FLUID MECHANICS I

SEMM 2313

PRESSURE

INTRODUCTION

In this chapter we will consider an important class of problems in which the fluid is either at rest or moving in such a manner that there is no relative motion between adjacent particles.

In both instances there will be no shearing stresses in the fluid, and the only forces that develop on the surfaces of the particles will be due to the pressure.

The absence of shearing stresses greatly simplifies the analysis

There are no shearing stresses present in a fluid at rest.

PRESSURE

The term pressure is used to indicate the normal force per unit area at a given point acting on a given plane within the fluid mass of interest.

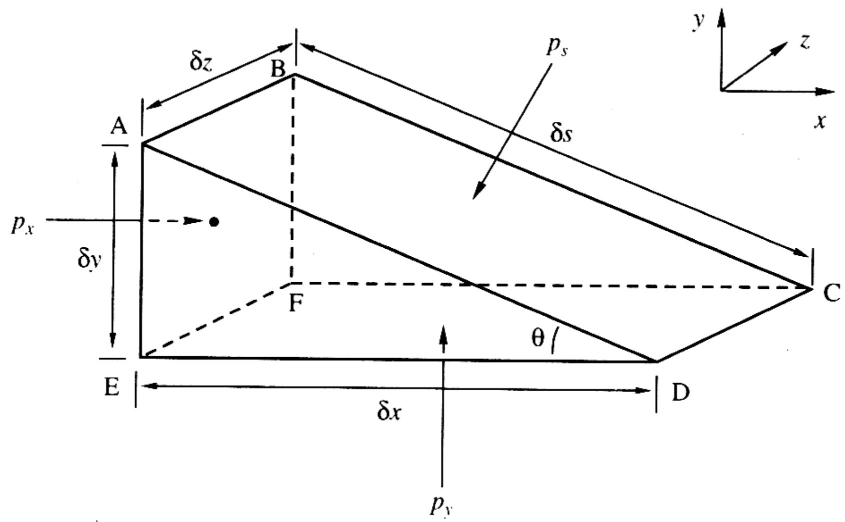
The equations of motion (Newton's second law, ($F = ma$) in the y and z directions are, respectively.

PASCAL'S LAW FOR PRESSURE AT A POINT

By considering the equilibrium of a small fluid element in the form of a triangular prism surrounding a point in the fluid, as shown below, a relationship can be established between the pressure p_x in the *x*-direction, p_y in the *y*-direction and p_s normal to any plane inclined at any angle to the horizontal at this point.

If the fluid is at rest, p_x will act at right angles to the plane ABFE, p_y at right angles to CDEF and p_s at right angle to ABCD.

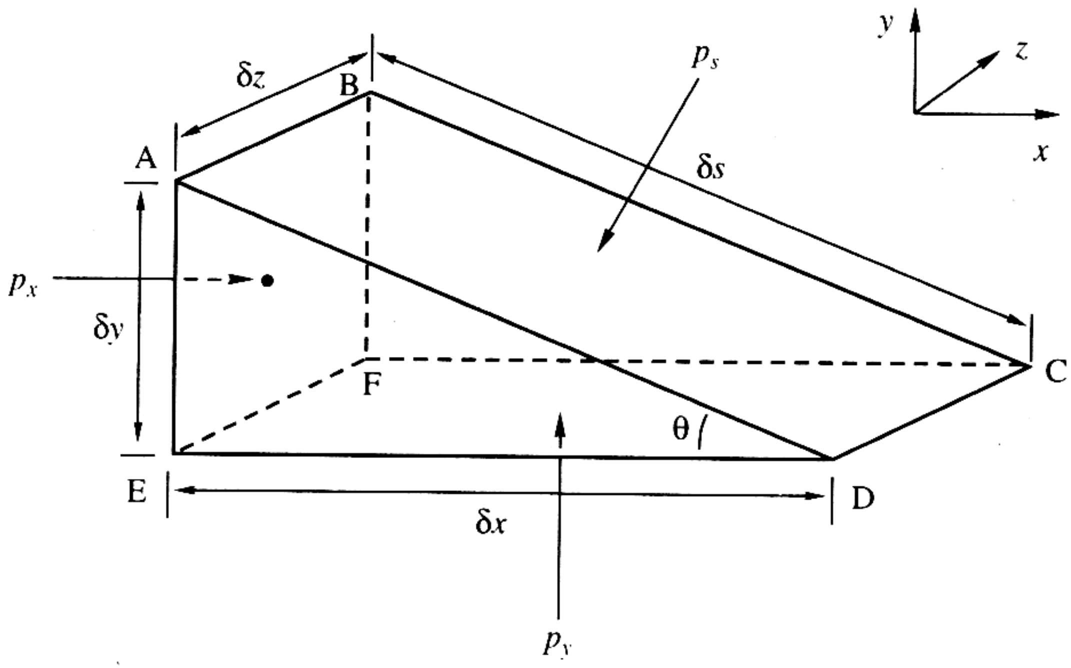
Equality of pressure in all directions at a point



Since the fluid is at rest, there will be no shearing forces on the faces of the element and the element will not be accelerating.

The sum of the forces in any direction must, therefore, be zero.

Equality of pressure in all directions at a point



Considering the x-direction :

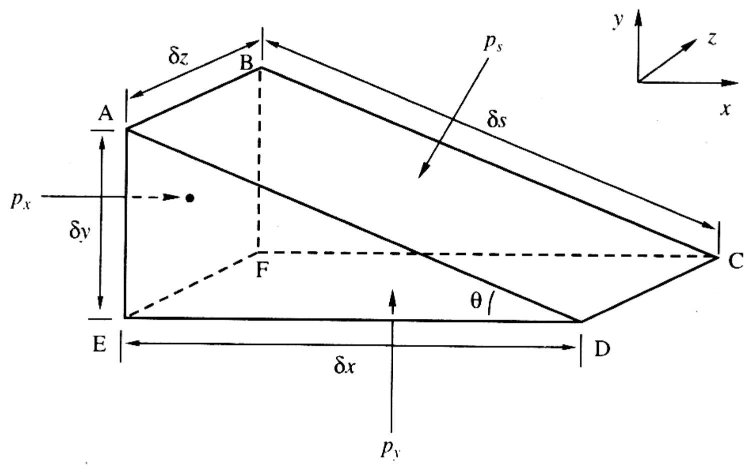
Force due to $F_x = p_x \times (area\ ABFE) = p_x \delta y \delta z$

Component of force due to $F_{s-x} = p_s \times (area\ ABCD) \sin\theta$

$$\sin\theta = \frac{\delta y}{\delta s}$$

$$F_{s-x} = p_s \times \delta z \times \delta s \times \frac{\delta y}{\delta s} = p_s \times \delta z \times \delta y$$

Equality of pressure in all directions at a point



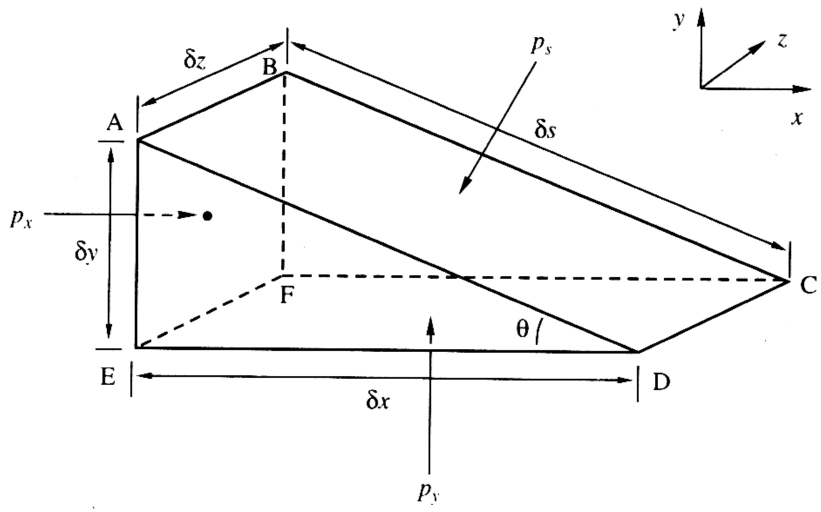
As p_y has no compound in the x-direction.

The element will be in equilibrium if :

$$p_x \delta y \delta z = p_s \delta y \delta z$$

$$p_x = p_s$$

Equality of pressure in all directions at a point



<u>Similarly in y-direction :</u>

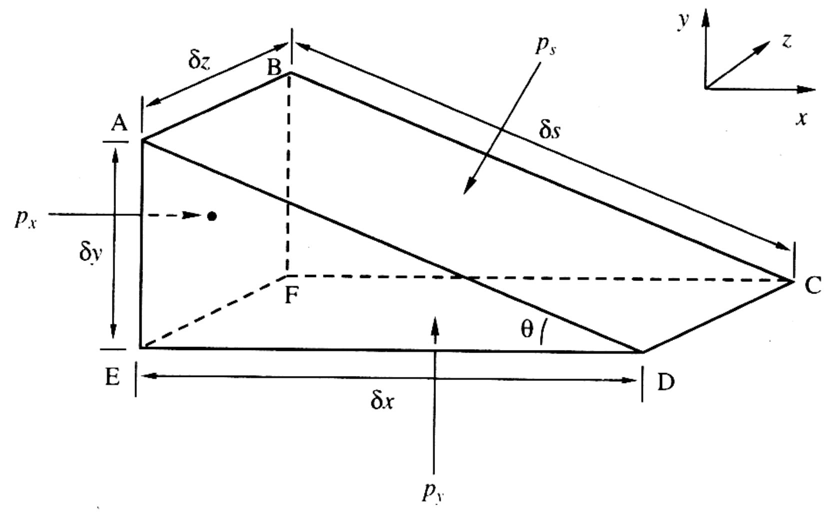
Force due to $F_y = p_y \times area\ CDEF = p_y \delta x \delta z$

Component of force due to $F_{s-y} = p_s \times (area\ ABCD) \cos\theta =$

$$\cos\theta = \frac{\delta x}{\delta s}$$

$$F_{s-y} = p_s \times \delta z \times \delta s \times \frac{\delta x}{\delta s} = p_s \times \delta z \times \delta x$$

Equality of pressure in all directions at a point



Weight of element

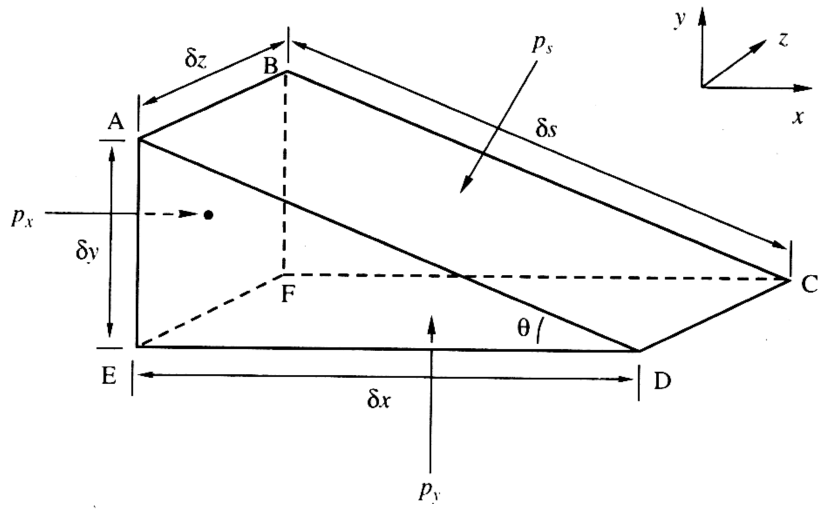
$$W = mg = \rho g \times (Volume) = \rho g \times \frac{1}{2}\delta x \delta y \delta z$$

As p_x has no component in the y-direction.

The element will be in equilibrium if ;

$$p_y \delta x \delta z = p_s \delta z \delta x + \rho g \frac{1}{2}\delta x \delta y \delta z$$

Equality of pressure in all directions at a point



Since δx, δy and δz are all very small quantities, $\delta x \delta y \delta z$ is negligible in comparison with the other two terms, and the equation reduces to:

$$p_y = p_s$$

Now, we can conclude that ;

$$p_x = p_y = p_s$$

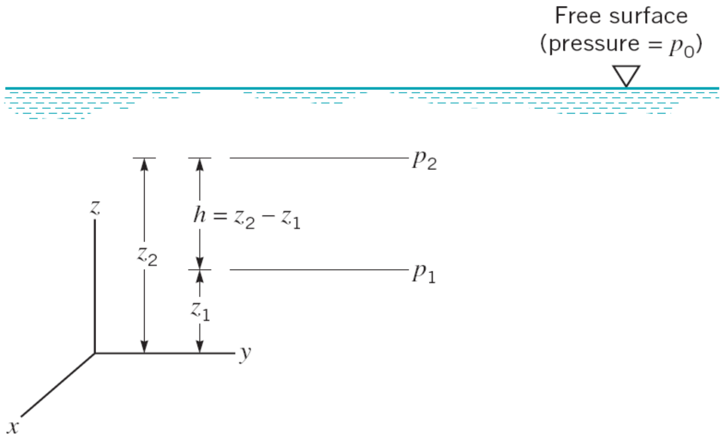
$$p_y = p_z = p_s$$

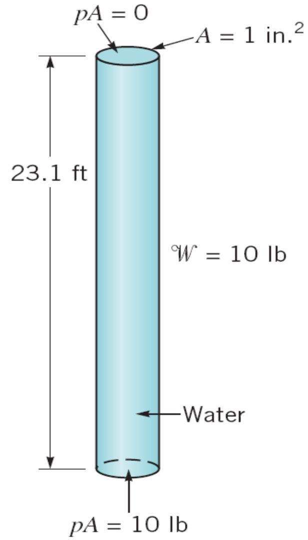
The pressure at a point in a fluid at rest is independent of direction.

We can conclude that 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.

This important result is known as *Pascal's law* named in honor of *Blaise Pascal* (1623–1662).

PRESSURE FOR INCOMPRESSIBLE FLUID



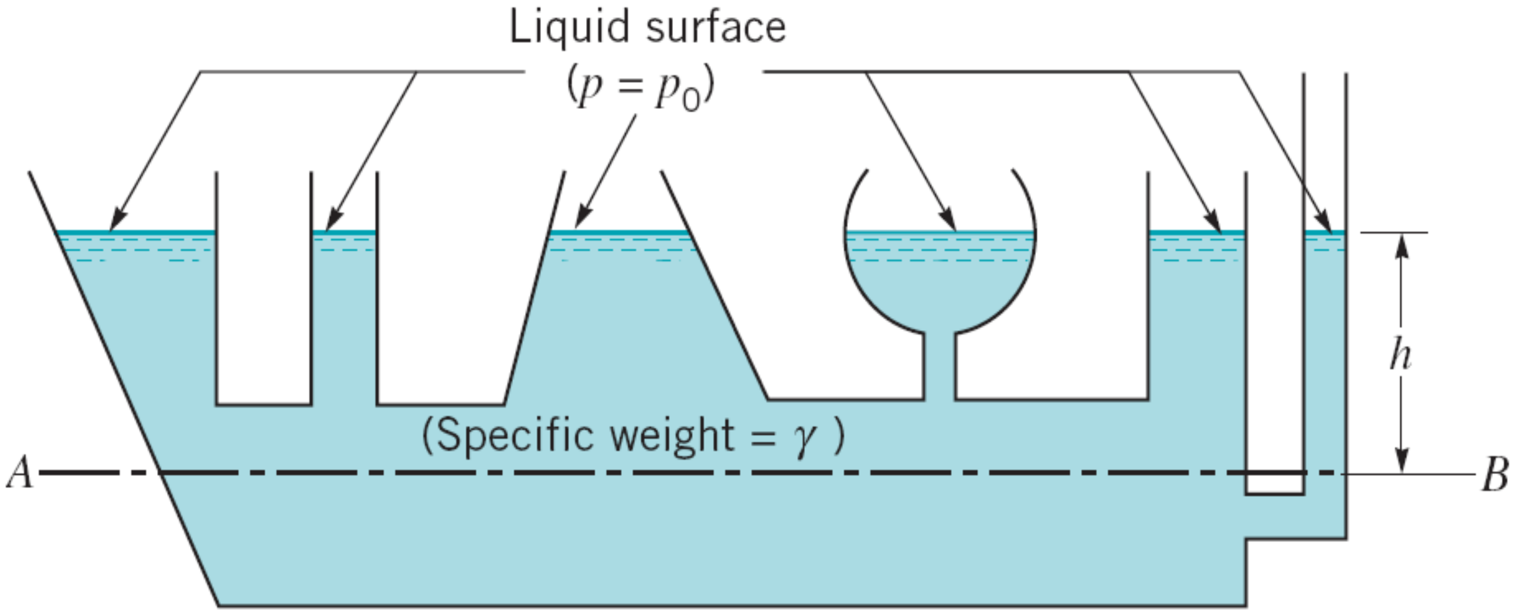


$$F = PA = mg = \rho g(Volume) = \rho gAh$$

$$P = \frac{\rho gAh}{A}$$

$$P = \rho gh$$

Pascal's Paradox



In a container, the pressure of a liquid at the same level remains the same.

STANDARD ATMOSPHERE

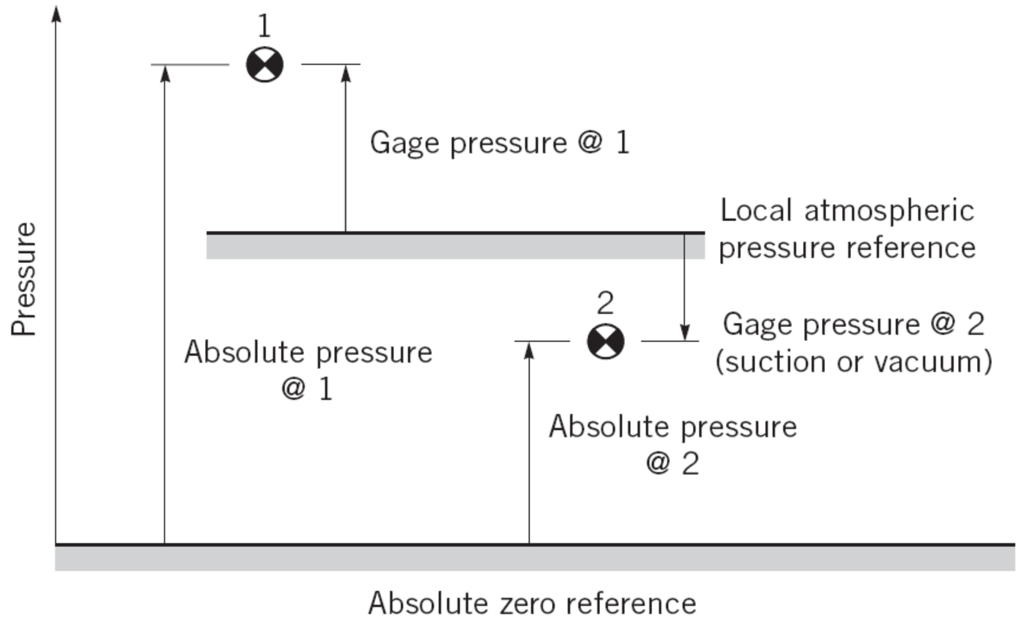
Properties of U.S. Standard Atmosphere at Sea Level[a]

Property	SI Units	BG Units
Temperature, T	288.15 K (15 °C)	518.67 °R (59.00 °F)
Pressure, p	101.33 kPa (abs)	2116.2 lb/ft^2 (abs) [14.696 $lb/in.^2$ (abs)]
Density, ρ	1.225 kg/m^3	0.002377 $slugs/ft^3$
Specific weight, γ	12.014 N/m^3	0.07647 lb/ft^3
Viscosity, μ	$1.789 \times 10^{-5}\ N \cdot s/m^2$	$3.737 \times 10^{-7}\ lb \cdot s/ft^2$

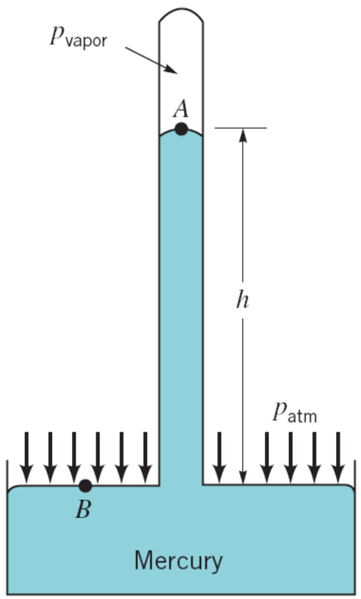
[a] Acceleration of gravity at sea level = 9.807 m/s^2 = 32.174 ft/s^2.

MEASUREMENT OF PRESSURE

The pressure at a point within a fluid mass will be designated as either an *absolute pressure* or a *gage pressure*. Absolute pressure is measured relative to a perfect vacuum (absolute zero pressure), whereas gage pressure is measured relative to the local atmospheric pressure.



A barometer is used to measure atmospheric pressure.



mercury barometer

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

MANOMETRY

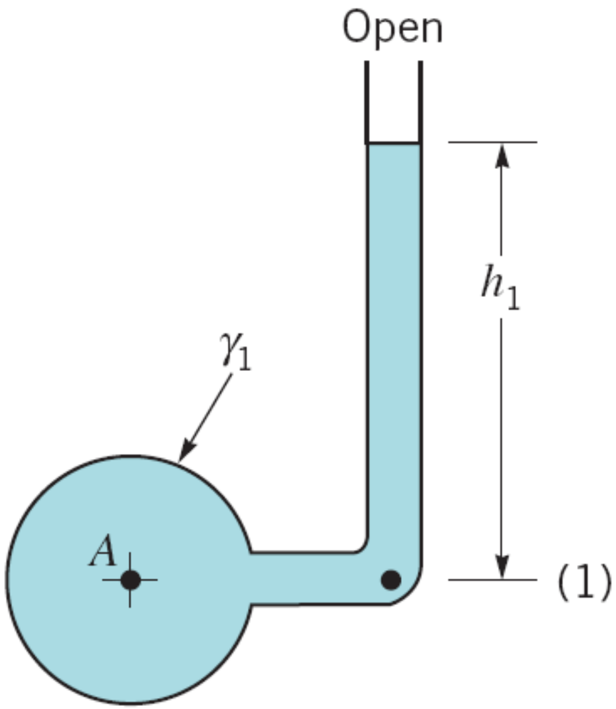
A standard technique for measuring pressure involves the use of liquid columns in vertical or inclined tubes.

Pressure measuring devices based on this technique are called *manometers*.

The *mercury barometer* is an example of one type of manometer, but there are many other configurations possible, depending on the particular application.

Three common types of manometers include the *piezometer tube*, the *U-tube manometer*, and the *inclined-tube manometer*.

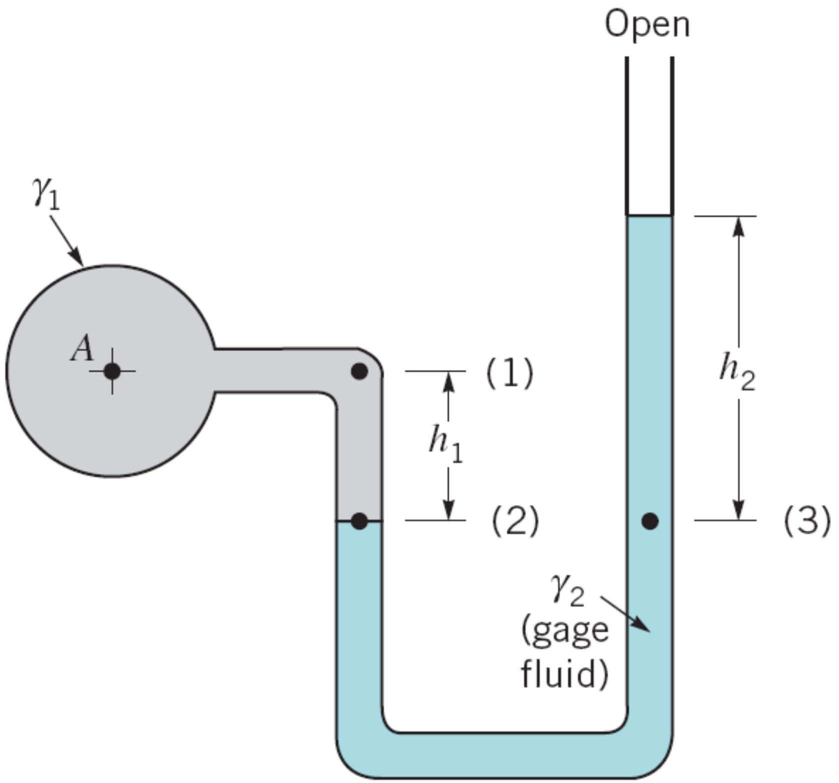
PIEZOMETER TUBE



$$p = \rho g h + p_o$$

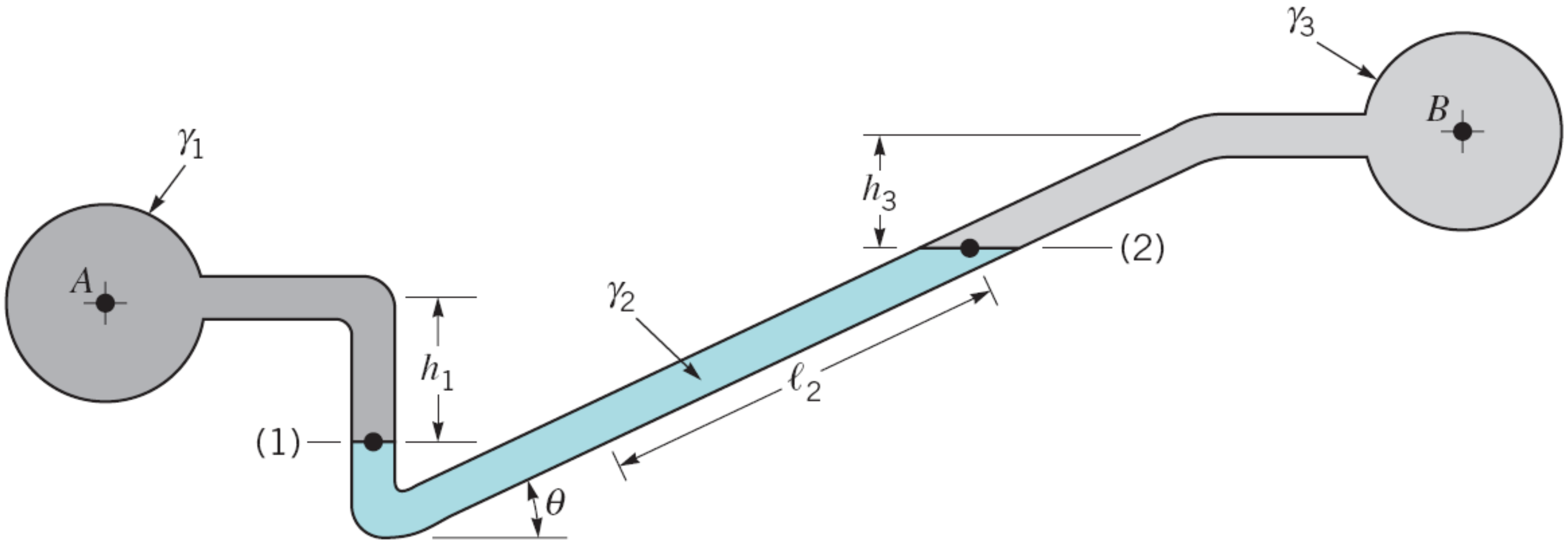
$$p_A = \gamma_1 h_1 = \rho_1 g h_1$$

U-TUBE MANOMETER



$$p_A = \rho_2 g h_2 - \rho_1 g h_1$$

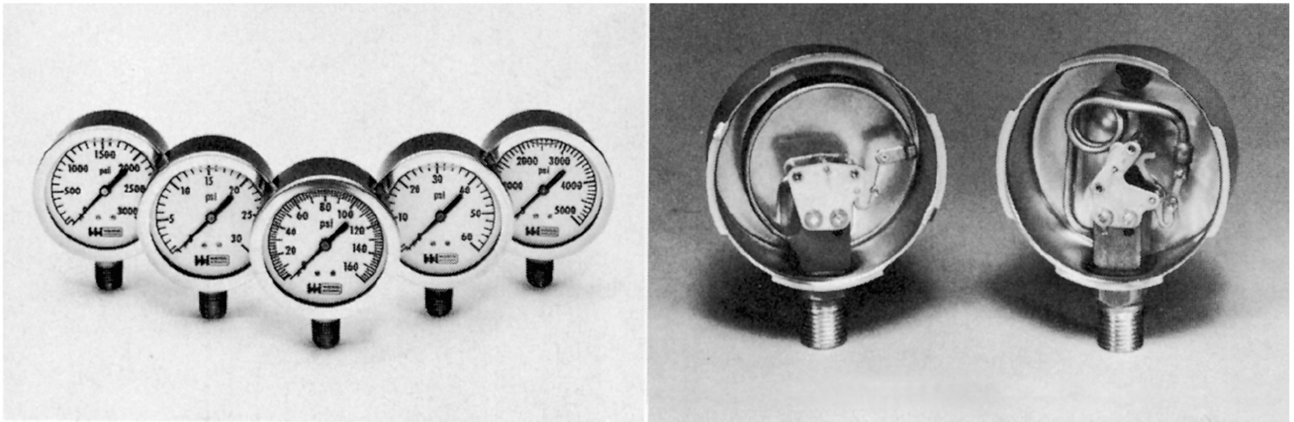
INCLINED-TUBE MANOMETER



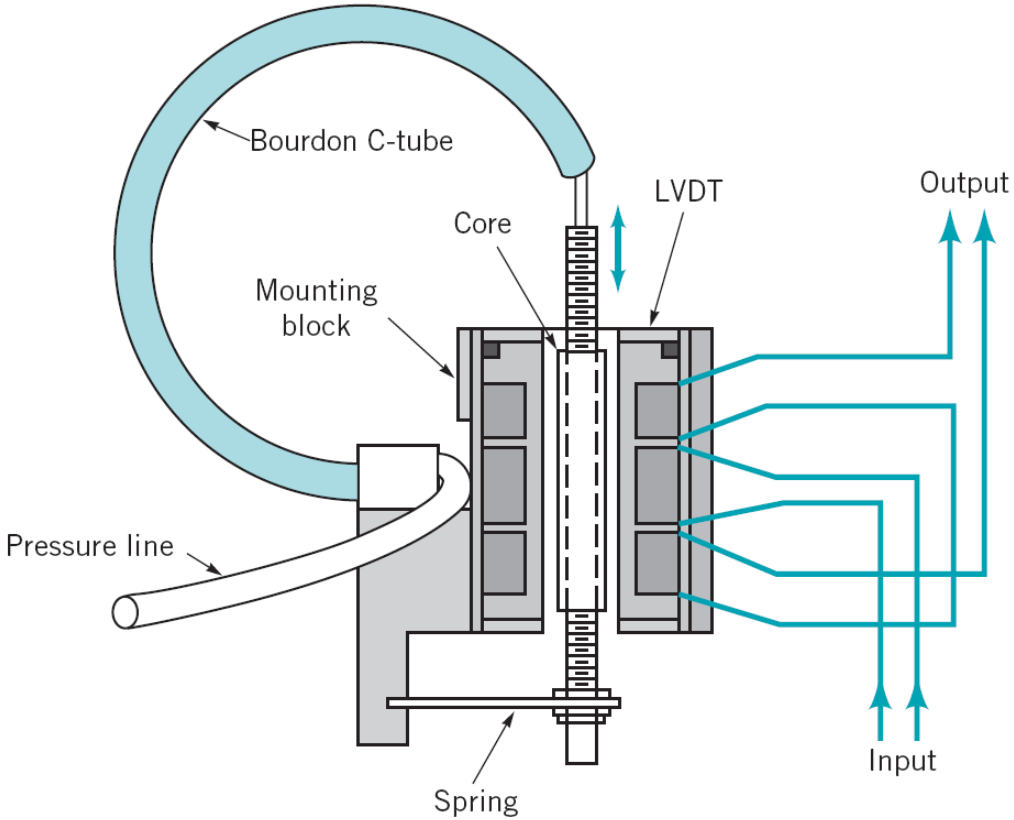
$$p_A - p_B = \rho_2 g \ell_2 \sin\theta + \rho_3 g h_3 - \rho_1 g h_1$$

MECHANICAL AND ELECTRONIC PRESSURE DEVICES

A *Bourdon tube pressure gage* uses a hollow, elastic, and curved tube to measure pressure.



(*a*) (*b*)


Bourdon C-tube
LVDT
Output
Core
Mounting
block
Pressure line
Spring
Input

PROBLEMS FOR CHAPTER 2 - PRESSURE

Question 1

The basic elements of a hydraulic press are shown in Figure 1. The plunger has an area of 3-cm^2, and a force, F_1, can be applied to the plunger through a lever mechanism having a mechanical advantage of 8 to 1. If the large piston has an area of 150 cm^2, what load, F_2, can be raised by a force of 30 N applied to the lever? Neglect the hydrostatic pressure variation.

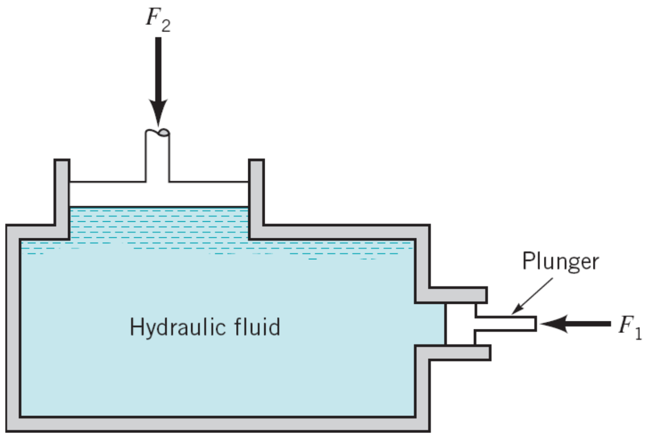


Figure 1

Question 2

A U-tube manometer is connected to a closed tank containing air and water as shown in Figure 2. At the closed end of the manometer the absolute air pressure is 140kPa. Determine the reading on the pressure gage for a differential reading of 1.5-m on the manometer. Express your answer in gage pressure value. Assume standard atmospheric pressure and neglect the weight of the air columns in the manometer.

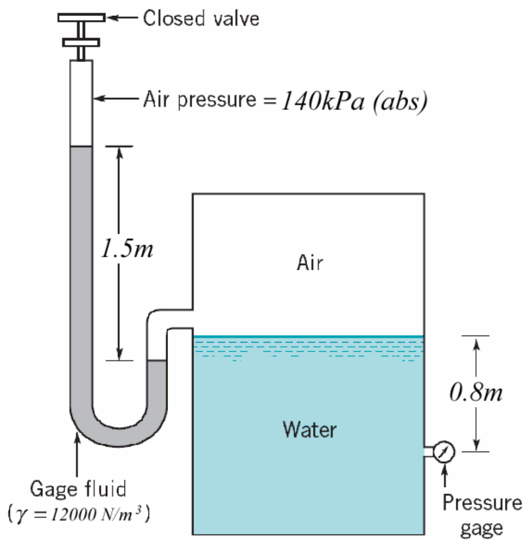


Figure 2

Question 3

A closed cylindrical tank filled with water has a hemispherical dome and is connected to an inverted piping system as shown in Figure 3. The liquid in the top part of the piping system has a specific gravity of 0.8, and the remaining parts of the system are filled with water. If the pressure gage reading at *A* is 60 kPa, determine: **(a)** the pressure in pipe *B*, and **(b)** the pressure head, in millimeters of mercury, at the top of the dome (point *C*).

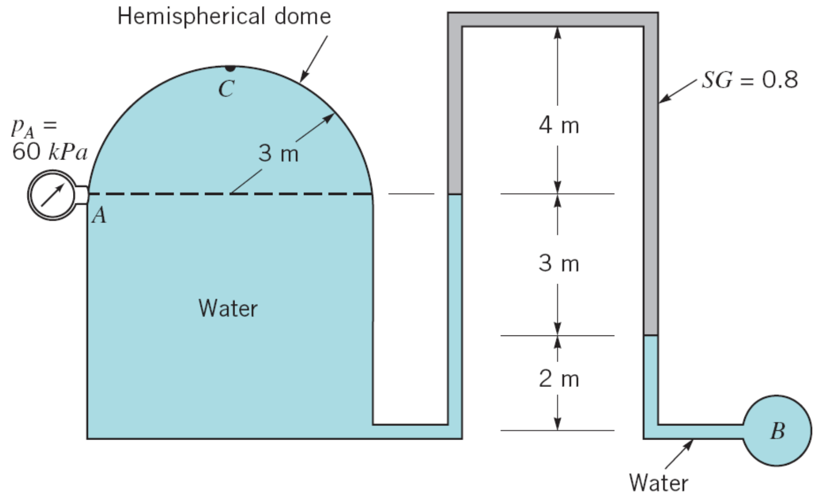


Figure 3

Question 4

A U-tube manometer contains oil, mercury, and water as shown in Figure 4. For the column heights indicated what is the pressure differential between pipes A and B?

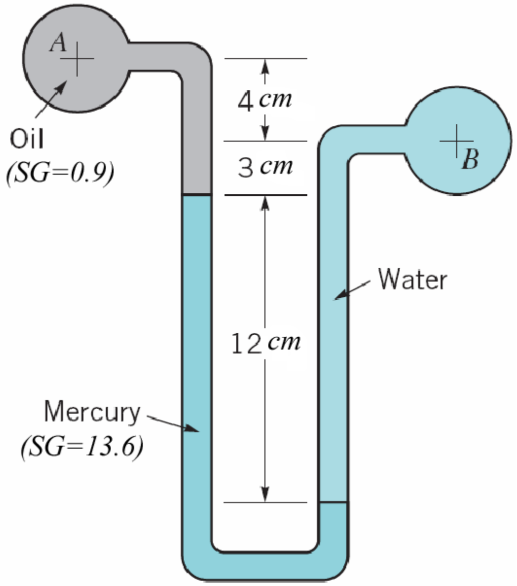


Figure 4

Question 5

A U-tube manometer is connected to a closed tank as shown in Figure 5. The air pressure in the tank is 120 Pa and the liquid in the tank is oil ($\gamma = 12000\ \mathrm{N/m^3}$). The pressure at point *A* is 20 kPa. Determine: **(a)** the depth of oil, *z*, and **(b)** the differential reading, *h*, on the manometer.

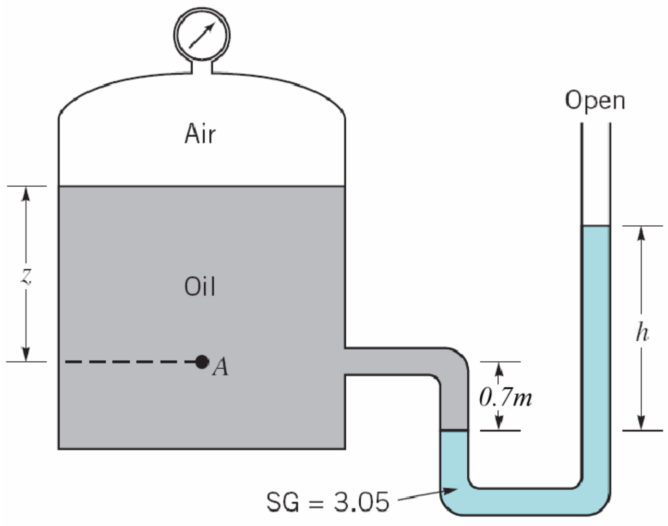


Figure 5

Question 6

The inverted U-tube manometer of Figure 6 contains oil ($SG = 0.9$) and water as shown. The pressure differential between pipes A and B, $p_A - p_B$, is -5 kPa. Determine the differential reading, h.

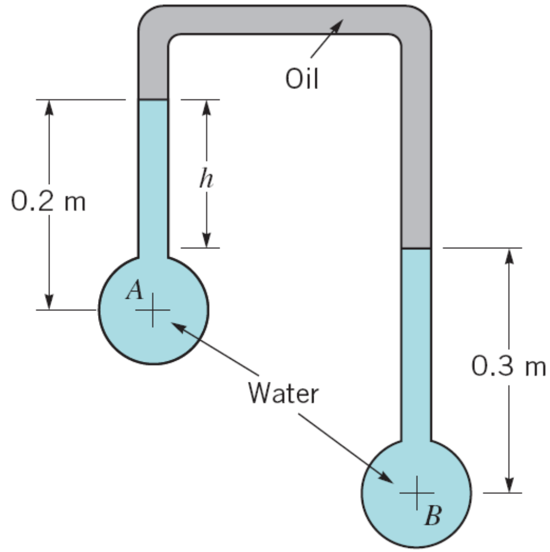


Figure 6

Question 7

A piston having a cross-sectional area of 0.07 m^2 is located in a cylinder containing water as shown in Figure 7. An open U-tube manometer is connected to the cylinder as shown. For $h_1 = 60$ mm and $h = 100$ mm, what is the value of the applied force, P, acting on the piston? The weight of the piston is negligible.

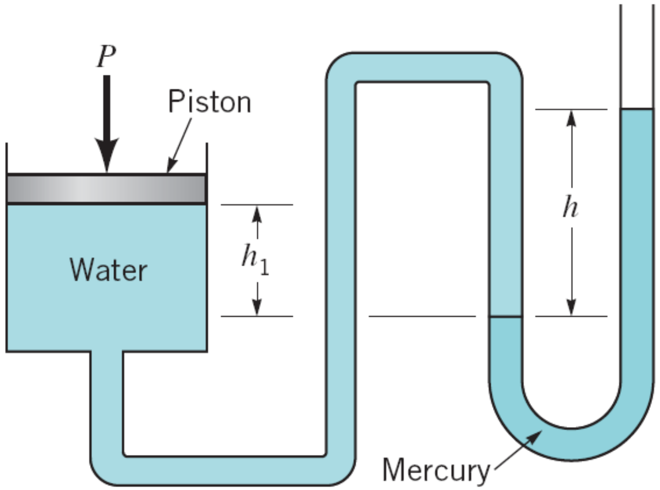


Figure 7

Question 8

For the inclined-tube manometer of Figure 8, the pressure in pipe *A* is 8 kPa. 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?

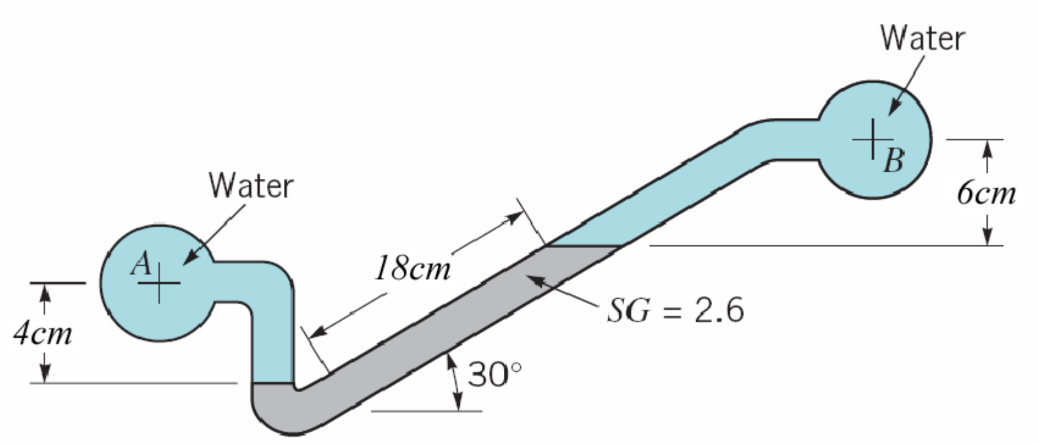
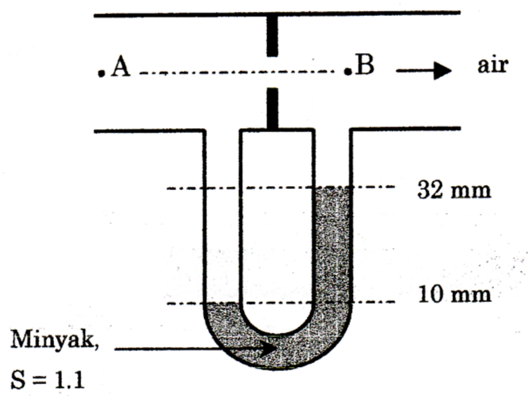


Figure 8

PAST YEAR QUESTION FOR PRESSURE

QUESTION 1



Rajah 1

a. Berikan definisi tekanan mutlak, tekanan tolok dan tekanan atmosfera. Nyatakan hubungan antara ketiga-tiga jenis tekanan ini.

b. Rajah 1 menunjukkan sebuat manometer yang digunakan untuk mencari perbezaan tekanan di antara dua titik di dalam paip. Tentukan magnitude $P_A - P_B$

QUESTION 2

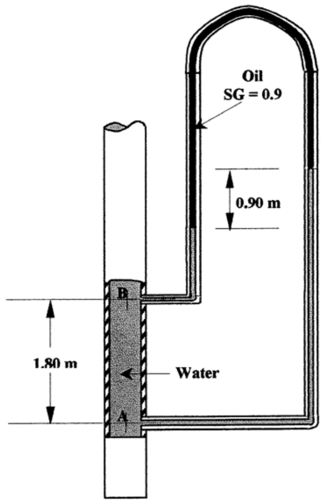
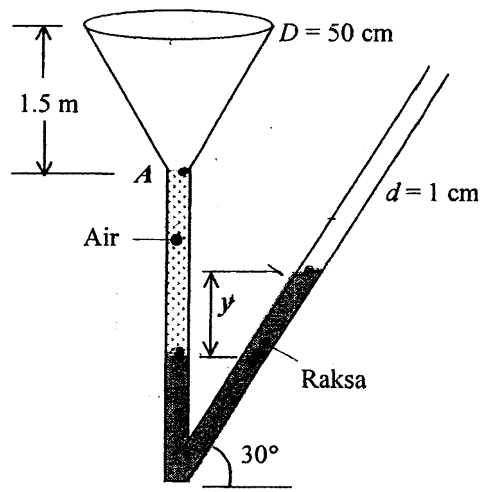


Figure 2

Figure 2 shows a manometer being used to indicate the difference in pressure between two points in a pipe. Calculate $P_A - P_B$

QUESTION 3



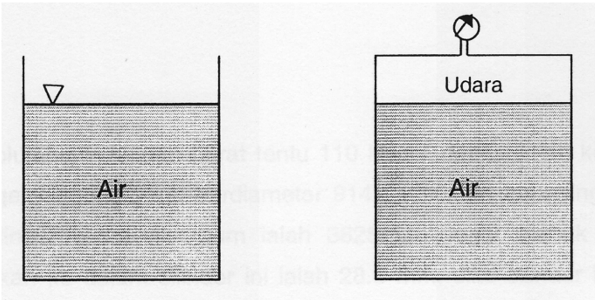
Rajah 3

Rajah 3 menunjukkan sebuah tangki kon yang terbuka disambung dengan manometer tiub-U condong. Apabila air masuk sehingga aras *A* dan tangki kon dalam keadaan kosong, bacaan manometer raksa menunjukkan y=100mm. Dengan data yang diberikan, tentukan nilai y yang baru apabila kon dipenuhi dengan air.

PAST YEAR QUESTION FOR PRESSURE

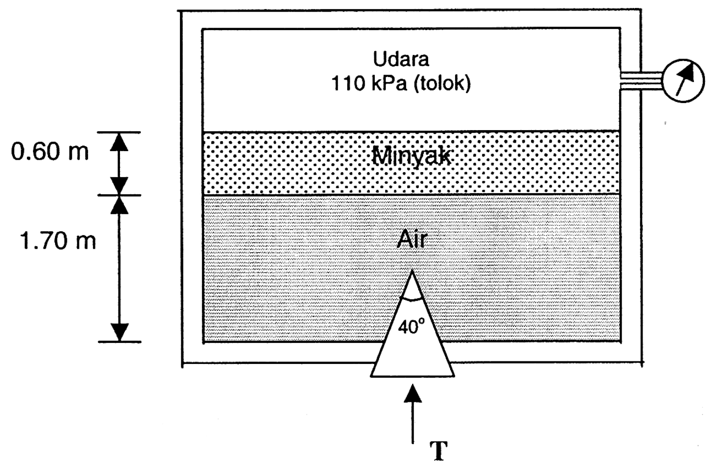
QUESTION 4

a. Dengan bantuan gambarajah, lakarkan taburan daya yang bertindak pada dinding kanan kedua-dua buah tangki yang ditunjukkan dalam rajah S1.



Rajah S1

b. Sebuah kon bersedut 40º digunakan untuk menyumbat lubang berdiameter 0.45-m pada dasar sebuah tangki tertutup seperti yang ditunjukkan dalam Rajah S2. Jika tangki tersebut mengandungi minyak berketumpatan bandingan 0.85, air dan udara bertekanan 110-kPa (tolok), tentukan daya luar, T minimum bagi memastikan kon tersebut kekal pada kedudukannya. Diberi isipadu kon ialah $\frac{1}{3}\pi r^2 t$ m³ dengan t ialah tinggi kon.



Rajah S2