank. The column heights are $h_1 = 0.9m, h_2 = 0.15m, h_3 = 0.23m$. Determine the pressure reading of the gauge.**

# Manometers

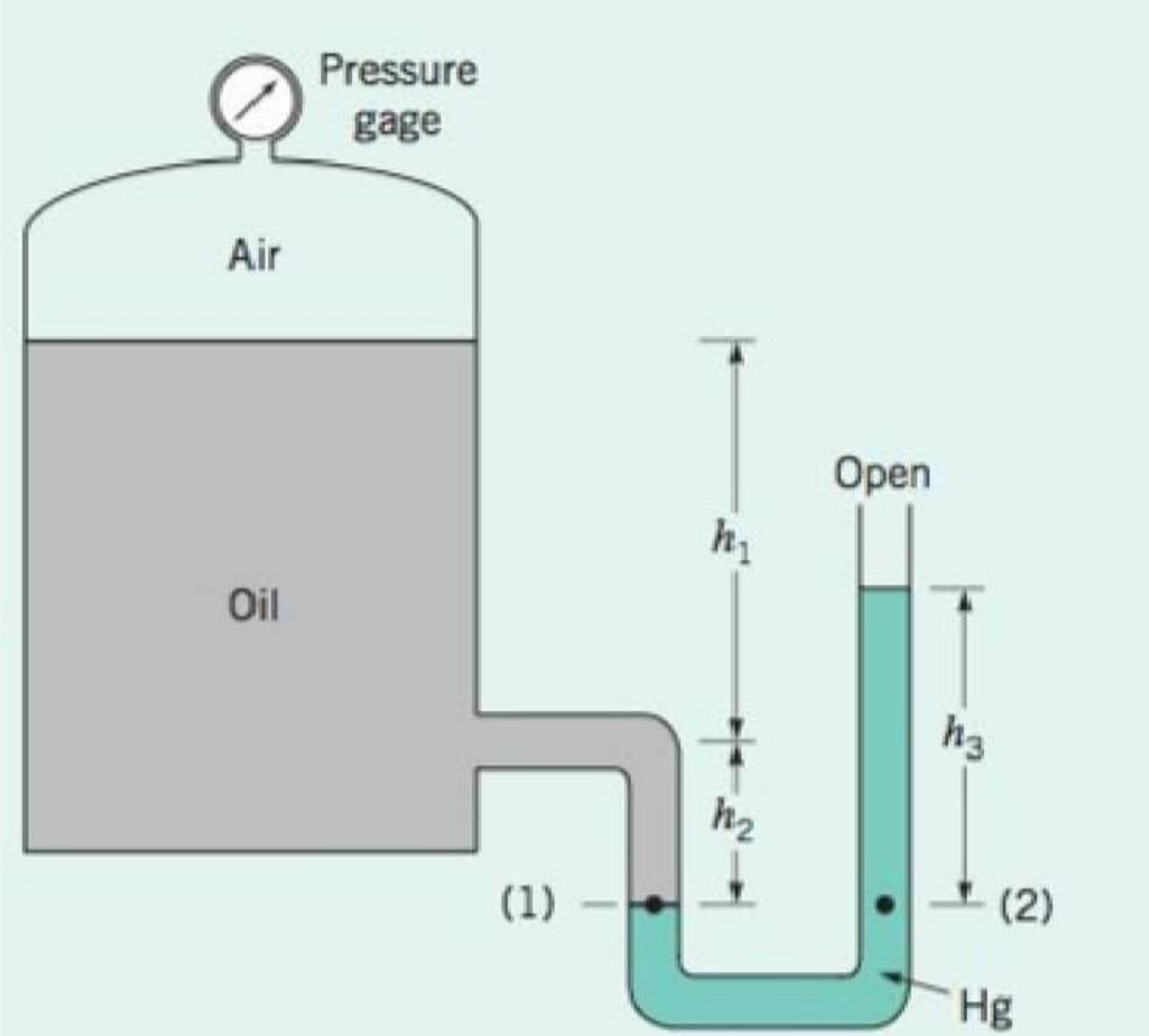



**Fig. 4: Class Activity 1**

**Class Activity 1**

**Pressure at (1) is the same as pressure at (2) because the two points are at the same elevation in a homogeneous fluid at rest**

$$p_1 = p_{air} + \gamma_{oil}(h_1 + h_2)$$

$$p_2 = p_{open} + \gamma_{Hg} h_3$$

$$p_{air} + \gamma_{oil}(h_1 + h_2) = \gamma_{Hg} h_3$$

$$p_{air} = \gamma_{Hg} h_3 - \gamma_{oil}(h_1 + h_2)$$

**Students should complete this exercise to obtain the pressure reading of the gauge**

# Manometers

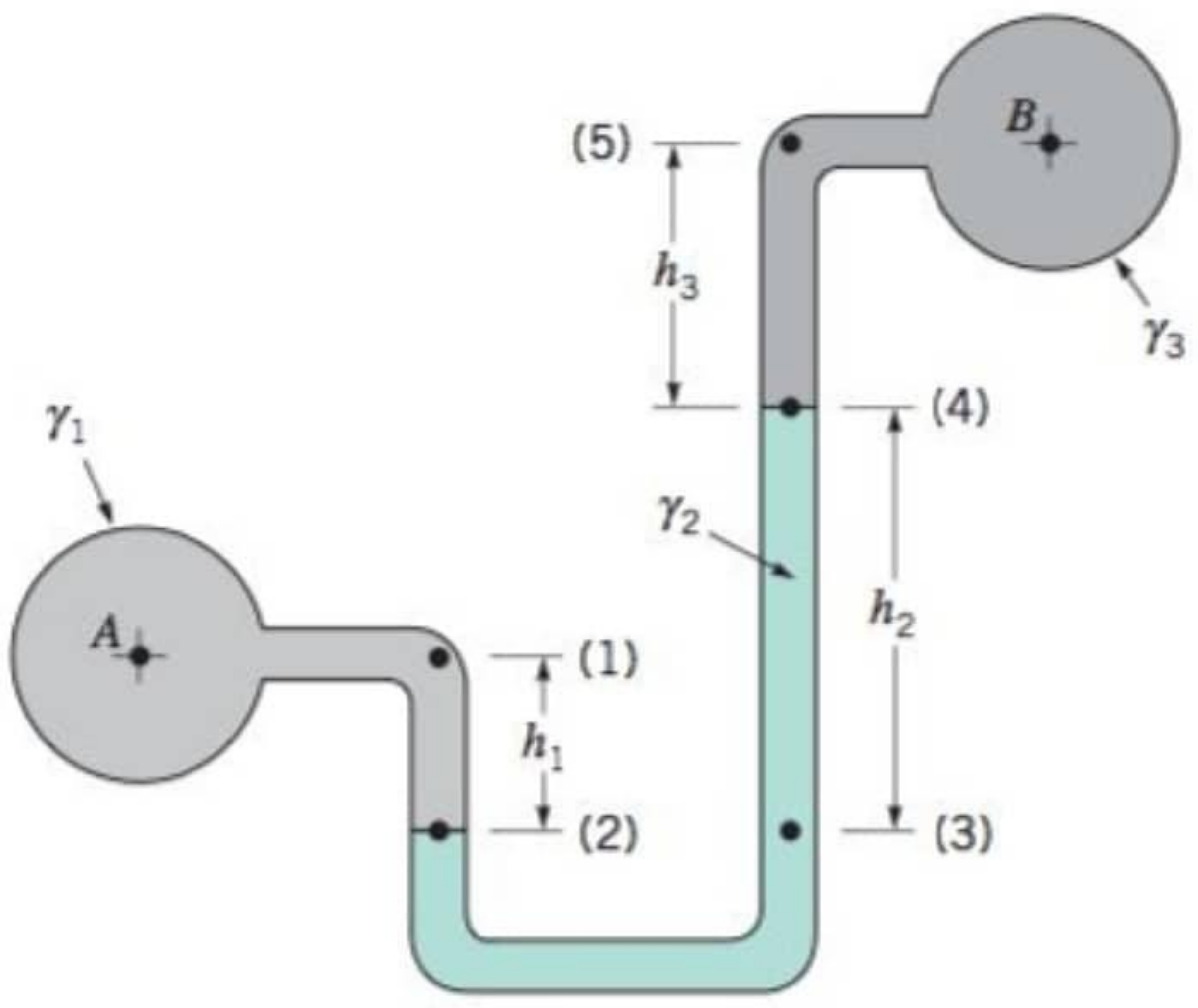



Fig. 5: Differential U-Tube Manometer

- **The U-Tube manometer is also used to measure the difference in pressure between two containers as shown in Figure 5.**

- **This type of U-Tube manometer is called the differential U-tube manometer**

- **Following the same procedure as before,**

$$p_2 = p_3$$

$$p_2 = p_A + \gamma_1 h_1; \quad p_3 = p_B + \gamma_3 h_3 + \gamma_2 h_2$$

$$p_A + \gamma_1 h_1 = p_B + \gamma_3 h_3 + \gamma_2 h_2$$

$$p_A - p_B = \gamma_3 h_3 + \gamma_2 h_2 - \gamma_1 h_1$$

# Manometers

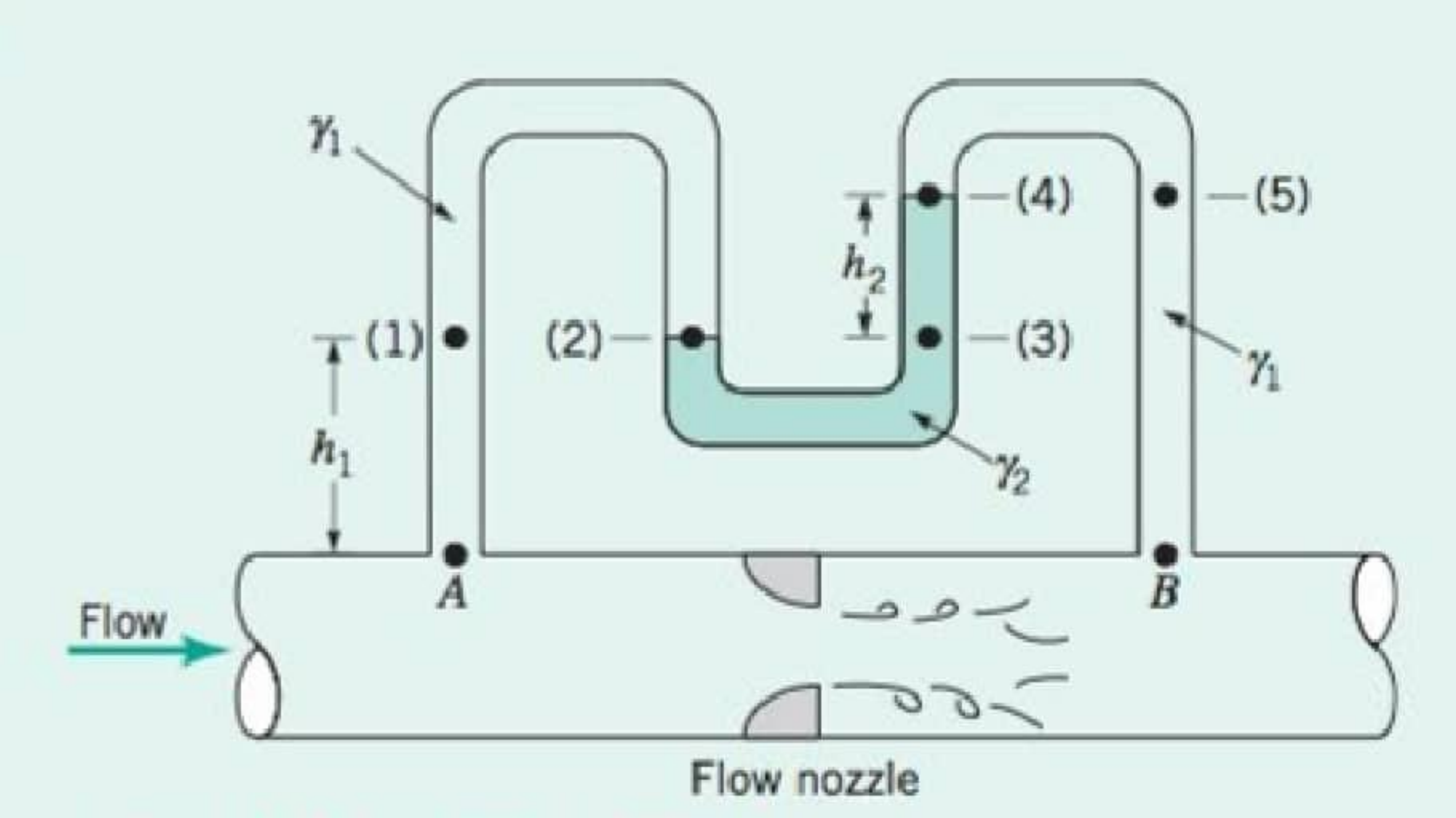



Fig. 6: Class Activity 2

**Class Activity 2**

**The volume flow rate through a pipe can be determined by means of a flow nozzle located in a pipe as shown in Figure 6. The nozzle creates a pressure drop $p_A - p_B$ along the pipe.**

**(a) Determine the equation for $p_A - p_B$ in terms of the specific weight of the flowing fluid, the specific weight of the gauge fluid and the various heights indicated in the figure**

**(b) Determine the value of the pressure drop for the following parameters**

$$\gamma_1 = 9.8\ kN/m^3, \gamma_2 = 15.6\ kN/m^3, h_1 = 1m, h_2 = 0.5m$$

# Manometers

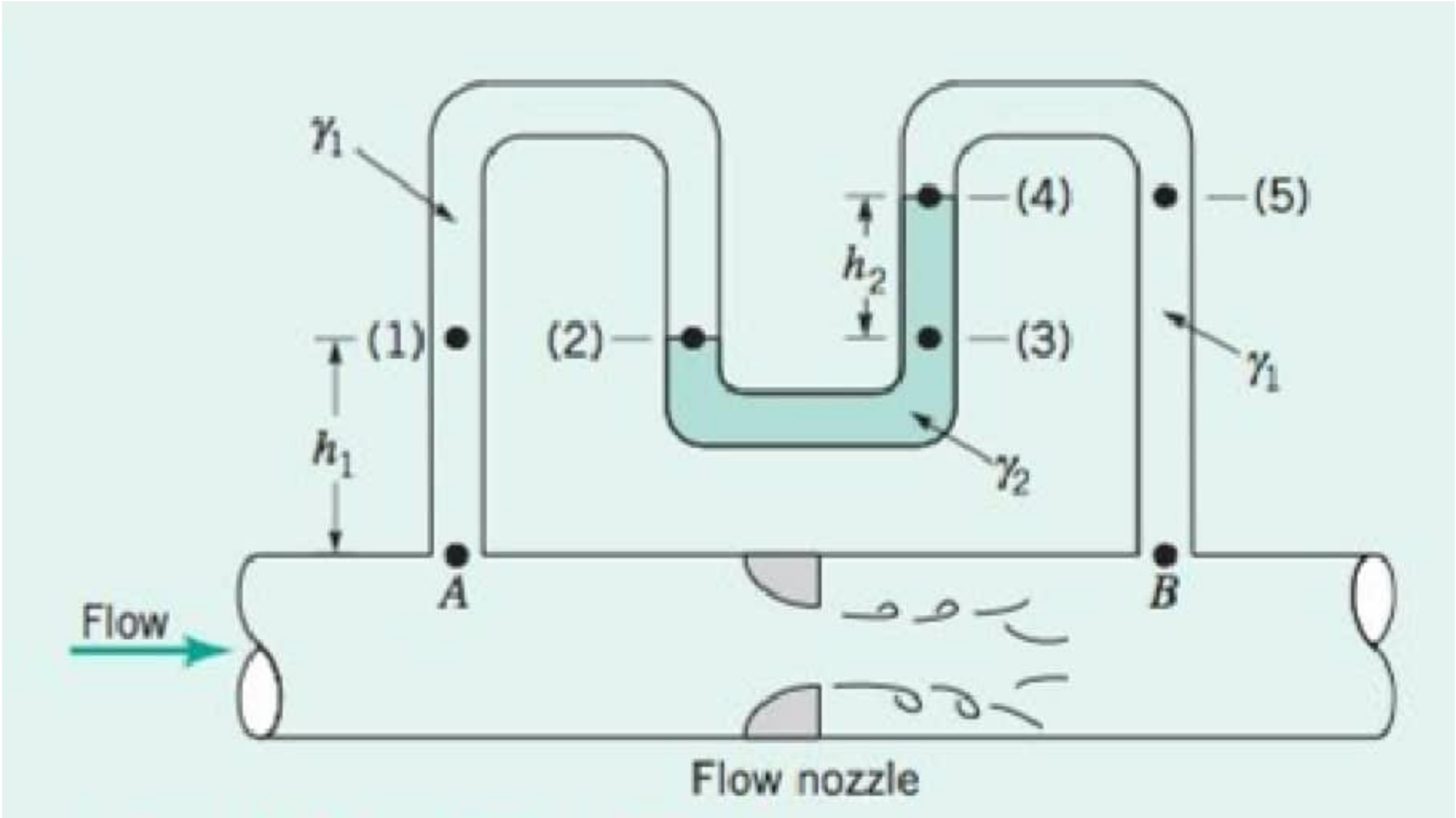



**Fig. 6: Class Activity 2**

**Class Activity 2**

**Pressure at (1) is equal to the pressure at (2) and the pressure at (2) is equal to the pressure at (3). Also, pressure at (4) is equal to the pressure at (5)**

$$p_2 = p_A - \gamma_1 h_1$$

$$p_3 = p_B - \gamma_1(h_1 + h_2) + \gamma_2 h_2$$

$$p_A - \gamma_1 h_1 = p_B - \gamma_1(h_1 + h_2) + \gamma_2 h_2$$

$$p_A - p_B = \gamma_1 h_1 - \gamma_1(h_1 + h_2) + \gamma_2 h_2$$

$$p_A - p_B = h_2(\gamma_2 - \gamma_1)$$

**Students should complete this class activity by solving for the pressure difference using the given parameters**

# Manometers

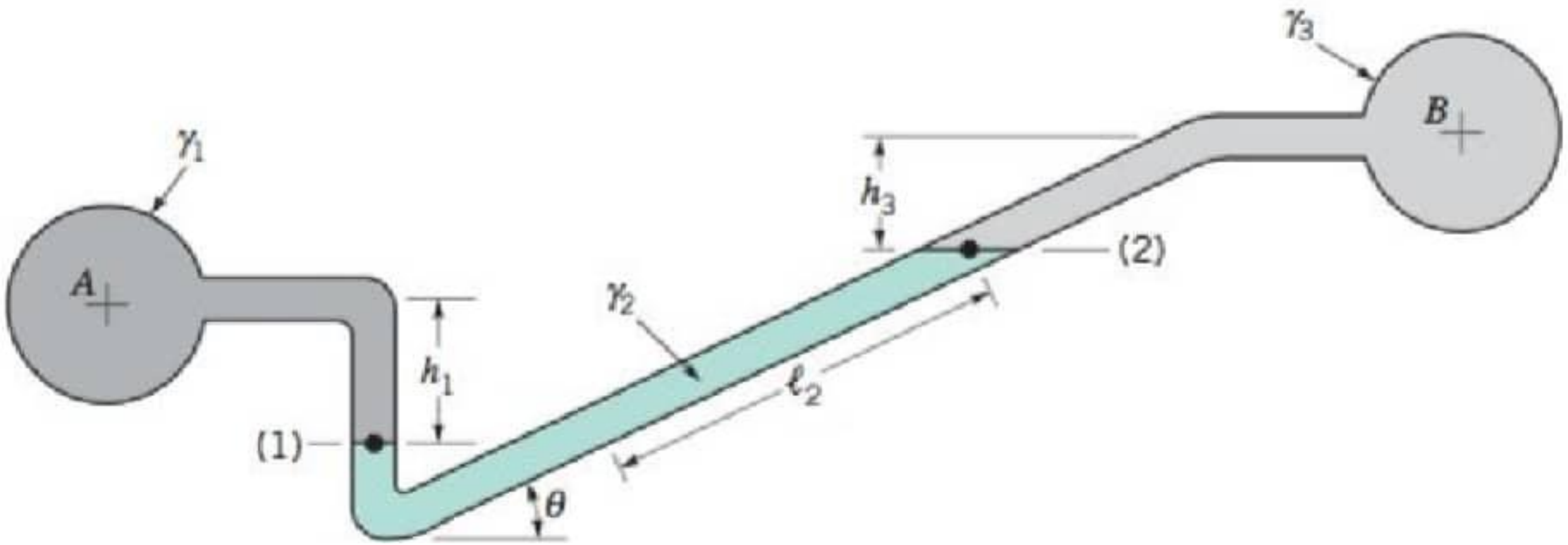



Fig. 7: Inclined-Tube Manometer

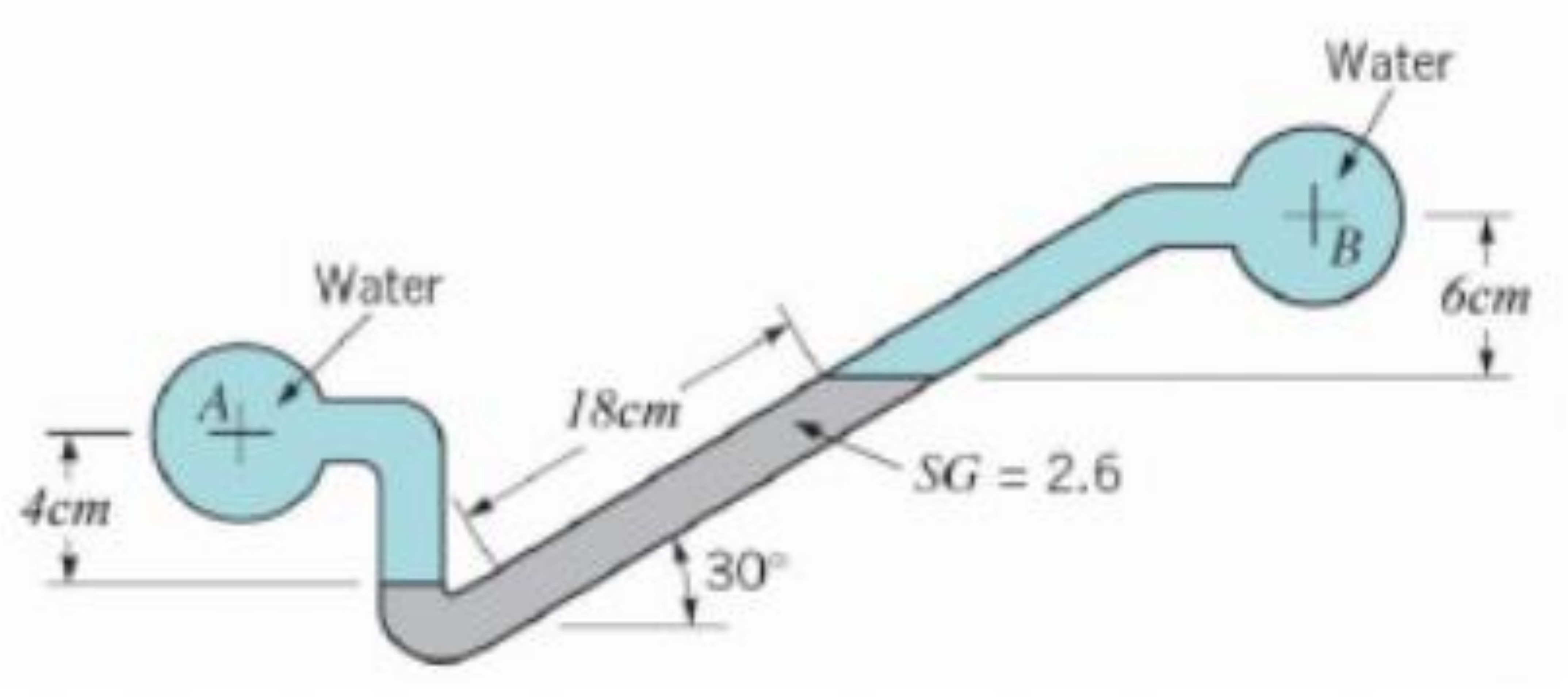
- Inclined-Tube Manometer
- This kind of manometer is used to measure small pressure changes
- Moving from point A to B

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

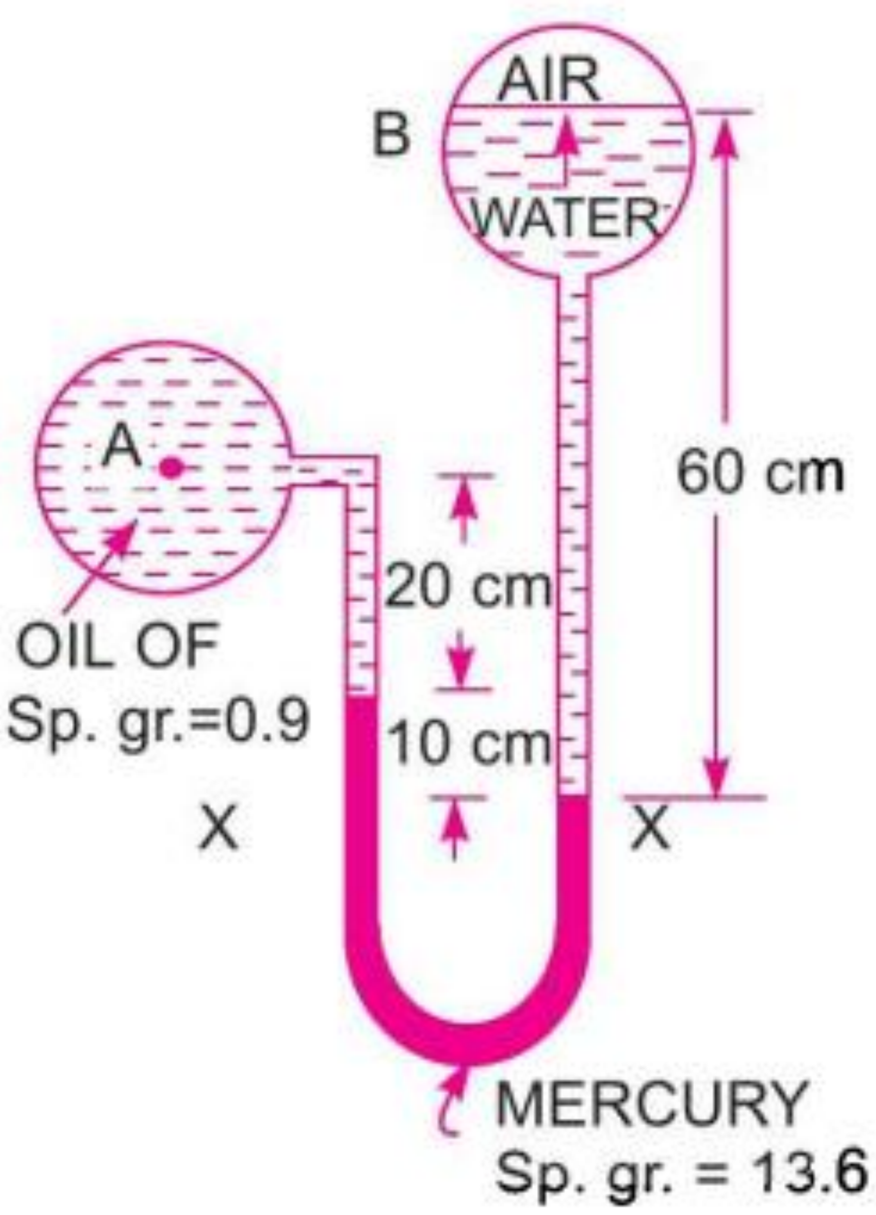
- Note that the pressure difference between point 1 and 2 is due to the vertical distance between them

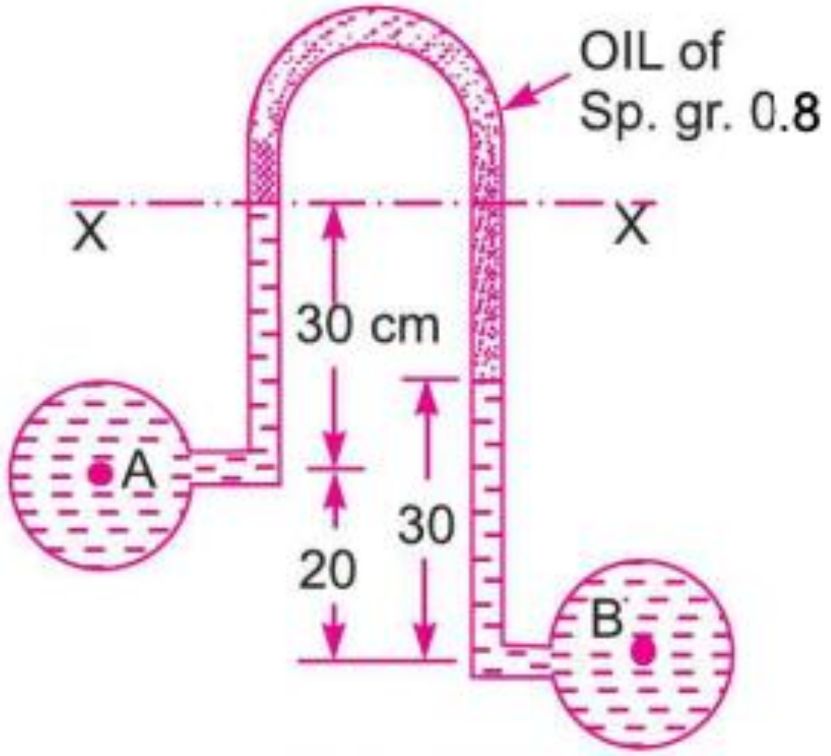
# Take Home Practice Questions

**For the inclined-tube manometer shown in the figure below, the pressure at A is 8 kPa. The fluid in both pipes A and B is water and the gauge fluid has a specific gravity of 2.6. Write the manometer equation and determine the pressure at B.**



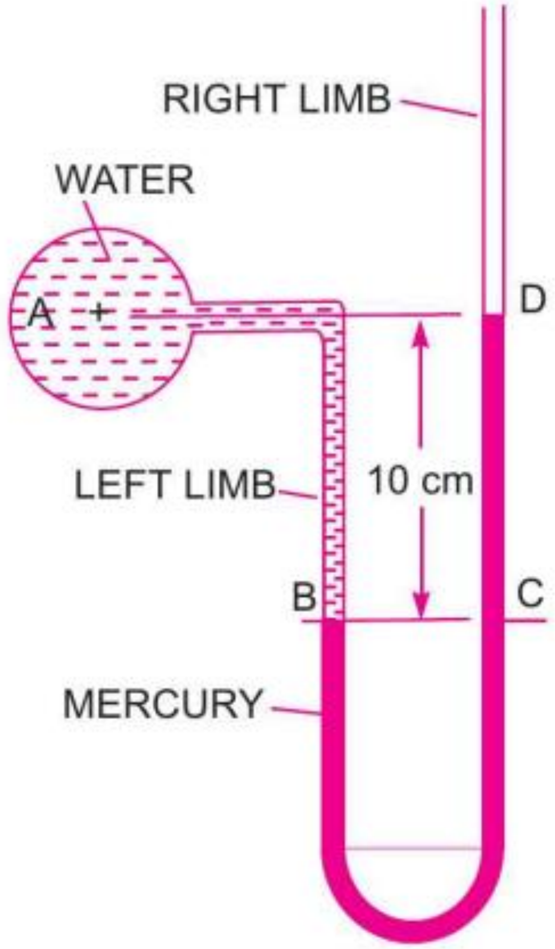
# Take Home Practice Questions




**2. An inverted differential U-tube manometer is connected to two pipes which convey water. The gauge fluid is oil whose specific gravity is 0.8. Find the pressure difference between A and B.**

**1. A differential U-Tube manometer shown above is connected to two containers A and B. If air pressure at B is $9.81\ N/cm^2$(abs), find the absolute pressure at A**




**3. A U-Tube manometer is used to measure the pressure of water in a pipeline. The right limb of the manometer contains mercury and it is open to the atmosphere. What is the pressure at A?**

# Mechanical & Electronic Pressure-Measuring Devices

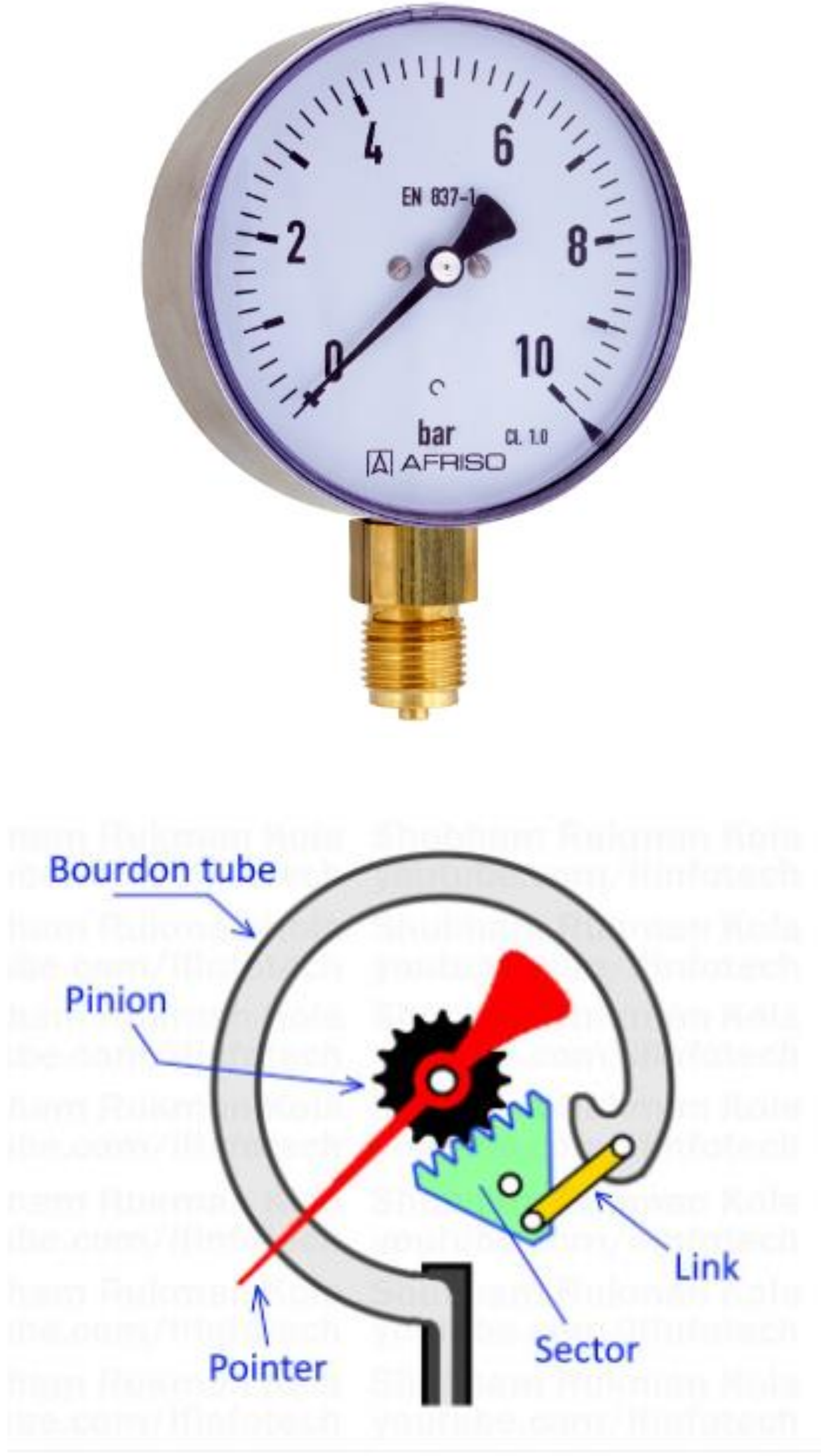



**Fig. 8: Bourdon gauge**

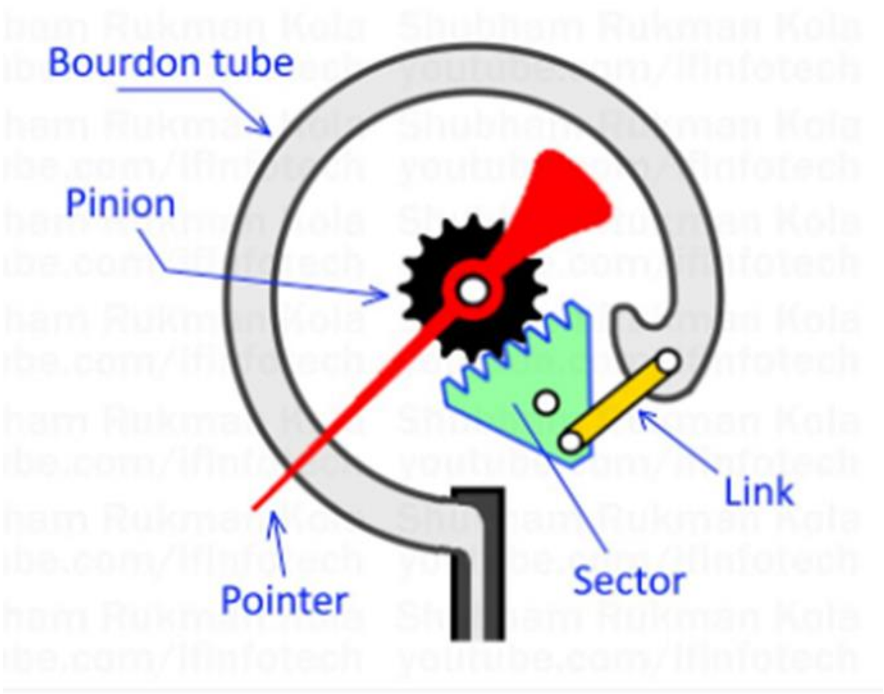
- **Although manometers are widely used, they are not well suited for measuring very high pressures that are changing rapidly with time**

- **Measurements requiring one or more column heights also makes the process time consuming**

- **To overcome these challenges other types of pressure-measuring instruments have been developed**

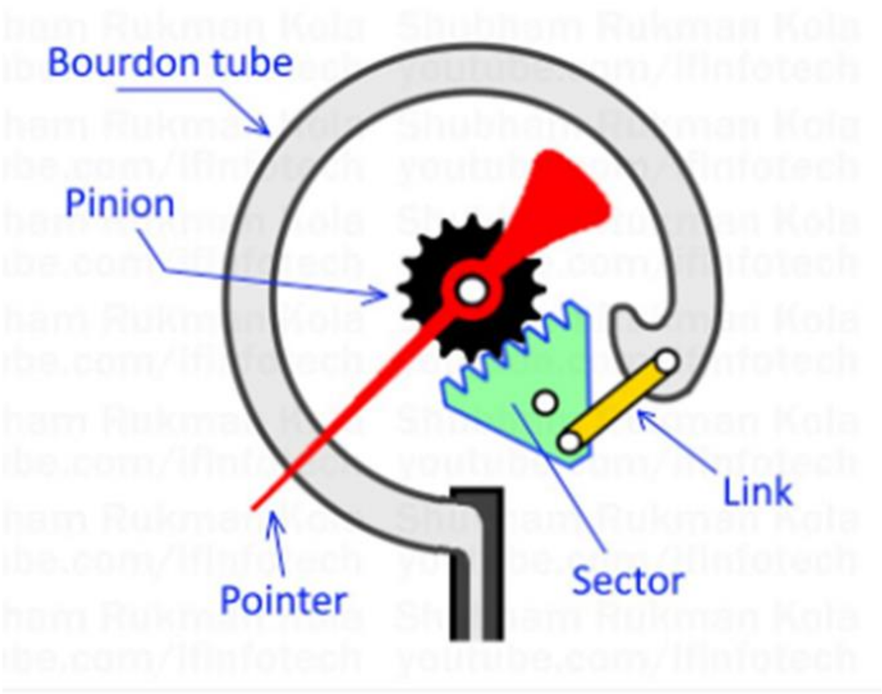
- **An example is the Bourdon gauge**

# Mechanical & Electronic Pressure-Measuring Devices



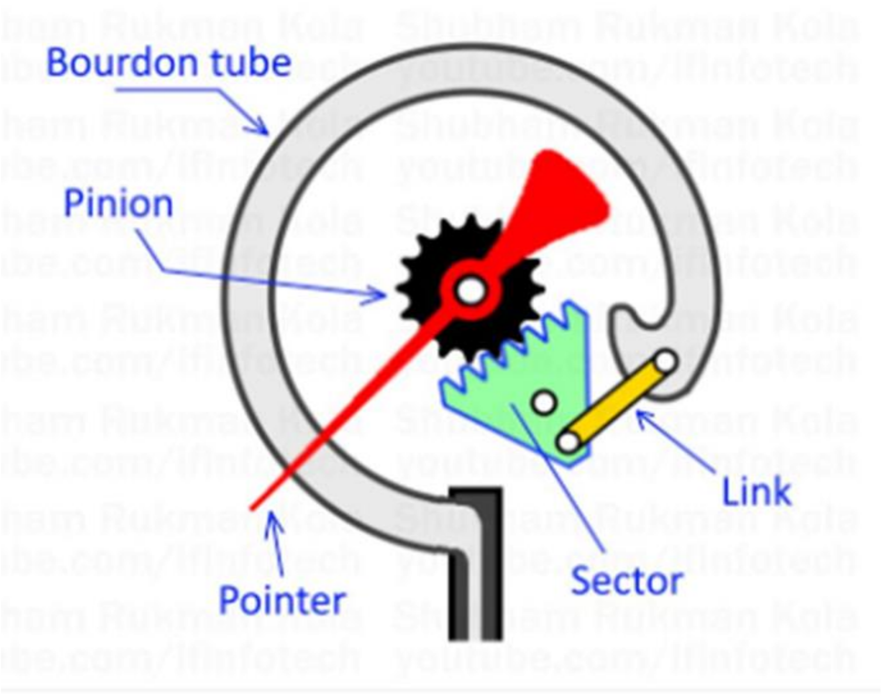

- In the picture shown, the bourdon pressure gauge is attached to the pipeline of the system's inlet pipe.
- The socket block holds the inlet pipe in place, allowing the pressure to flow into the stationary end of the tube.
- This pressure is distributed throughout the elastic C-shaped tube between the fixed and the moving ends. As the inlet pressure increases, the C-shape tube straightens.

# Mechanical & Electronic Pressure-Measuring Devices




- The pivot and pivot pin attached to the moving end of the tube connects this movement with the sector gear.
- This leads to an amplified motion which causes a deflection of the indicator needle for every small change in inlet pressure.
- When the inlet pressure increases, the indicator moves clockwise (from left to right) over a calibrated scale.

# Mechanical & Electronic Pressure-Measuring Devices




- Once the pressure drops, the tube regains its helix shape, and the indicator moves in an anticlockwise direction (from right to left).

- Due to its design, the bourdon tube is sensitive to pressure changes, making it suitable for high-precision applications.

- It is also resistant to corrosion and vibration.

- The Bourdon Gauge is a mechanical pressure-measuring device

# Mechanical & Electronic Pressure-Measuring Devices


Fig. 9: Digital pressure gauge

https://www.afriso.com/en/PM/Industrial-technology/Electronic-pressure-measuring-instruments

- In the case of an electronic pressure measuring device, a sensor is required to detect the pressure and/or its change, and to convert it accurately and repeatedly into an electrical signal utilizing a physical operating principle.

- The electrical signal is then a measure of the magnitude of the applied pressure or change in pressure.

# SUMMARY

1. Mercury Barometer
2. Piezometer Tube
3. Simple U-Tube Manometer
4. Differential U-Tube Manometer
5. Inclined-Tube Manometer
6. Mechanical & Electronic Pressure-Measuring Devices

# Next Lecture

- **Hydrostatic Force on Plane Surfaces**

✓ **Hydrostatic force in open tanks**
✓ **Hydrostatic force on an inclined plane**
✓ **Hydrostatic force on a plane circular surface**
✓ **Pressure Prism Concept**