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FACULTY OF ENGINEERING AT SHOUBRA

Fluid Mechanics [1]

MEC 121

1st Year- Mechanical Engineering

2nd Term-(2024)

Dr. Samer Beskales

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Faculty: https://feng.bu.edu.eg/, University: https://bu.edu.eg/

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Credit

Based on

lecture notes and years of experience learning and teaching

under the umbrella of Prof. Dr. Samir Sobhy

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❖ Course Content

Lecture	Date	Topic	Instructor
1	13/2/2024	Fluid Properties	Prof. Dr. Samir Sobhy
2	20/2/2024	Fluid Properties	Prof. Dr. Samir Sobhy
3	27/2/2023	Kinematics	Prof. Dr. Samir Sobhy
4	5/3/2024	Momentum	Prof. Dr. Samir Sobhy
5	12/3/2024	Moment of momentum	Prof. Dr. Samir Sobhy
6	19/3/2024	Fluid Statics	Dr. Samer Beskales
7	26/3/2024	Fluid Statics	Dr. Samer Beskales
		Midterm	
8	9/4/2024	Bernoulli’s Equation	Prof. Dr. Ibrahim Shahin
9	16/4/2024	Application on Bernoulli	Prof. Dr. Ibrahim Shahin
10	23/4/2024	Flow through pipes	Prof. Dr. Ibrahim Shahin
11	30/4/2024	Flow through pipes	Prof. Dr. Ibrahim Shahin
12	7/5/2024	Dimensional Analysis	Dr. Samer Beskales
		Oral exam	

Teaching Assistant: Eng. Abanoub Zaki

❖ Course Materials

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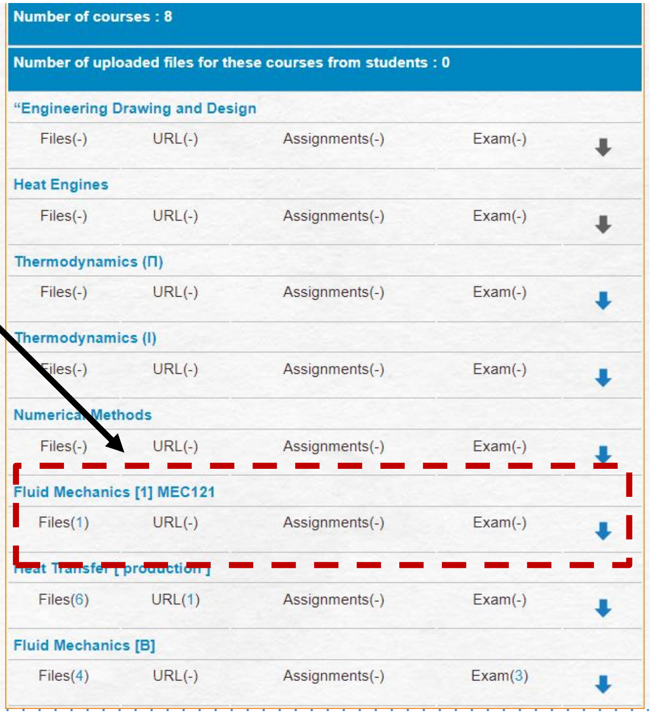
- **All materials are posted on the official instructor page on the university website:**
  Dr.Samer Beskales: www.bu.edu.eg/staff/sameraagaiby3

- **Using Shared links**

1

2

3



❖ Text Books: Chapter [2] – Fluid Statics

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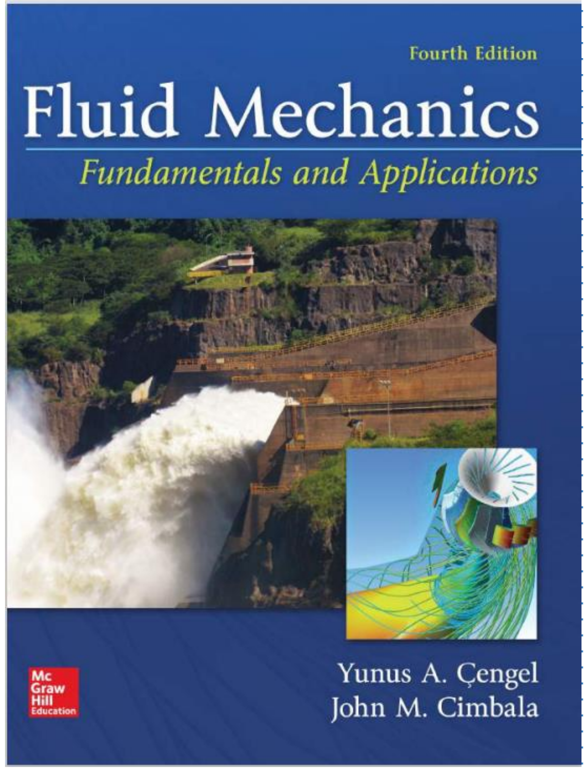
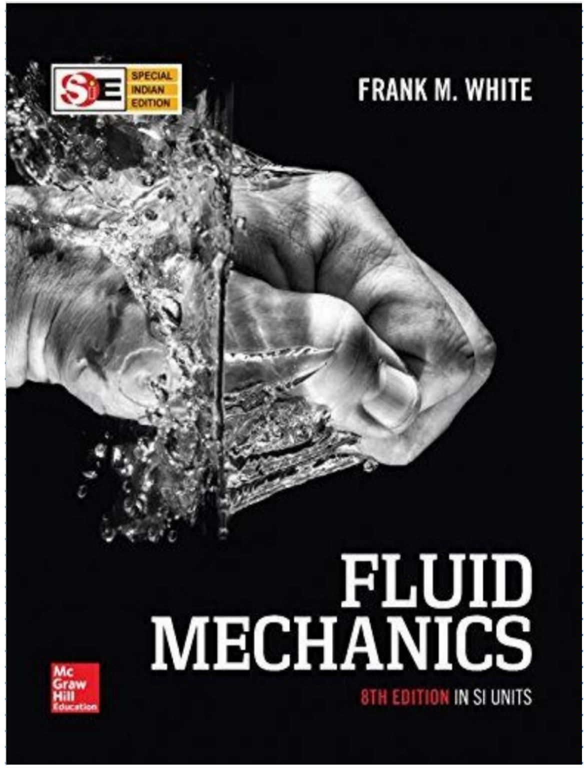
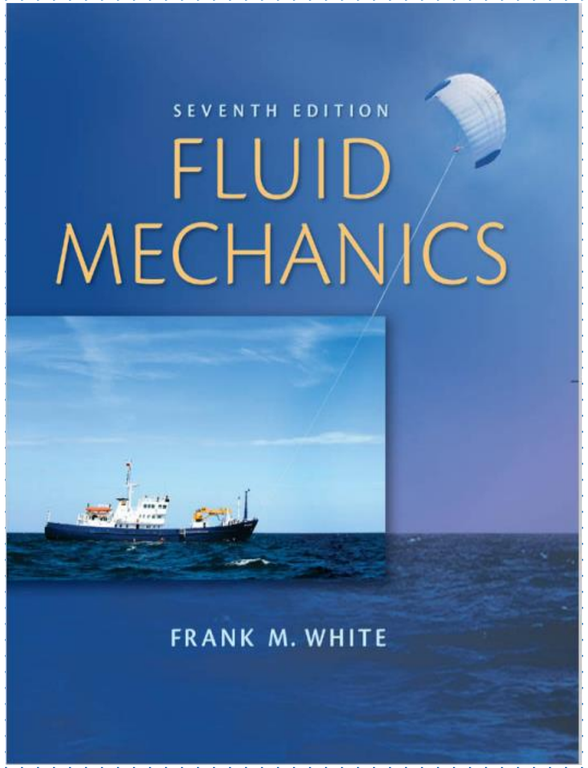


Pages : 76-136.



Pages : 59-132.



Pages : 65-137

❖ Course Assessment

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Second Semester: Mechanical Power Engineering Program

Code	Subject	Contact Hours				Marks				Duration of Final Examination (hours)
		Lecture	Tutorial	Laboratory	Total	Semester Work	Lab./Oral Exam.	Written Exam.	Total	
MEC121	Fluid Mechanics (1)	2	1	2	5	45	30	75	150	3

❖ **Semester Work**

- **Mid-Term Exam** 20
- **Attendance** 5
- **Reports** 5
- **Assignments** 5
- **Quizzes** 10

- **Oral Exam** 20
- **Lab Experiments** 10

- **Bonus (for working in Fluid lab)**

❖ Fluid Statics

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Chapter Two-Objectives

❶ Pressure measurements

▪ Determine the variation of pressure in a fluid at rest
▪ Calculate pressure using various kinds of manometers

❷ Force on Submerged Surfaces

▪ Calculate the forces and moments exerted by a fluid at rest on plane or curved submerged surfaces

❸ Buoyancy and stability

▪ Analyze the stability of floating and submerged bodies

❹ Accelerated Fluid

▪ Analyze the variation of pressure in fluids that undergo linear acceleration and in rotating containers.

❖ Lab Experiments- Fluid Statics

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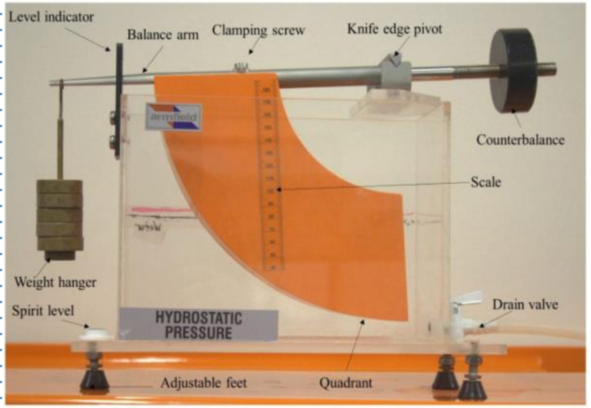
❶ Bourdon Tube Calibration

❷ Center of Pressure and Hydrostatic Force



❸ Metacenter Determination

❹ Free and Forced Vortex

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❖ What is the definition of PRESSURE ?

- Pressure is defined as a normal force exerted by a fluid per unit area.
- *pressure only when we deal with a gas or a liquid and normal stress when deals with solids*

$$\textbf{Pressure} = \frac{force}{Area} = \frac{N}{m^2} = Pa$$

Blaise Pascal
French (1623-1662)

❖ Units of pressure (SI Units)

- *Pressure is Scalar quantity*

$$\frac{N}{m^2} = \frac{kg.m}{S^2.m^2} = \frac{kg.}{S^2.m} = ML^{-1}T^{-2}$$

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

Other units: mm H_2o, mm Hg

$$1kg_f / cm^2 = 9.8\ N / cm^2 = 9.8*10^4\ N / m^2 = 9.8*10^4\ Pa = 0.98\ bar \simeq 1\ bar$$

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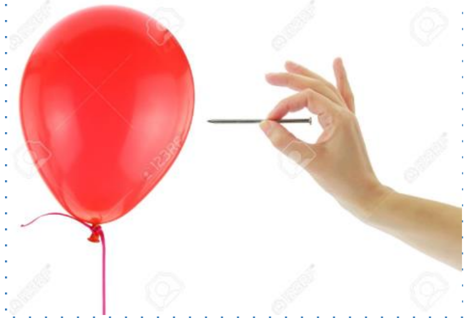
❖ *Which produces the greater pressure on the balloon, the bed of nails, or the single nail?*



Single Nail

Bed of Nails

➢ https://www.youtube.com/watch?v=BCG62iC7NZc

❖ Types of Pressure: Absolute, gage, and vacuum pressures

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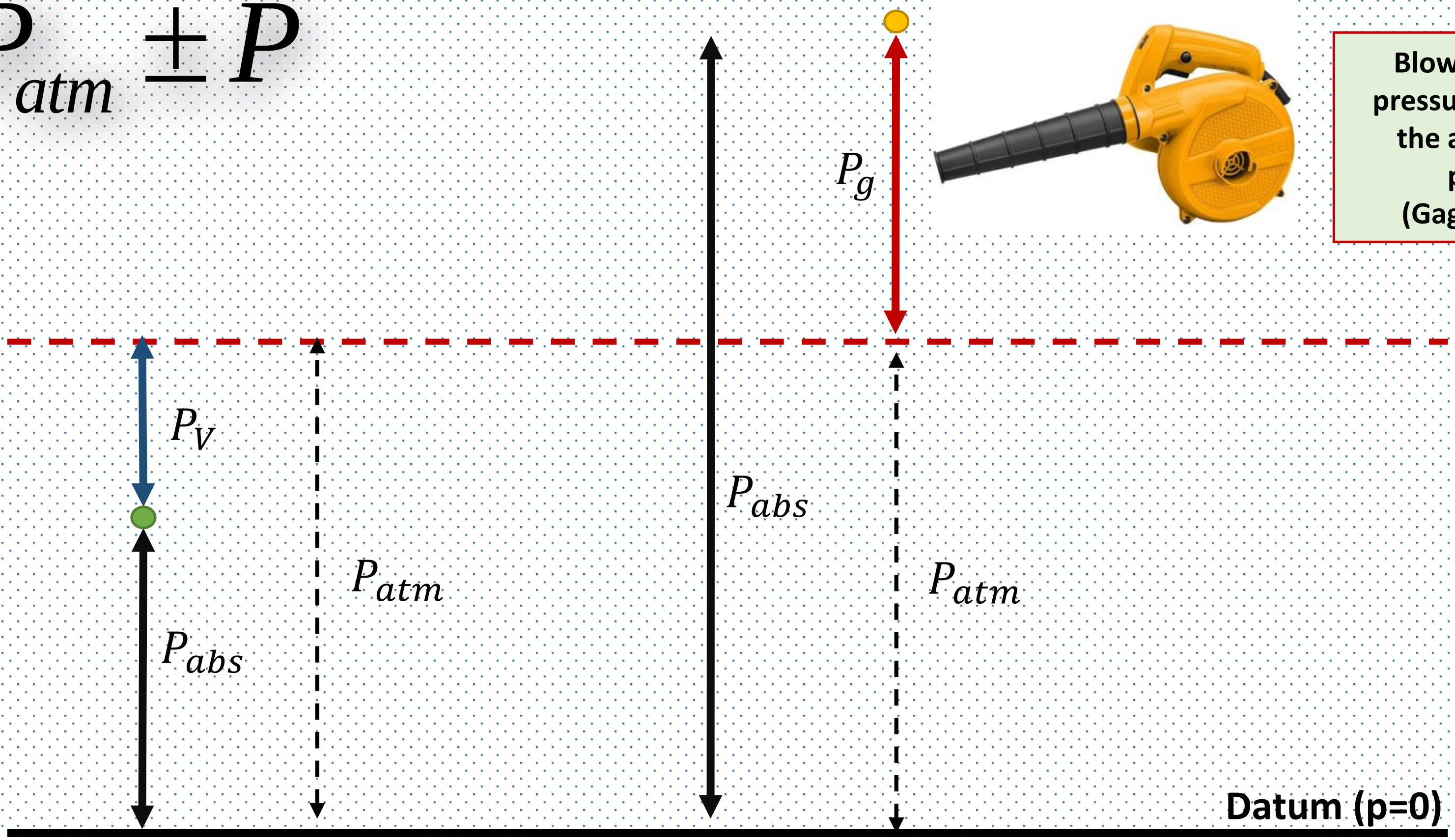
$$P_{abs} = P_{atm} \pm P$$

Vacuum cleaner produces less pressure than the atmospheric pressure (Vacuum Pressure)



Blower produces pressure larger than the atmospheric pressure (Gage Pressure)

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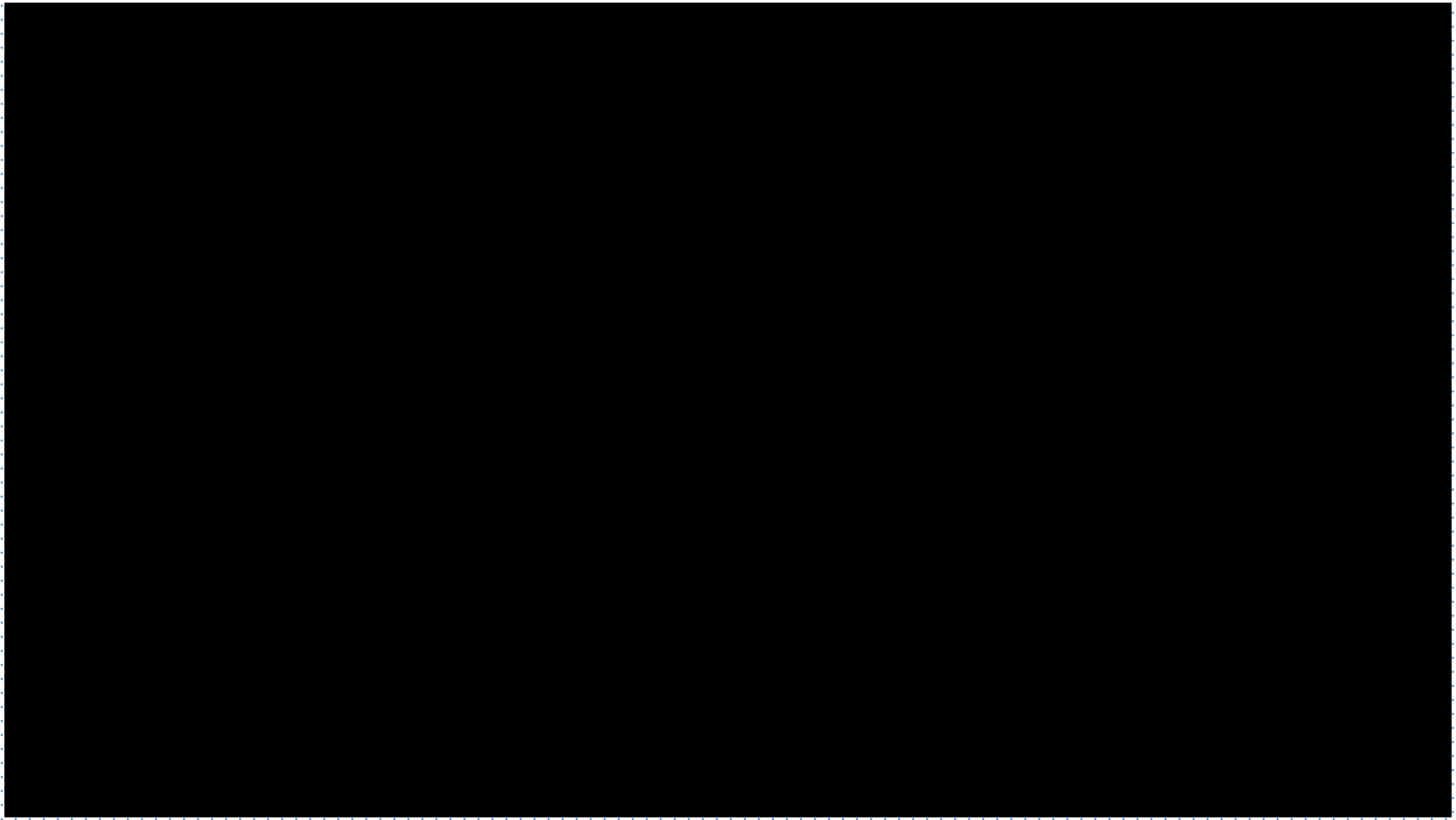
Pressure variation demonstrated with marshmallows (Boyle's Law)



$$P_1 V_1 = P_2 \ V_2$$

➢ https://www.youtube.com/watch?v=MsZOq-CnRgw

❖ Variation of Pressure with Depth

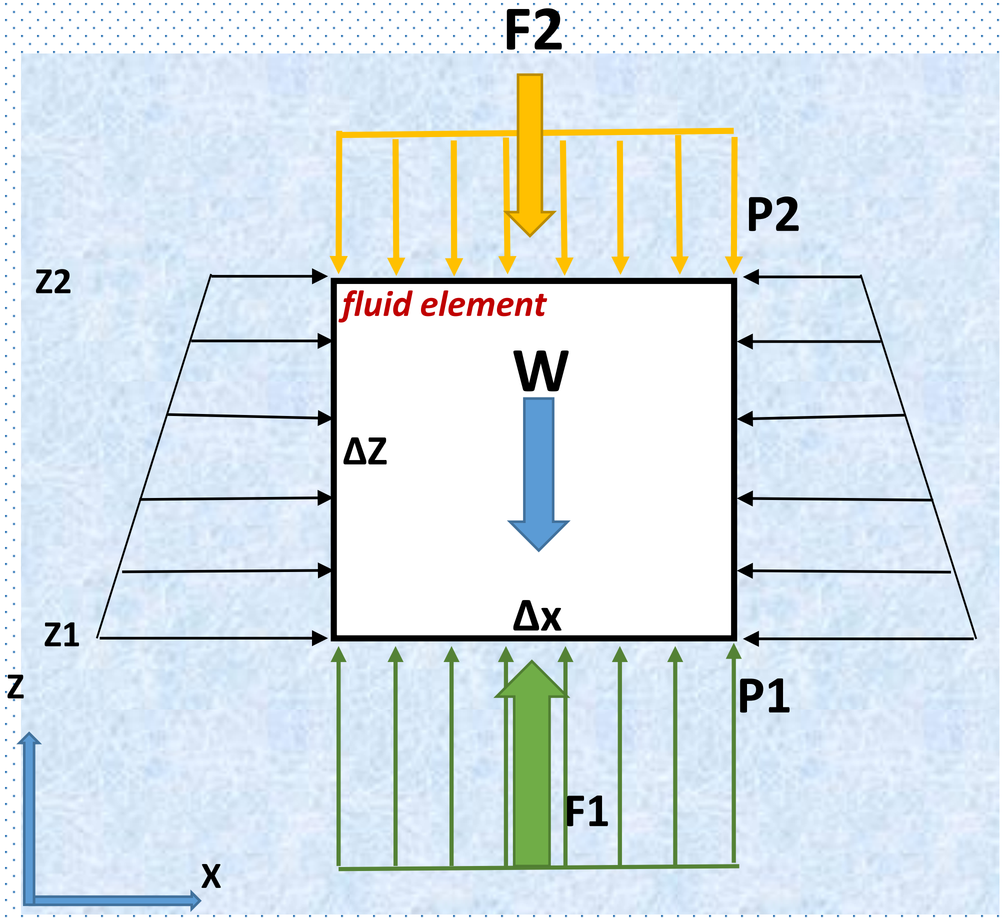
- consider a rectangular fluid element of height Δz, length Δx, and unit depth (Δy = 1 into the page) in equilibrium, as shown

$$\sum F_z = 0 \qquad F_1 - F_2 - w = 0$$

$$P_1(\Delta x\,\Delta y) - P_2(\Delta x\,\Delta y) - \rho g(\Delta x\,\Delta y\,\Delta z) = 0$$

$$P_1 - P_2 - \rho g(\Delta z) = 0$$

$$P_2 - P_1 = -\rho g(\Delta z) = -\gamma(\Delta z)$$



❑ Conclusion:

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

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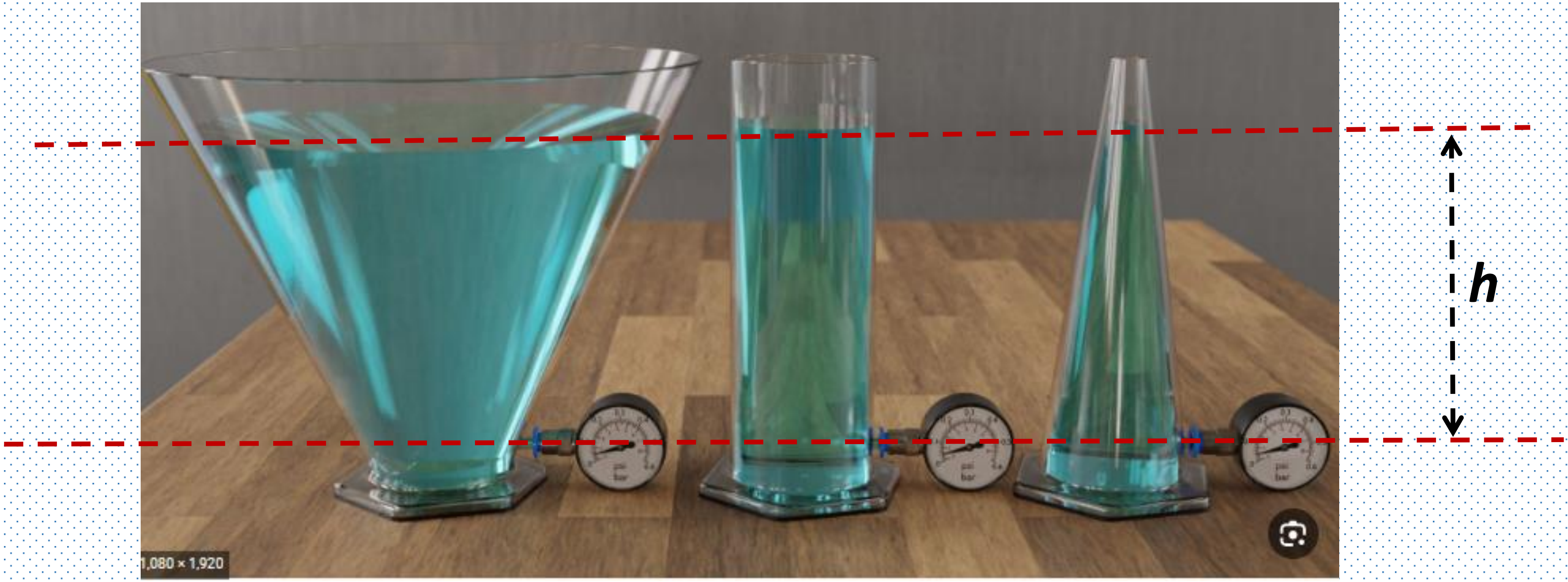
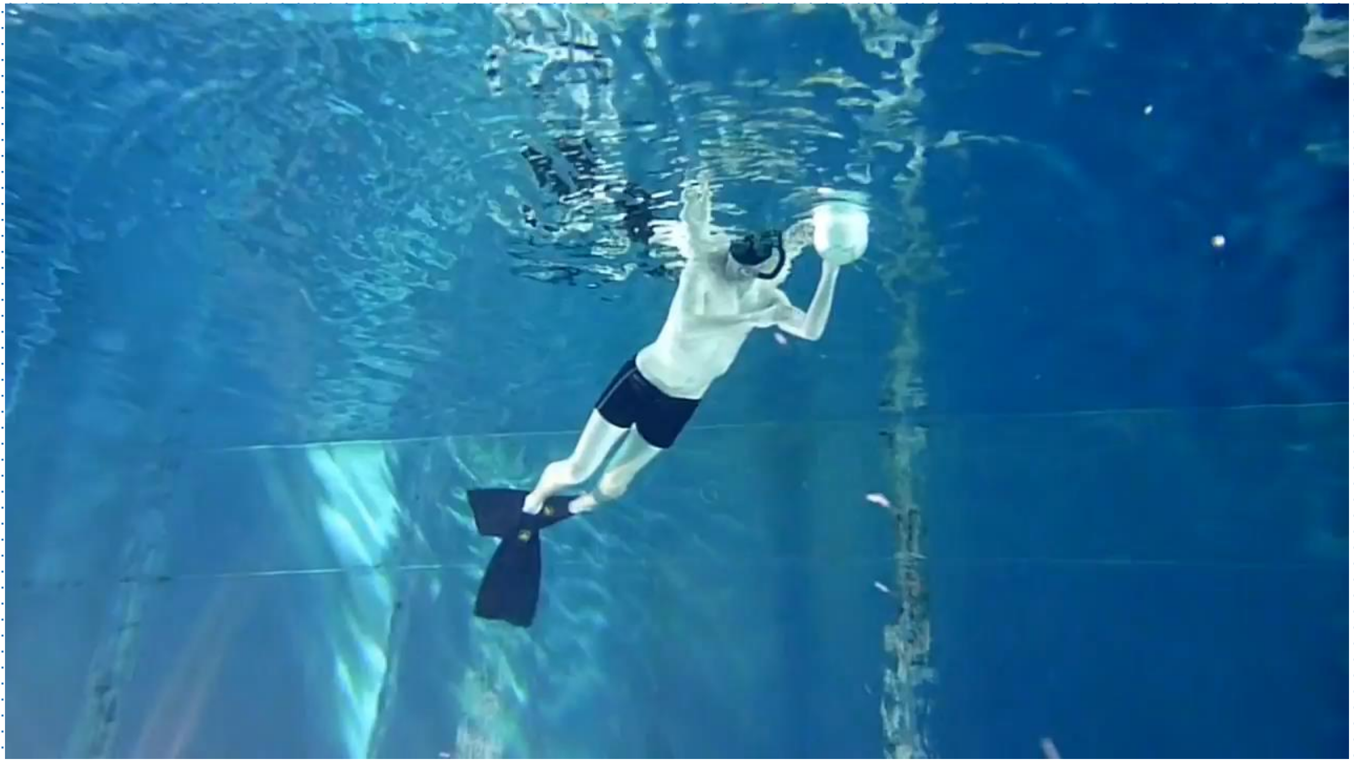
- **Under hydrostatic conditions, the pressure gauge gives the same reading at the bottom of each container at the same liquid and same level [h] from the free surface regardless of container geometry**



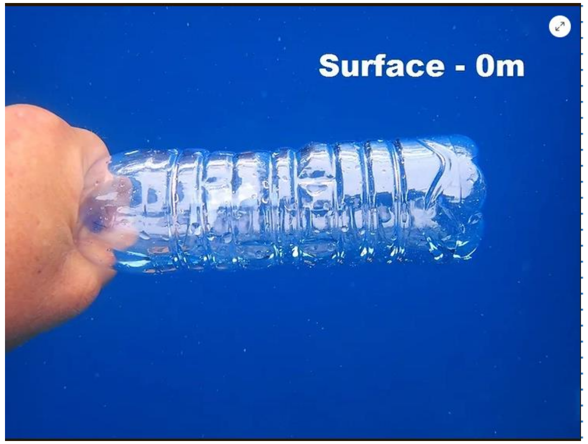
❖ Effects of water pressure on ball filled with air

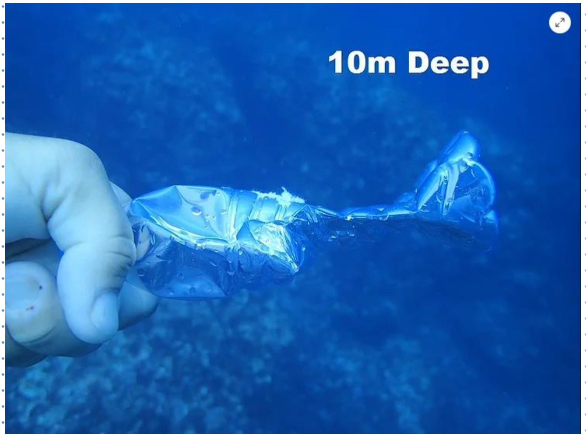
- As the ball goes deep into the water, the pressure increases and the volume of air inside the ball decreases, according to the equation:

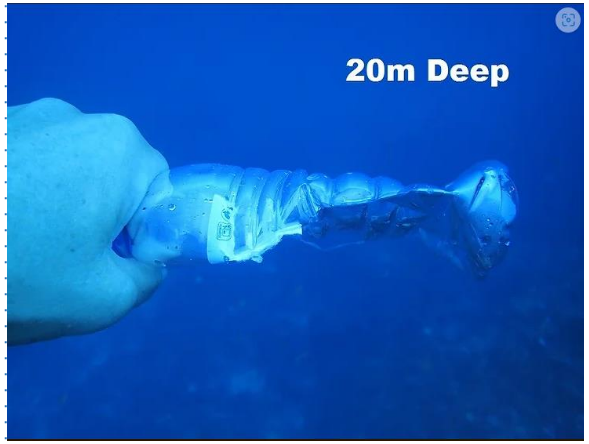


$$P_1 V_1 = P_2 \; V_2$$

➢ https://www.youtube.com/watch?v=dL08xX4lBQg







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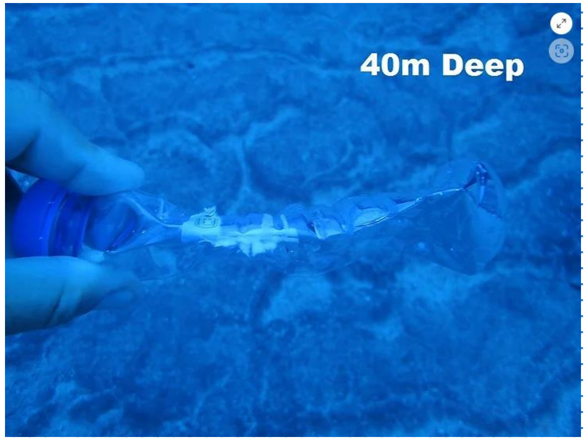
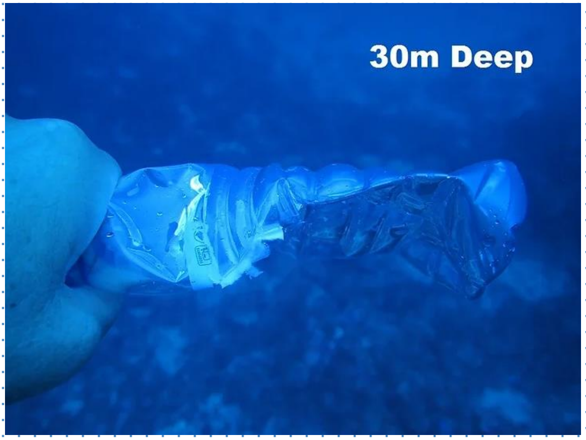
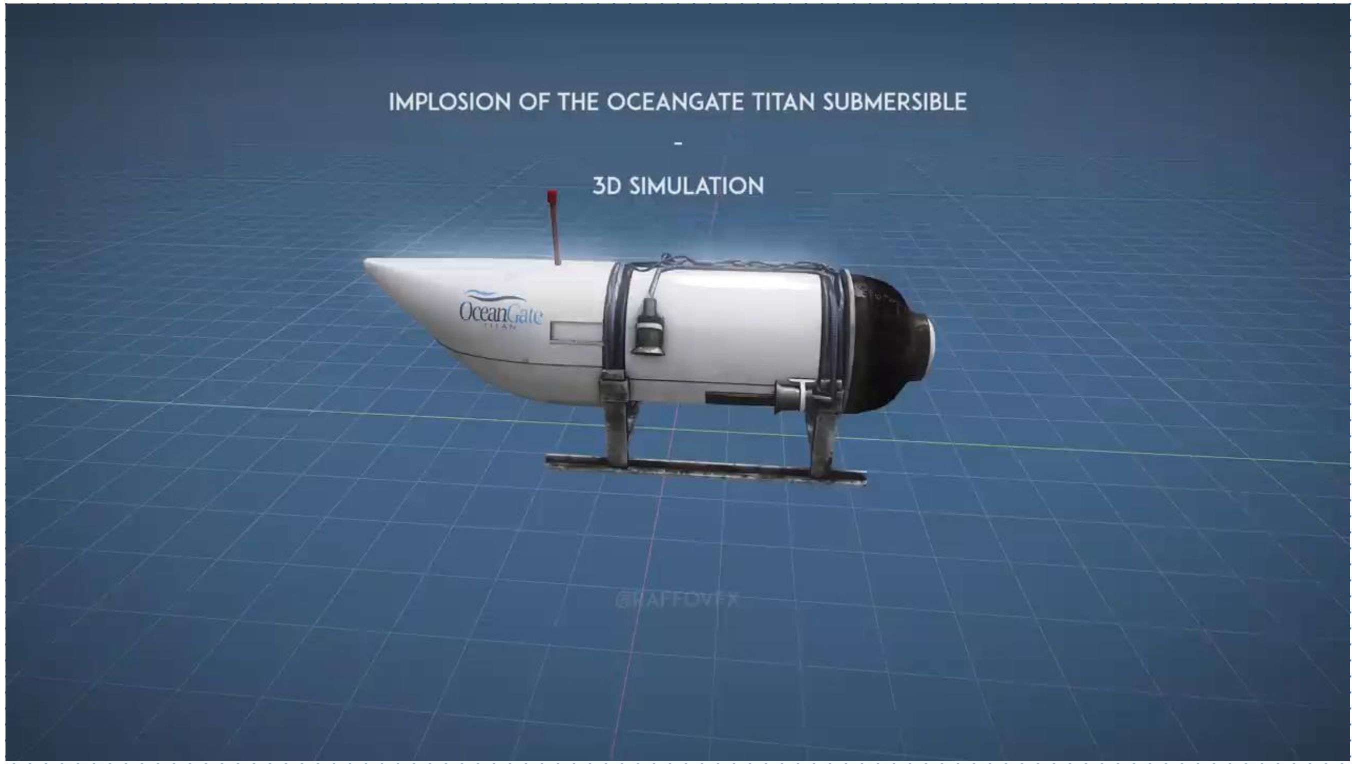




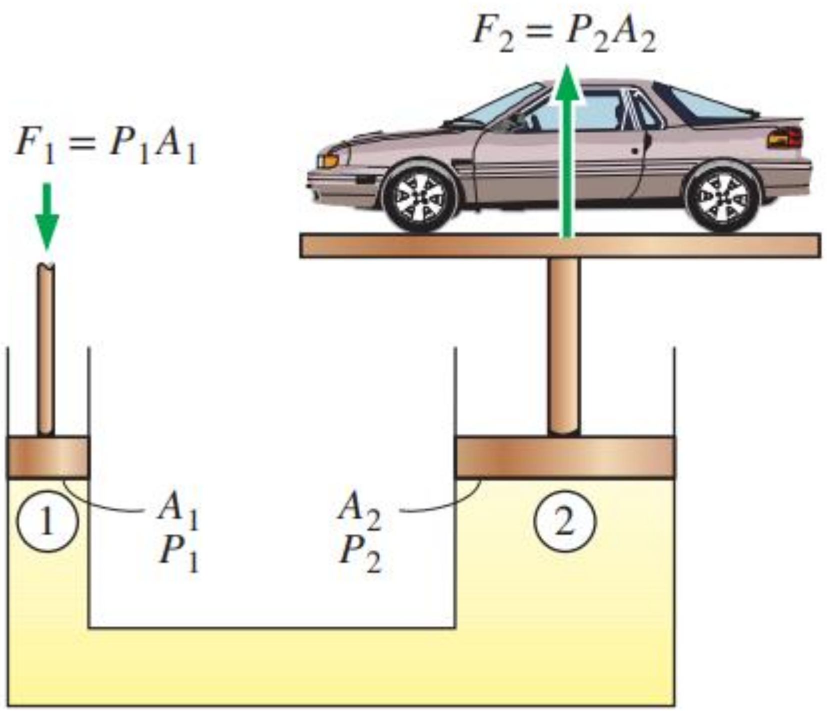
- ❖ **For Divers in deep water , could you imagine the breathing scenario? Explain and write your comment !**

❖ The Titan Submarine Implosion - 3d Simulation



- https://www.youtube.com/watch?v=oPJISUHY1kU

❖ Operation of a Hydraulic Jack



➢ https://www.youtube.com/watch?v=qGQ4fojjwvQ

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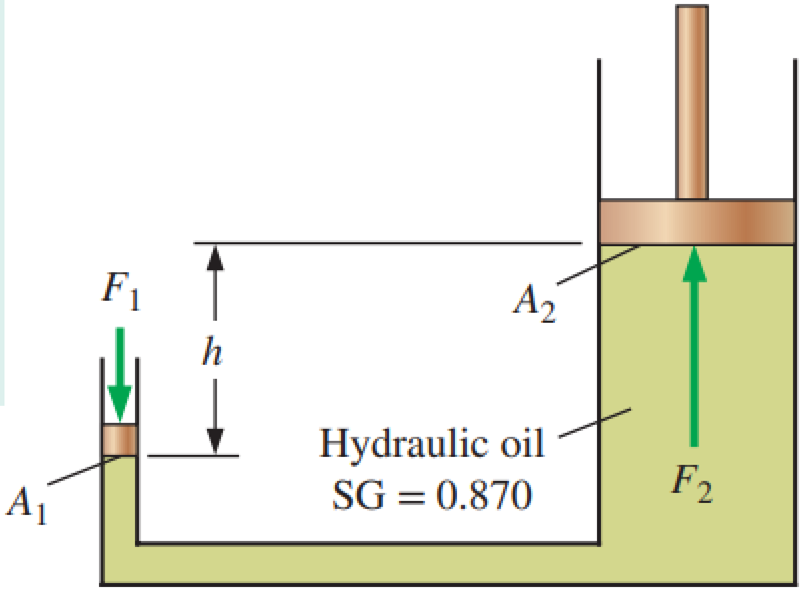
Example (1)

Operation of a Hydraulic Jack

Consider a hydraulic jack being used in a car repair shop, as in Fig. 3–12. The pistons have an area of $A_1 = 0.8\ \text{cm}^2$ and $A_2 = 0.04\ \text{m}^2$. Hydraulic oil with a specific gravity of 0.870 is pumped in as the small piston on the left side is pushed up and down, slowly raising the larger piston on the right side. A car that weighs 13,000 N is to be jacked up.
(*a*) At the beginning, when both pistons are at the same elevation ($h = 0$), calculate the force F_1 in newtons required to hold the weight of the car.
(*b*) Repeat the calculation after the car has been lifted two meters ($h = 2$ m). Compare and discuss.



Analysis (*a*) When $h = 0$, the pressure at the bottom of each piston must be the same. Thus,

$$P_1 = \frac{F_1}{A_1} = P_2 = \frac{F_2}{A_2} \rightarrow F_1 = F_2\frac{A_1}{A_2} = (13{,}000\ \text{N})\frac{0.8\ \text{cm}^2}{0.0400\ \text{m}^2}\left(\frac{1\ \text{m}}{100\ \text{cm}}\right)^2 = \mathbf{26.0\ N}$$

At the beginning, when $h = 0$, the required force is thus $F_1 = 26.0$ N.

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(*b*) When $h \neq 0$, the hydrostatic pressure due to the elevation difference must be taken into account, namely,

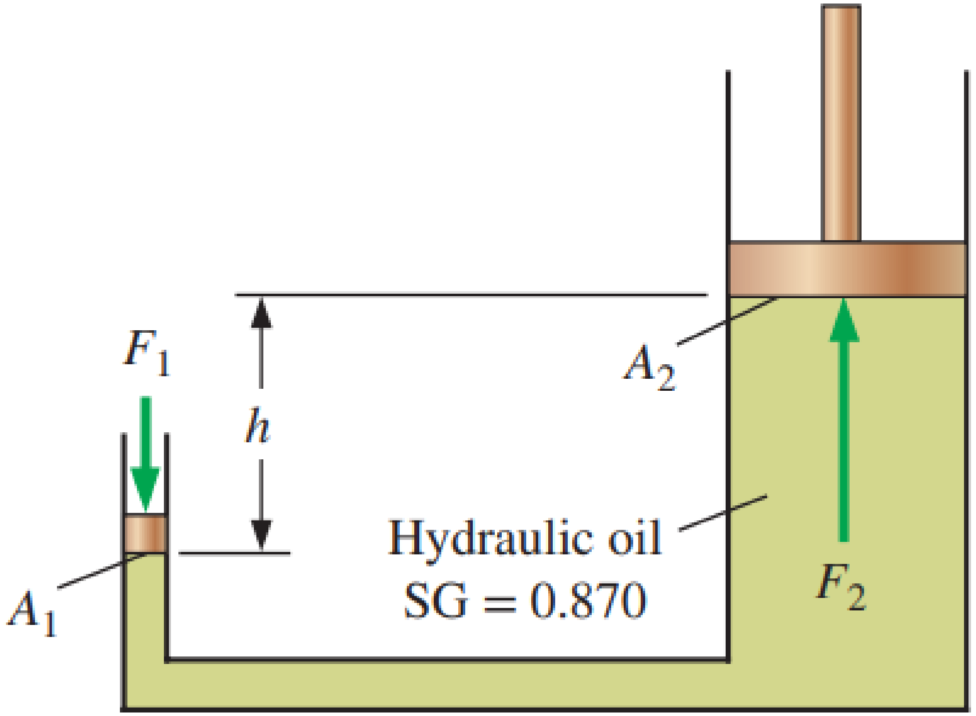
$$P_1 = \frac{F_1}{A_1} = P_2 + \rho g h = \frac{F_2}{A_2} + \rho g h$$

$$F_1 = F_2 \frac{A_1}{A_2} + \rho g h A_1$$

$$= (13{,}000 \text{ N}) \frac{0.00008 \text{ m}^2}{0.04 \text{ m}^2}$$

$$+ (870 \text{ kg/m}^3)(9.807 \text{ m/s}^2)(2.00 \text{ m})(0.00008 \text{ m}^2)$$

$$= \mathbf{27.4\ N}$$



❖ The Barometer

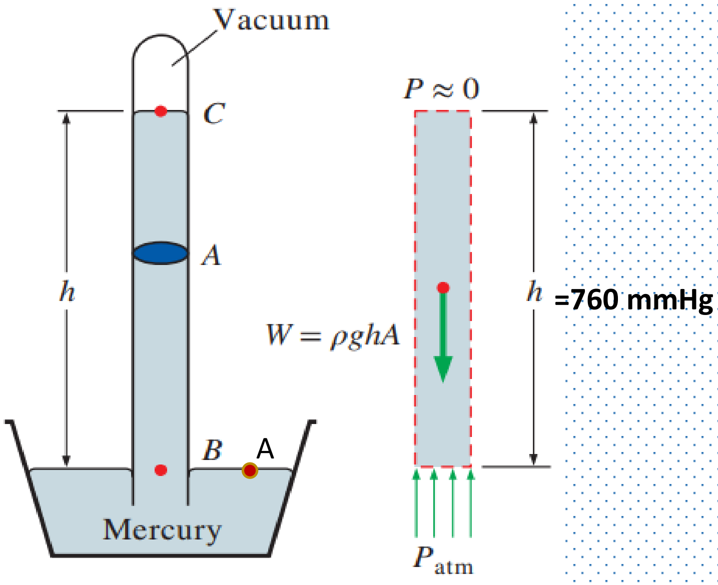
- The atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere.

Italian Evangelista Torricelli (1608–1647)

$$\because P_A = P_B \qquad \textit{Same Liquid Same Level}$$

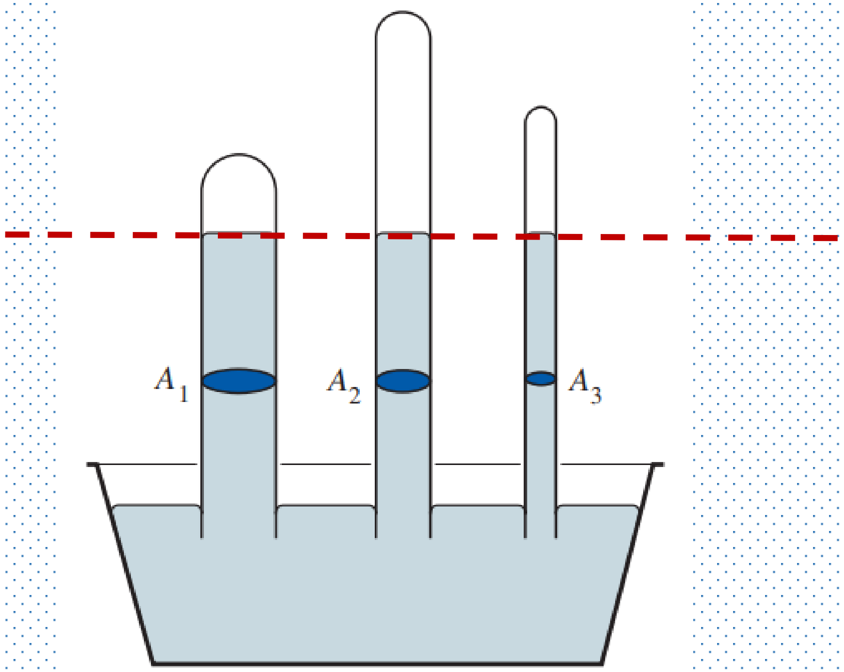
$$\therefore P_{atm} = \rho g h = (13600)(9.81)(76/1000)$$

$$= 101396.16\ Pa = 101.4 Kpa = 0.1014 Mpa$$



➢ ***The unit mmHg is also called the torr in honor of Torricelli.***

- Note that the length and the cross-sectional area of the tube have no effect on the height of the fluid column of a barometer, provided that the tube diameter is large enough to avoid surface tension (capillary) effects.



❖ Quiz

1- If water instead of mercury were used to measure the standard atmospheric pressure, what is the needed water column in meter?

❖ Heavy Newspaper !

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https://www.youtube.com/watch?v=7o8fhQximW0

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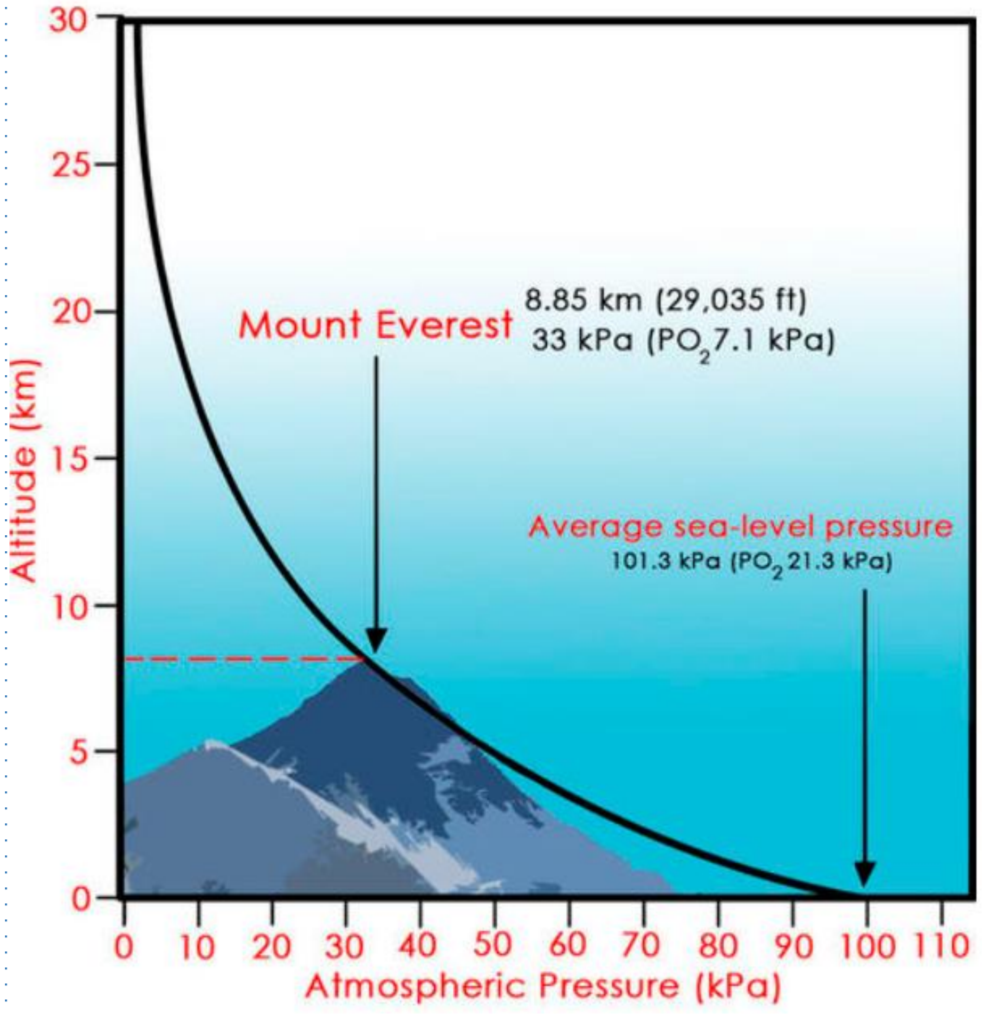
- Is the atmospheric pressure is constant at the same level all the times ? Comment on your answer.



$$\rho = \frac{P}{R.T}$$

❖ Effect of atmospheric pressure change on Airplanes

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1- why Airplanes need a longer runway at high altitudes?

Ans: To develop the required lift by increasing the velocity to compensate the reduction in the air density

$$F_L = (1/2)\,\rho\, u^2\, A\, C_L$$

Why Airplanes climb to very high altitudes for cruising ?

Ans: In order to reduce drag and thus achieve better fuel efficiency

$$F_D = (1/2)\,\rho\, u^2\, A\, C_D$$

❖ Relation between the pressure and boiling water

Boiling without heating ?

➢ https://www.youtube.com/watch?v=p4pniiO8ZaU

TABLE A-5

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific VOLUME, m³/kg: Sat. liquid, v_f	Specific VOLUME, m³/kg: Sat. vapor, v_g
1.0	6.97	0.001000	129.19
1.5	13.02	0.001001	87.964
2.0	17.50	0.001001	66.990
2.5	21.08	0.001002	54.242
3.0	24.08	0.001003	45.654
4.0	28.96	0.001004	34.791
5.0	32.87	0.001005	28.185
7.5	40.29	0.001008	19.233
10	45.81	0.001010	14.670
15	53.97	0.001014	10.020
20	60.06	0.001017	7.6481
25	64.96	0.001020	6.2034
30	69.09	0.001022	5.2287
40	75.86	0.001026	3.9933
50	81.32	0.001030	3.2403
75	91.76	0.001037	2.2172
100	99.61	0.001043	1.6941
101.325	99.97	0.001043	1.6734
125	105.97	0.001048	1.3750
150	111.35	0.001053	1.1594
175	116.04	0.001057	1.0037
200	120.21	0.001061	0.88578
225	123.97	0.001064	0.79329
250	127.41	0.001067	0.71873
275	130.58	0.001070	0.65732

❖ Cavitation

➢ https://www.youtube.com/watch?v=T7w6PbnRrxI

❖ Pressure Measurement Devices

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❑ Manometers (Gravity-based)

A- Simple Manometers

- Piezometer Tube
- Single Column Manometers
  - U Tube
  - Inclined

B- Differential Manometers

- U-Tube
- Inverted

❑ Pressure Gauges (Elastic deformation)

A- Bourdon Tube

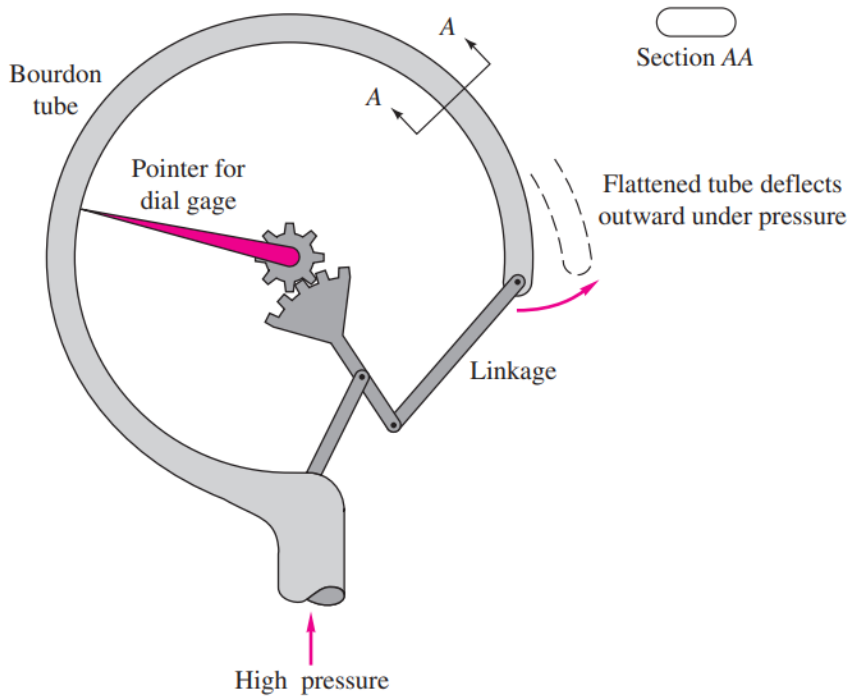
- C- Type
- Helical
- Spiral

B- Diaphragm pressure gauge

C- Bellows pressure gauge

❖ Pressure Measurement Devices

A- Pressure Gage (Bourdon tube- C Type)



Internal mechanism (schematic)

French engineer and inventor Eugene Bourdon (1808–1884)

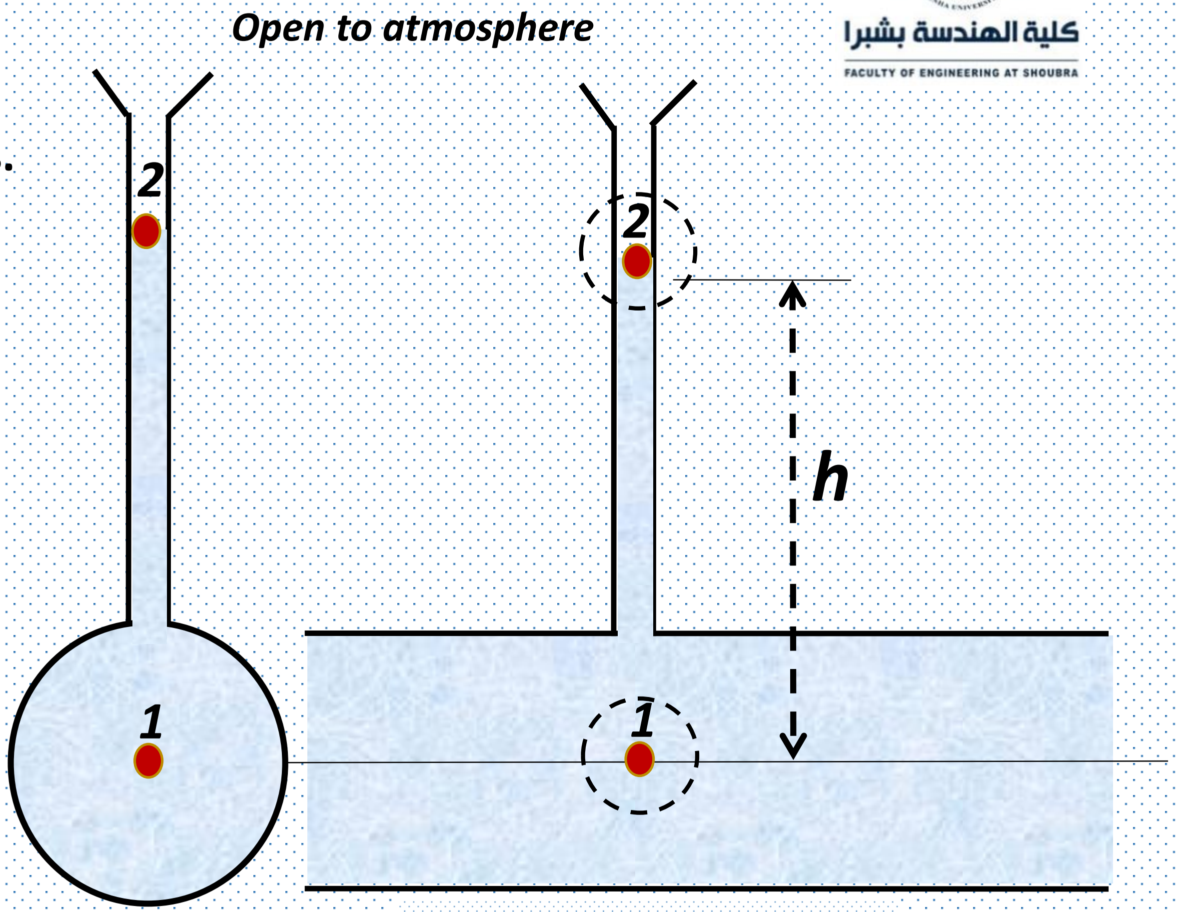
- https://www.youtube.com/watch?v=nE_n1lCuz30

- **For the Other types of Bourdon Tubes :***https://www.youtube.com/watch?v=p23u0HLOkwU*

Simple Manometers

1 Piezometer Tube

- The Piezometer is the simplest forms of manometers.
- Used to measure a moderate pressure of liquids.
- It is a glass tube inserted perpendicular to the wall.
- Extended vertically to a specific height so the liquid can freely rise without overflowing.



$$[P_1]_{abs} = \rho g h + P_2$$

$$[P_1]_{gage} = \rho g h = \gamma h$$

Limitation of Piezometers

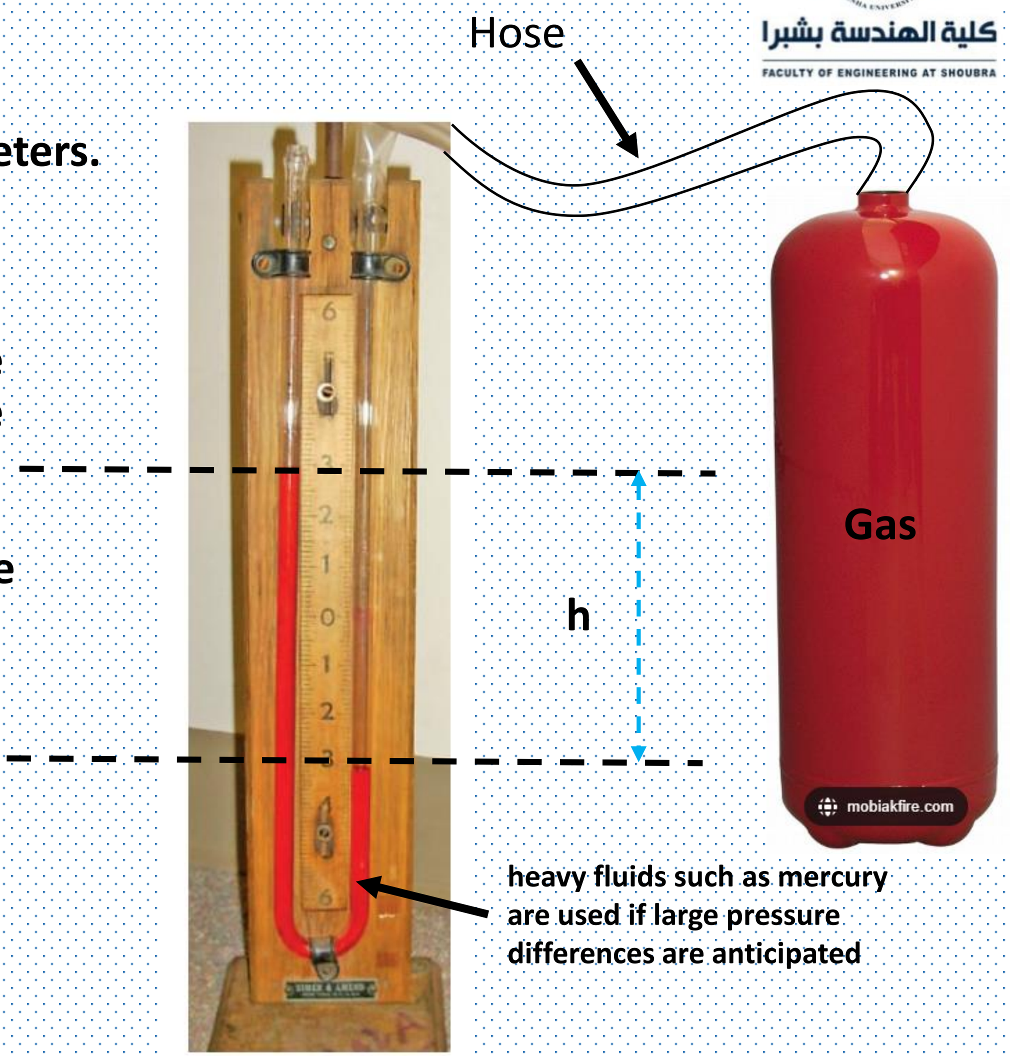
- Can only measure gauge pressure
- Not used in measuring gas pressure
- Can not measure large pressures
- For light liquids required a long tube

❖ Simple Manometers

❷ Single Column Manometer (U-Tube)

- It can be used to overcome the limitation of the Piezometers.
- It consists of a glass tube folded like the Letter U.
- In this type of manometers , one end is attached to the point where the pressure is to be measured and the other end is open to the atmospheric pressure.
- The tank pressure is represented by the difference in the manometer height (h)

$$P_{gas} = P_{atm} + \rho_{Manometer} gh$$



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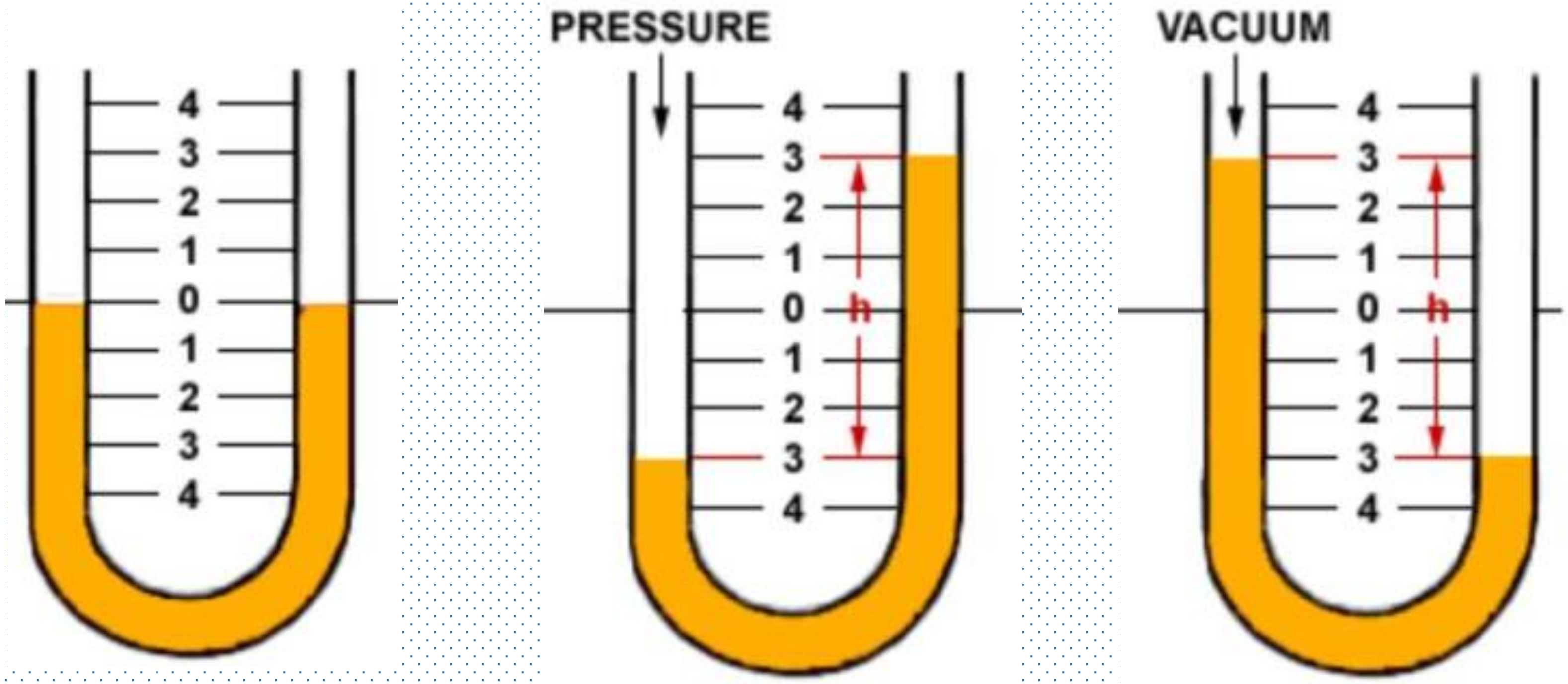
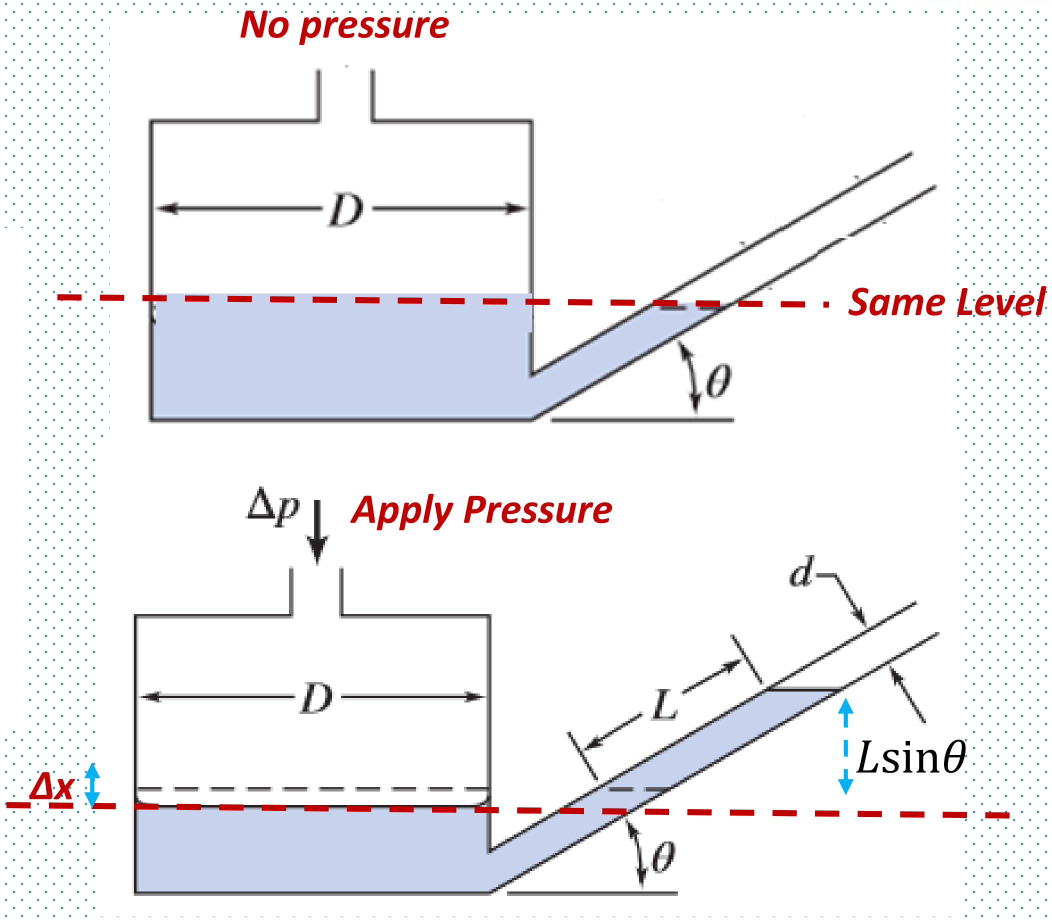


❖ Simple Manometers

Single Column Manometer (Inclined- Slant)

- Is used with small pressure difference

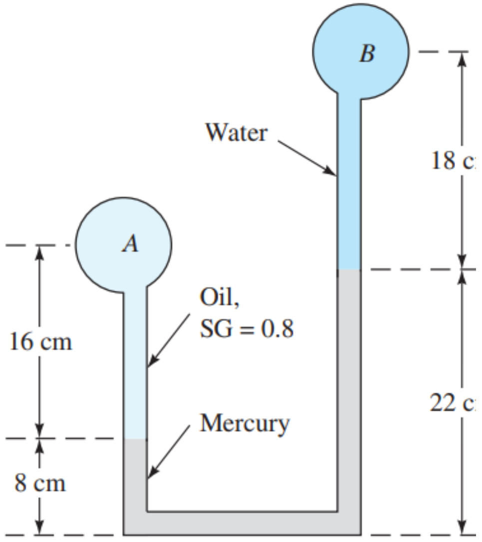


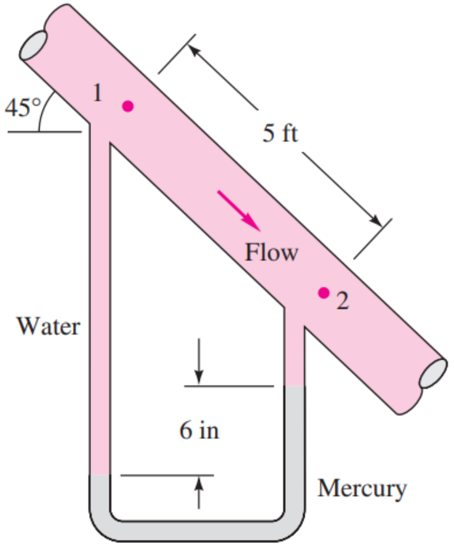
$$\Delta P = \rho g.(L\sin\theta + \Delta x)$$

❖ B- Differential Manometer

❑ U-tube

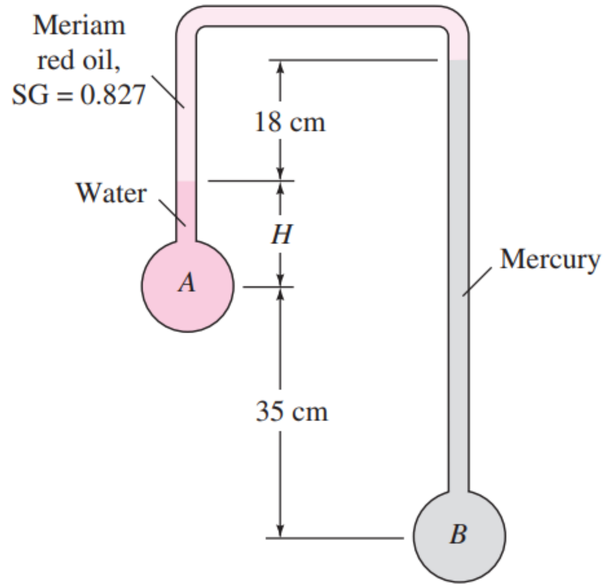
- Is used to measure the pressure difference between two points





❑ Inverted U-tube

- Inverted U-tube differential manometer will be used for measuring the vacuum pressure.
- Inverted U-tube differential manometer will have one inverted U-tube contained with light liquid.



Example (2) Measuring Pressure with a Manometer

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, as shown in Fig. 3–21. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.

SOLUTION The reading of a manometer attached to a tank and the atmospheric pressure are given. The absolute pressure in the tank is to be determined.

Assumptions The density of the gas in the tank is much lower than the density of the manometer fluid.

Properties The specific gravity of the manometer fluid is given to be 0.85. We take the standard density of water to be 1000 kg/m^3.

Analysis The density of the fluid is obtained by multiplying its specific gravity by the density of water,

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

Then from Eq. 3–13,

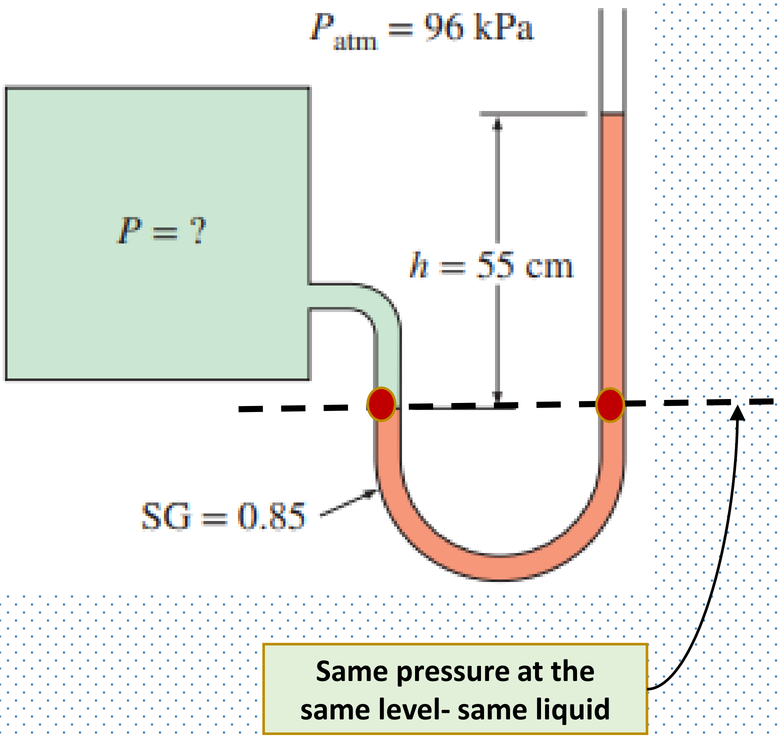
$$P = P_{atm} + \rho g h$$

$$= 96\ \text{kPa} + (850\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.55\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg·m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right)$$

$$= \mathbf{100.6\ kPa}$$

Discussion Note that the gage pressure in the tank is 4.6 kPa.

- ***Why we did not use a piezometer to measure the pressure in the tank?***



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Example (3)

The pressure difference between an oil pipe and water pipe is measured by a double-fluid manometer, as shown in Fig. P3–50. For the given fluid heights and specific gravities, calculate the pressure difference $\Delta P = P_B - P_A$.

❖ ***Remember the following when dealing with manometer problem***

+ ρ g h — Down

- ρ g h — Up

$$\gamma = (\gamma_w) * (S.G)$$

$$P_A + \gamma_w(0.55m) + \gamma_w(13.5)(0.2) - \gamma_w(1.26)(0.42) + \gamma_w(0.88)(0.1) = P_B$$

$$\Delta P = P_B - P_A = 27554.32\ N/m^2$$

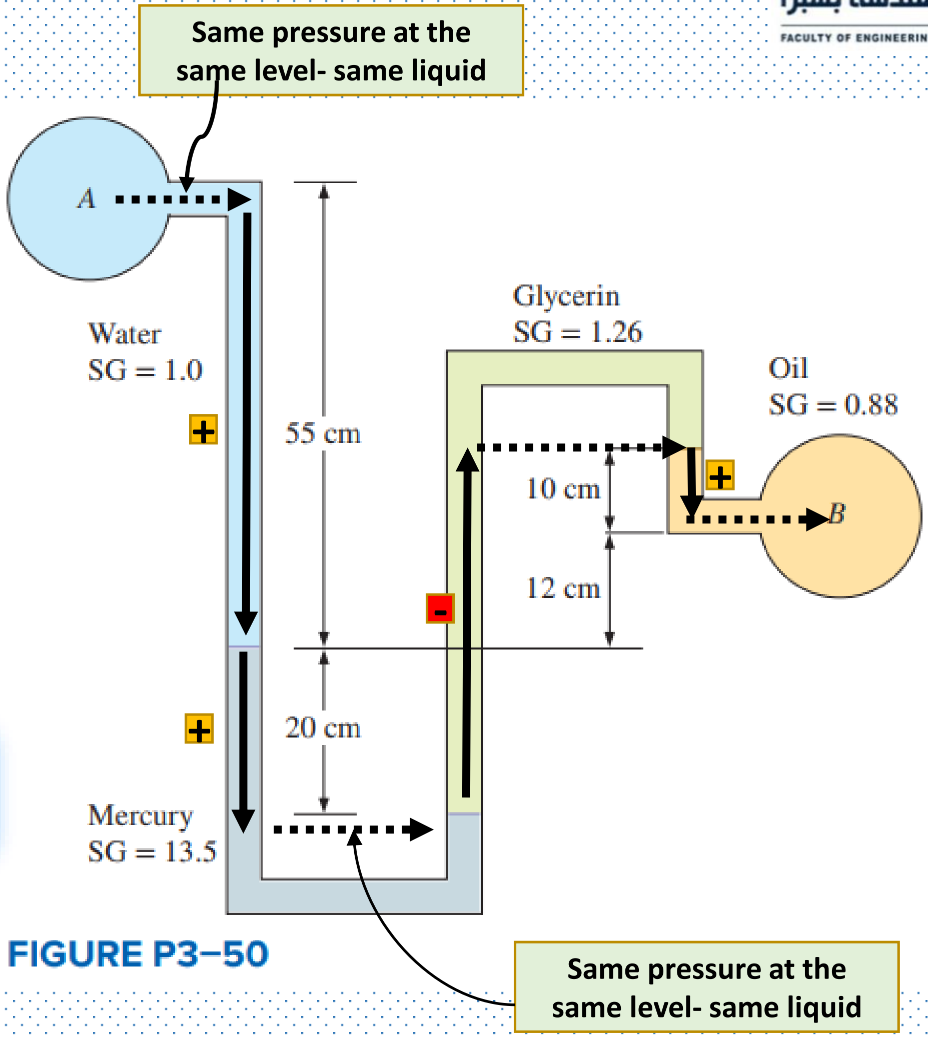
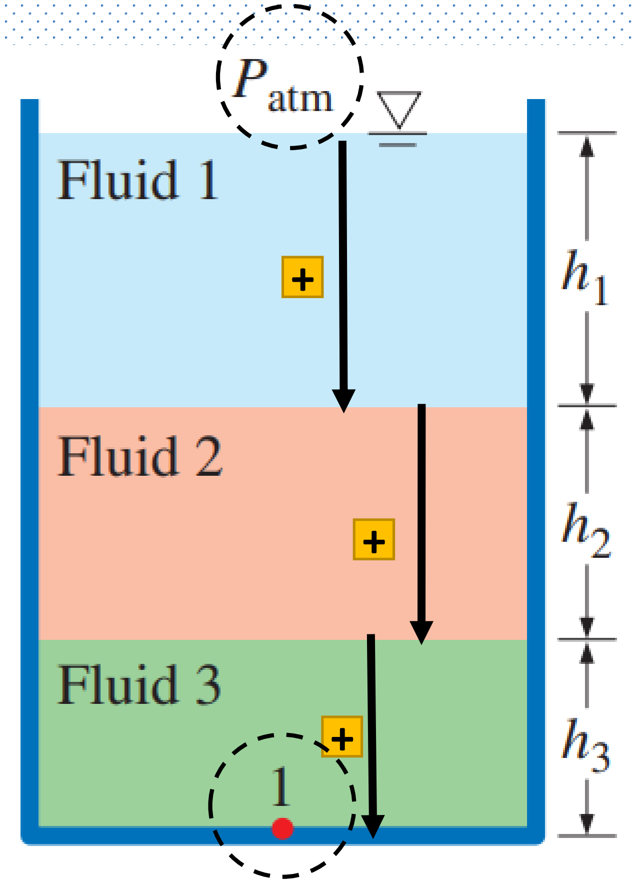


FIGURE P3–50

Example (4)

- Find the absolute pressure at bottom of the shown tank?

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



Example (5)

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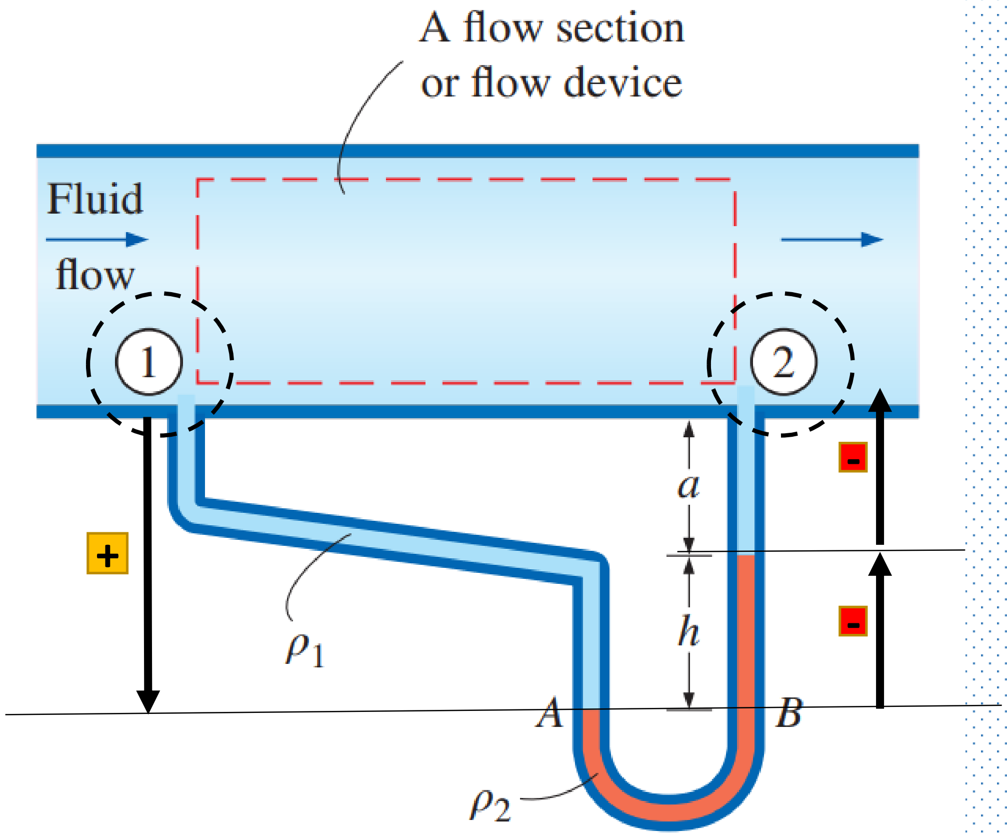
❖ Write down the equation of the shown differential manometer between point 1 and 2

$$P_1 + \rho_1 g(a+h) - \rho_2 gh - \rho_1 ga = P_2$$



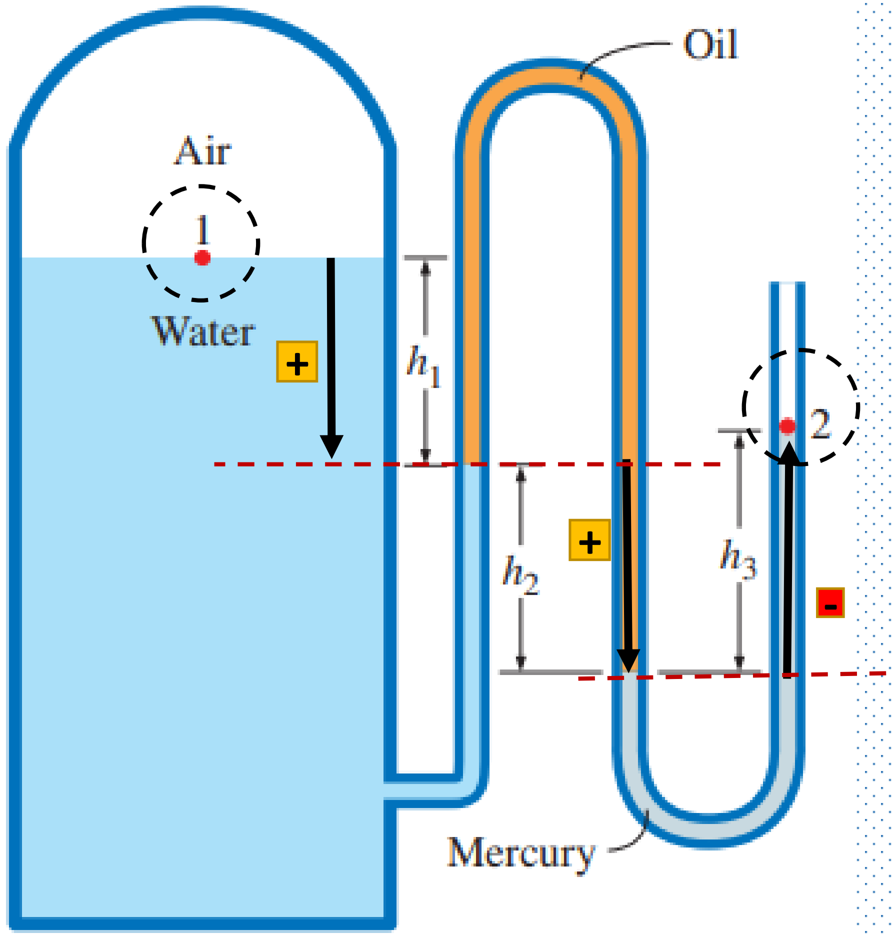
Example (6) Measuring Pressure with a Multifluid Manometer

The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in Fig. 3–24. 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 13,600 kg/m³, respectively.

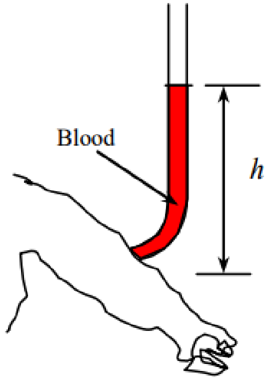
$$P_1 + \rho_{water} g h_1 + \rho_{oil} g h_2 - \rho_{mercury} g h_3 = P_2 = P_{atm}$$

Solving for P_1 and substituting,

$$\begin{aligned} P_1 &= P_{atm} - \rho_{water} g h_1 - \rho_{oil} g h_2 + \rho_{mercury} g h_3 \\ &= P_{atm} + g(\rho_{mercury} h_3 - \rho_{water} h_1 - \rho_{oil} h_2) \\ &= 85.6 \text{ kPa} + (9.81 \text{ m/s}^2)[(13{,}600 \text{ kg/m}^3)(0.35 \text{ m}) - (1000 \text{ kg/m}^3)(0.1 \text{ m}) \\ &\quad - (850 \text{ kg/m}^3)(0.2 \text{ m})]\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right) \\ &= \mathbf{130 \text{ kPa}} \end{aligned}$$



Example (7) The maximum blood pressure in the upper arm of a healthy person is about **120 mmHg**. If a vertical tube open to the atmosphere is connected to the **vein** in the arm of the person, ***determine how high the blood will rise in the tube***. Take the density of the blood to be **1040 kg/m3**



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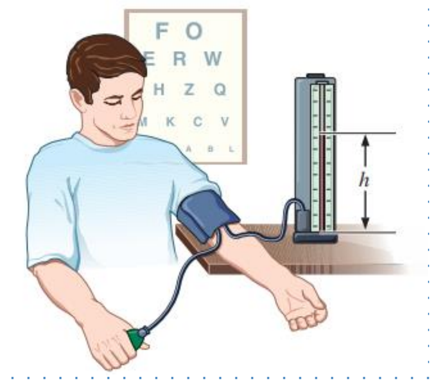
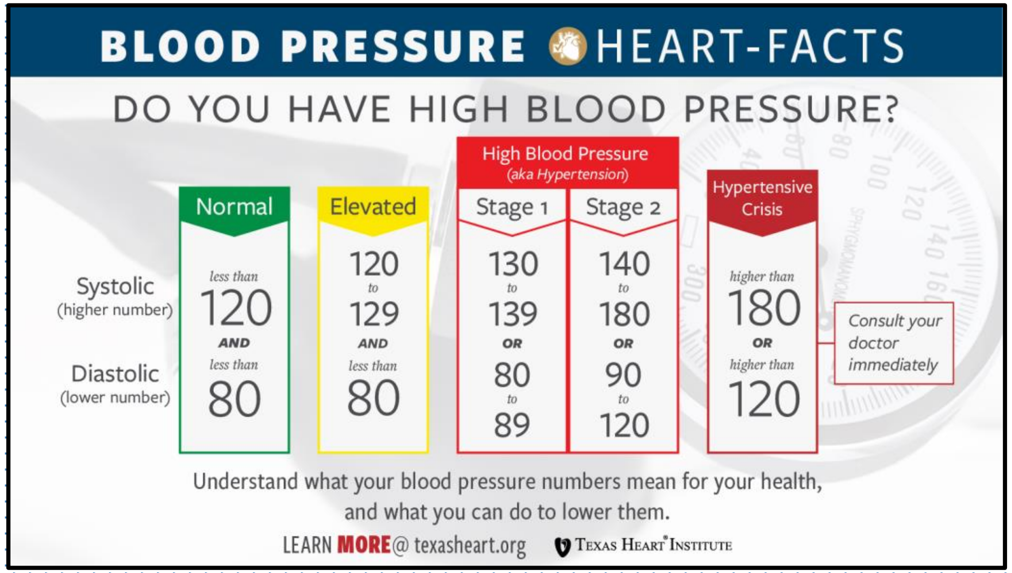
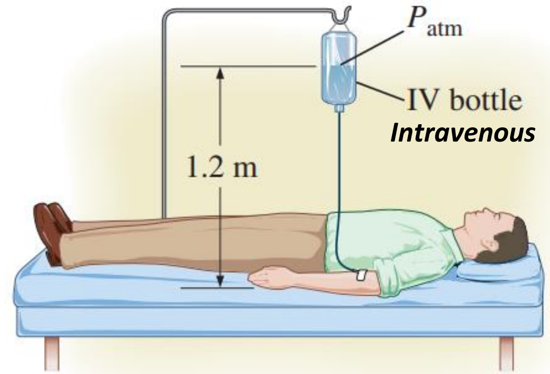




$$P = \rho_{\text{blood}} g h_{\text{blood}} = \rho_{\text{mercury}}\, g h_{\text{mercury}}$$

$$h_{\text{blood}} = \frac{\rho_{\text{mercury}}}{\rho_{\text{blood}}} h_{\text{mercury}} = \frac{13{,}600\ \text{kg/m}^3}{1040\ \text{kg/m}^3}(0.12\ \text{m}) = \mathbf{1.57\ m}$$

Note that the blood can rise about one and a half meters in a tube connected to the vein. This explains why IV tubes must be placed high to force a fluid into the vein of a patient.



❖ Lab Experiment no. 1 Bourdon Tube Calibration

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- **Objective:** To calibrate a Bourdon pressure gauge using a dead weight tester and determine the gauge error for increasing and decreasing pressure

1- Remove the piston from the apparatus and fill the cylinder with water to above the overflow hole (see Figure)

2- Remove any air bubbles from the transparent tube by tilting and tapping the apparatus

3- Position the apparatus on a bench and replace the piston. Make sure that the apparatus is absolutely level.

4- Gently rotate the piston to prevent it sticking in the cylinder, then record the Bourdon gauge reading.

5- Add weights to the piston in convenient increments and at each increment, record the gauge reading and the load on the piston.

6- Now, successively remove the weights from the piston and take readings as before so that you obtain results from decreasing pressure

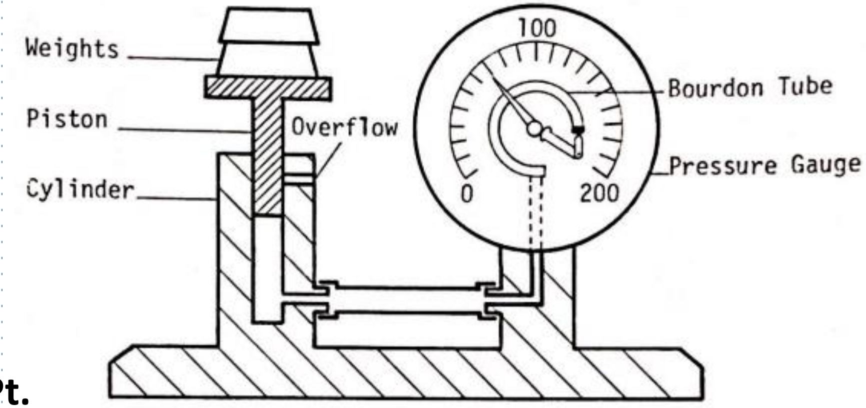
7- record the cross sectional area (a) and the weight W1 of the piston.

8- calculate the values of the true pressure Pt as

$$P_t = \frac{W \times 9{,}81}{a} \times 10^{-3} \quad kN/m^2$$

9- Plot graphs of gauge reading P against true pressure Pt for increasing and decreasing pressure.

10- obtain values of the gauge error (P-Pt) and plot a graph of gauge error against Pt.



❖ Report

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- **Required a report included the different types of pressure measurement instruments**
- **Pressure measurement instruments may be grouped into four categories as stated below:**

1. Gravity-based
2. Elastic deformation
3. Gas behavior
4. Electric output

❖ **(Deadline: Oral exam day on week no.14)**

Thank you