FACULTY OF MECHANICAL ENGINEERING

SKMM 1912 EXPERIMENTAL METHODS

UNIVERSITI TEKNOLOGI MALAYSIA

MEASUREMENT OF PRESSURE

MEASUREMENT OF PRESSURE - SOME DEFINITIONS

When a force is applied perpendicular to a surface area, it exerts pressure on that surface equal to the ratio of F to A, where F is the force and A is the surface area.

Hence, the formula for pressure (p) is $p = F/A$.

The principle SI unit is called a Pascal (Pa), or 1 N/m^2.

Other units used – lbf/in^2, kgf/cm^2, $tonf/in^2$, kp/cm^2, inH_2O, inHg, $dyne/cm^2$, torr

MEASUREMENT OF PRESSURE -UNITS FOR PRESSURE

There are also two other specialized units of pressure measurement in the SI system:

the bar, equal to 10^5 Pa, and

the torr, equal to 133 Pa.

The torr, once known as the "millimeter of mercury," is equal to the pressure required to raise a column of mercury (chemical symbol Hg) 1 mm. It is named for the Italian physicist Evangelista Torricelli (1608-1647), who invented the barometer.

MEASUREMENT OF PRESSURE -UNITS FOR PRESSURE

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (mmHg)	Pound-force per square inch (psi)
1 Pa	≡ 1 N/m²	10^{-5}	10.197×10^{-6}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100 000	≡ 10^{6} dyn/cm²	1.0197	0.98692	750.06	14.504
1 at	98 066.5	0.980665	≡ 1 kgf/cm²	0.96784	735.56	14.223
1 atm	101 325	1.01325	1.0332	≡ 1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	≡ 1 mmHg	19.337×10^{-3}
1 psi	6 894.76	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	≡ 1 lbf/in²

MEASUREMENT OF PRESSURE -Atmospheric Pressure

Atmospheric pressure is pressure caused by the weight of the atmosphere.

At sea level it has a mean value of **one atmosphere** (1 atm) = 760 mm of mercury = 14.70 lbs per square in. = 101.35 kilopascals = 100 kN/m^2 = 1 bar

Pressure reduces with increasing altitude

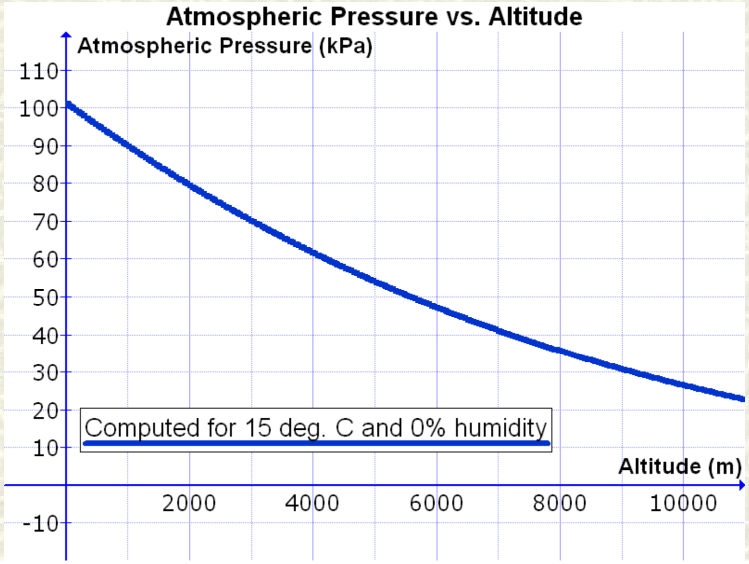
MEASUREMENT OF PRESSURE -Pressure Change

This plastic bottle was closed at approximately 2000m altitude, then brought back to sea level. As a result, air pressure crushes it.

MEASUREMENT OF PRESSURE - Vacuum

An outer-space in which there is no matter or in which the pressure is so low that any particles in the space do not affect any processes being carried on there. It is a condition well below normal atmospheric pressure

The most nearly perfect vacuum exists in intergalactic space, where it is estimated that on the average there is less than **one molecule per cubic meter**



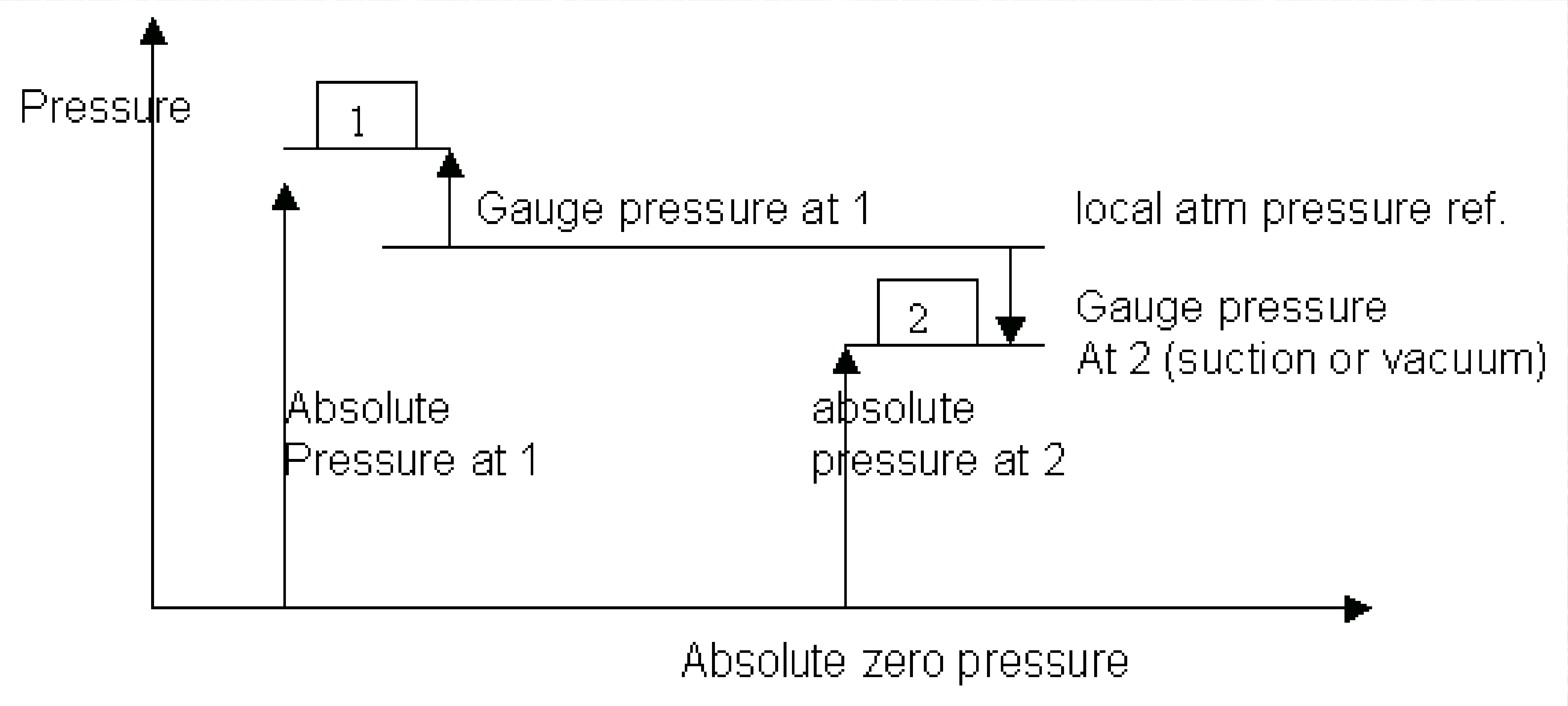
MEASUREMENT OF PRESSURE - Absolute, Gauge and Differential Pressure

Absolute pressure of a fluid is referenced against a perfect vacuum

Gauge pressure (eg. as read by barometer) is referenced against ambient air pressure, so it is equal to absolute pressure **minus** atmospheric pressure.

Differential pressure is the difference in pressure between two points.

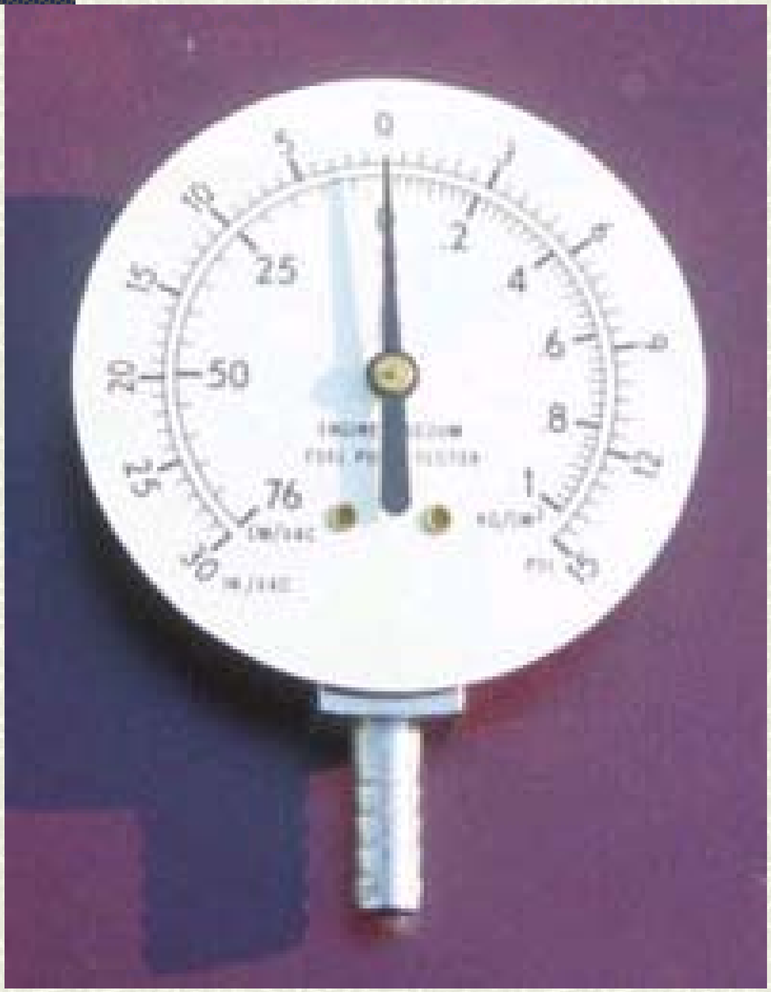
MEASUREMENT OF PRESSURE - PRESSURE DIAGRAM

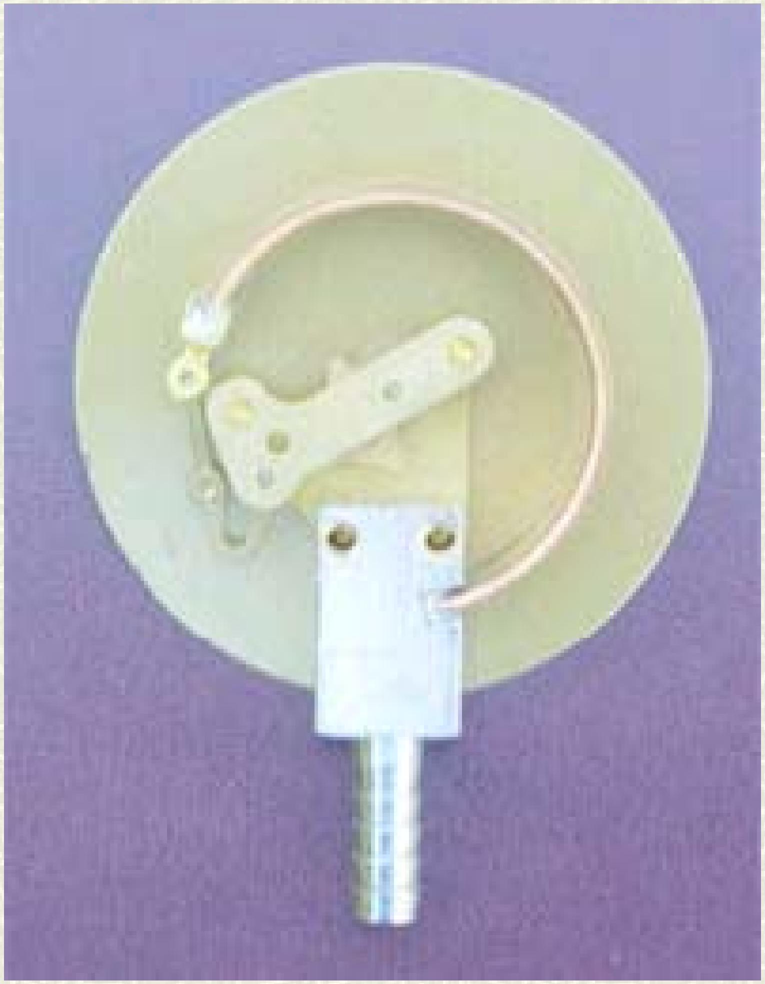


MEASUREMENT OF PRESSURE - METHOD TO MEASURE

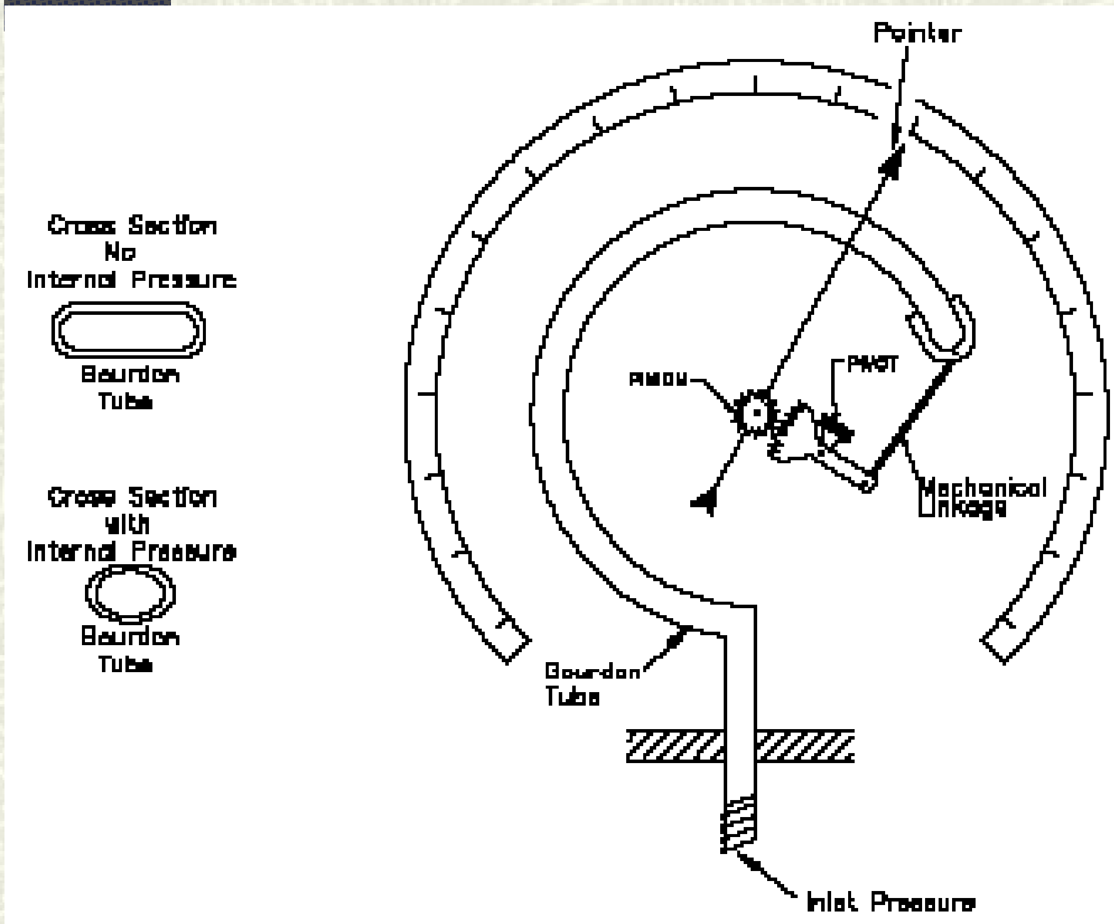
- By elastic deformation
  - Pressure creates force which in turn deforms the elastic material
- By liquid column
  - Hydrostatic pressure is the pressure due to the weight of a fluid.
  - $p = \rho g h$

ELASTIC DEFORMATION – Bourdon Tube



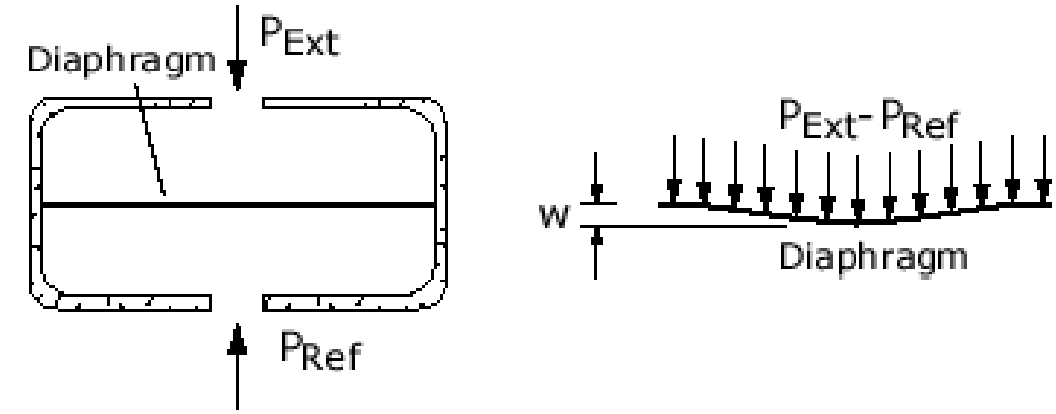


A Bourdon gauge uses a coiled tube which as it expands due to pressure increase causes a rotation of an arm connected to the tube.

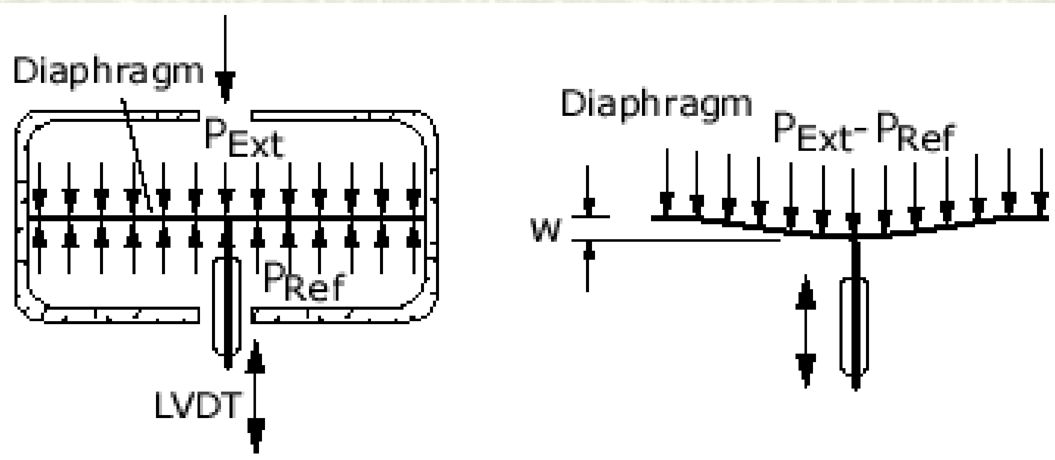


- Coiled tube made of copper
- Mechanical movement linked by rack and pinion
- Range = 100kN/m^2 – 300MN/m^2

ELASTIC DEFORMATION – Diaphragm (membrane) Based



Typical Diaphragm Pressure Gage



LVDT-Based Diaphragm Pressure Gage

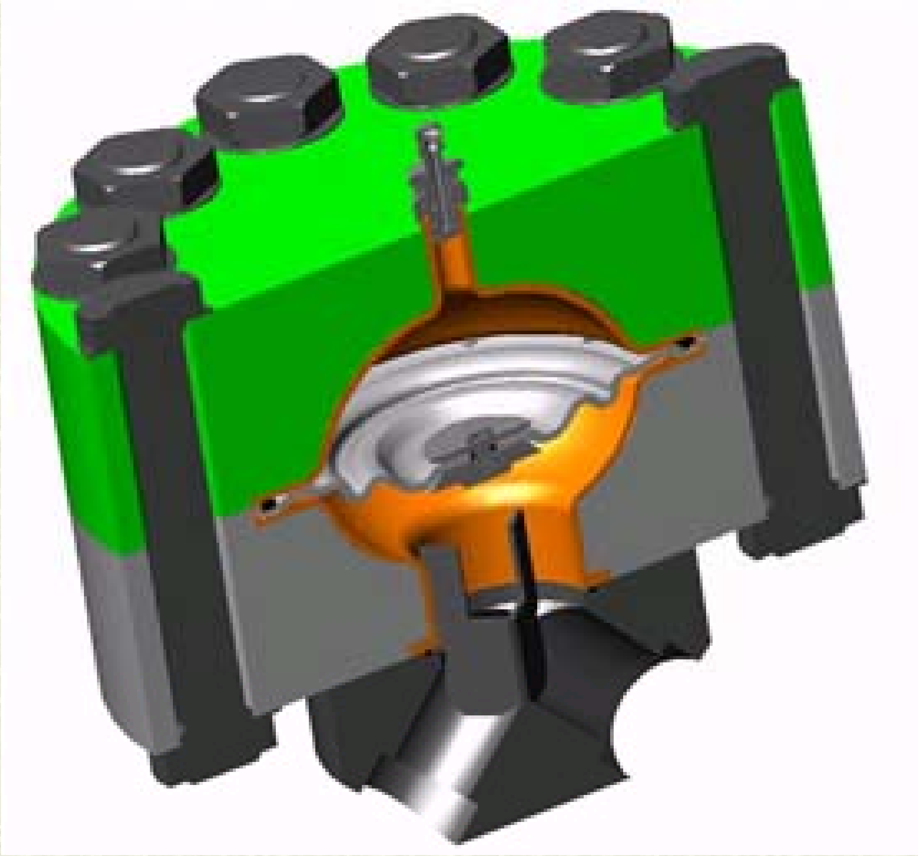
LVDT = linear variable displacement transducer

Spring can be used instead of LVDT and attached to force (F) measuring device

$p = k\boldsymbol{x}/A$

ELASTIC DEFORMATION – Diaphragm Based

INDUSTRIAL PRESSURE DIAPHRAGM ASSEMBLY



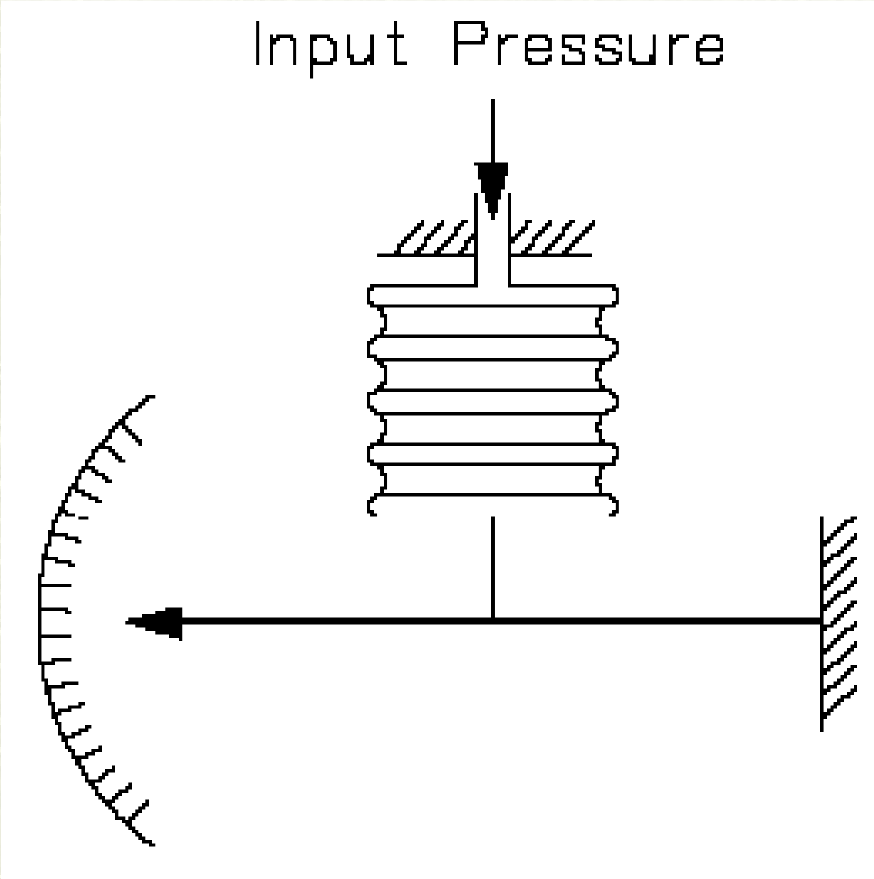
ELASTIC DEFORMATION – Diaphragm Based

Diaphragm Shape

- flat for low pressure measurement or
- Corrugated for high pressure measurement

Material = Copper-beryllium

ELASTIC DEFORMATION – Bellows Based



For extremely low pressure measurement (0.5 – 75psig to a 1000psig$_{max}$)

psig = pound per square inch gauge

ELASTIC DEFORMATION – Aneroid Gauge

FITTED WITH BELLOW

ELASTIC DEFORMATION – Aneroid Concept

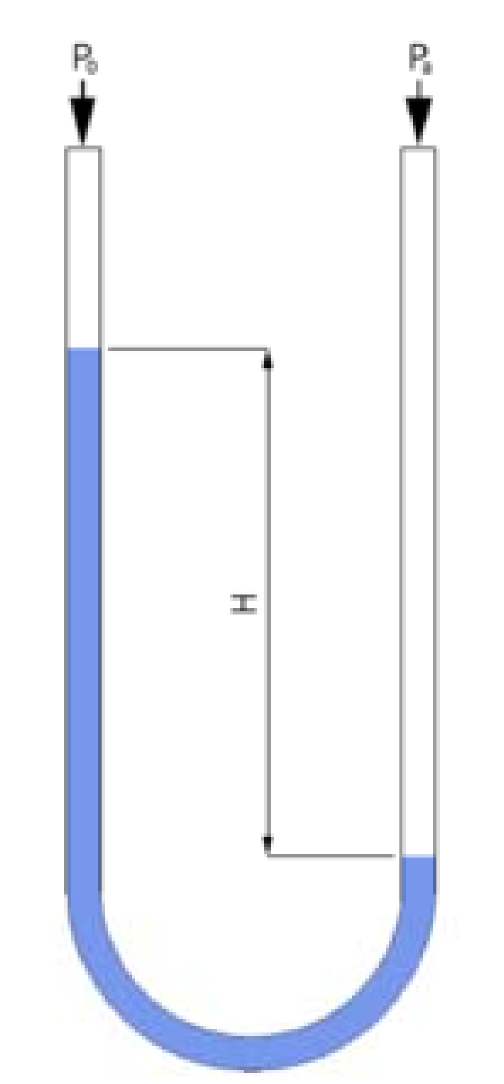
An enclosed and sealed bellows chamber, called an **aneroid**, which means "without liquid".

The important component is a sealed chamber made of thin metal in semi vacuum state

The chamber shrinks when atmospheric pressure increases, and expands when atmospheric pressure reduces

Can be used as altimeter.

LIQUID COLUMN – Concept



Liquid column gauges consist of a vertical column of liquid in a tube whose ends are exposed to different pressures.

The column will rise or fall until its weight is in equilibrium with the pressure differential between the two ends of the tube

LIQUID COLUMN – Hydrostatic Pressure

Hydrostatic Pressure in a Liquid

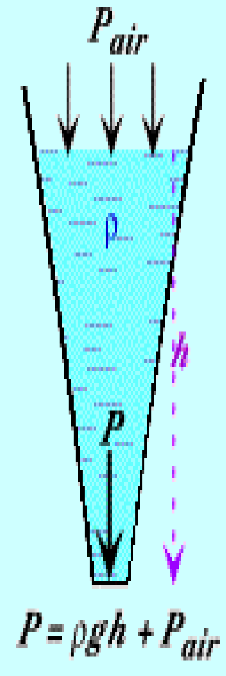
- The pressure at a given depth in a static liquid is a result the weight of the liquid acting on a unit area at that depth plus any pressure acting on the surface of the liquid.

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

- The pressure due to the liquid alone (i.e. the gauge pressure) at a given depth depends only upon the density of the liquid **ρ** and the distance below the surface of the liquid **h**.

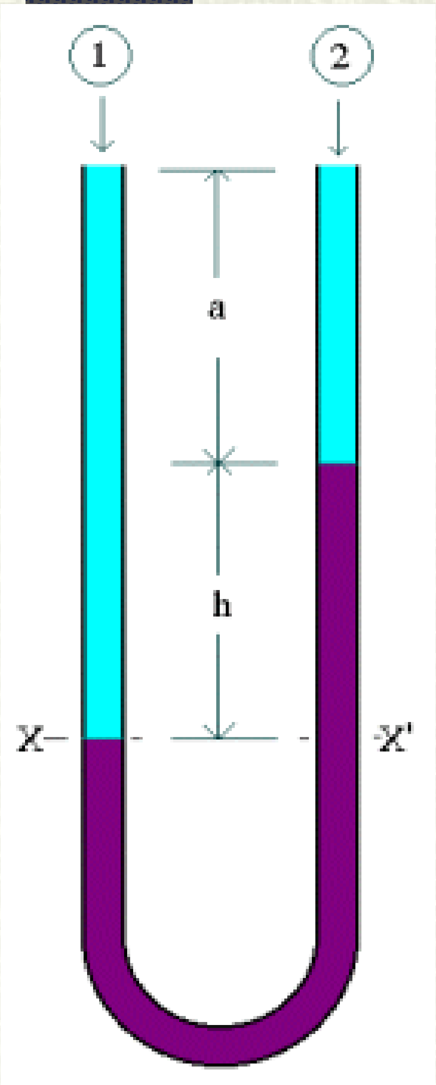
$$P = \rho g h$$

- Pressure is not really a vector even though it looks like it in the sketches. The arrows indicate the direction of the force that the pressure would exert on a surface it is contact with.



LIQUID COLUMN – U-tube Manometer

LIQUID COLUMN – U-Tube Manometer



Equating the pressure at the level X'(pressure at the same level in a continuous body of fluid is equal)

LHS; $P_x = P_1 + \rho g(a+h)$

RHS; $P_{x'} = P_2 + \rho g a + \rho_m g h$

Since $P_x = P_{x'}$

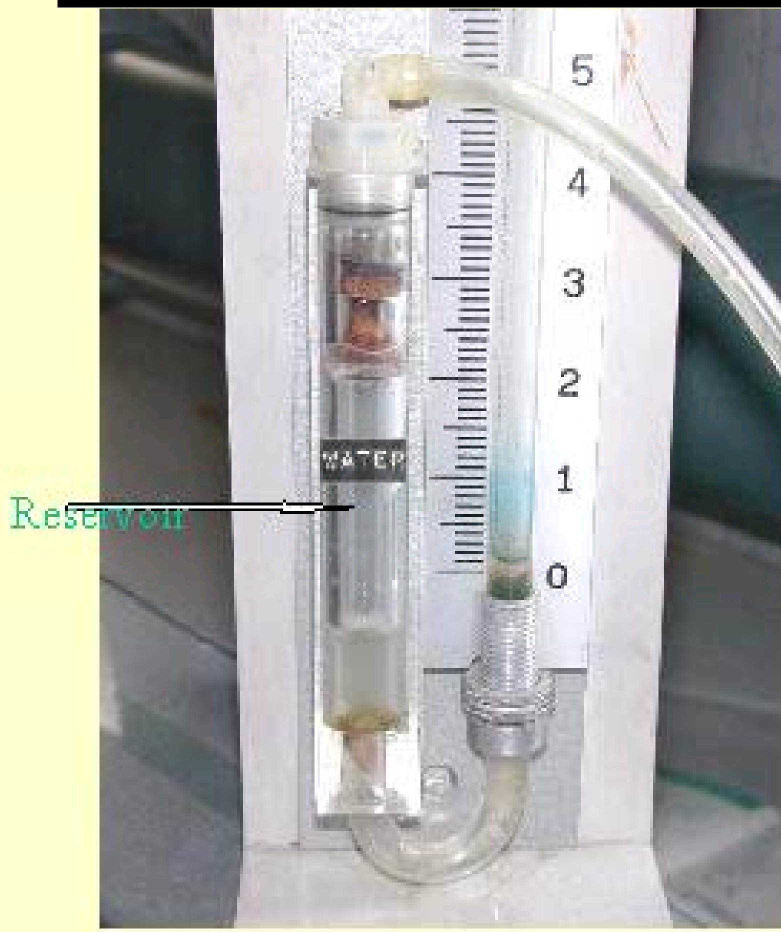
$P_1 + \rho g(a+h) = P_2 + \rho g a + \rho_m g h$

$P_1 - P_2 = \rho_m g h - \rho g h$

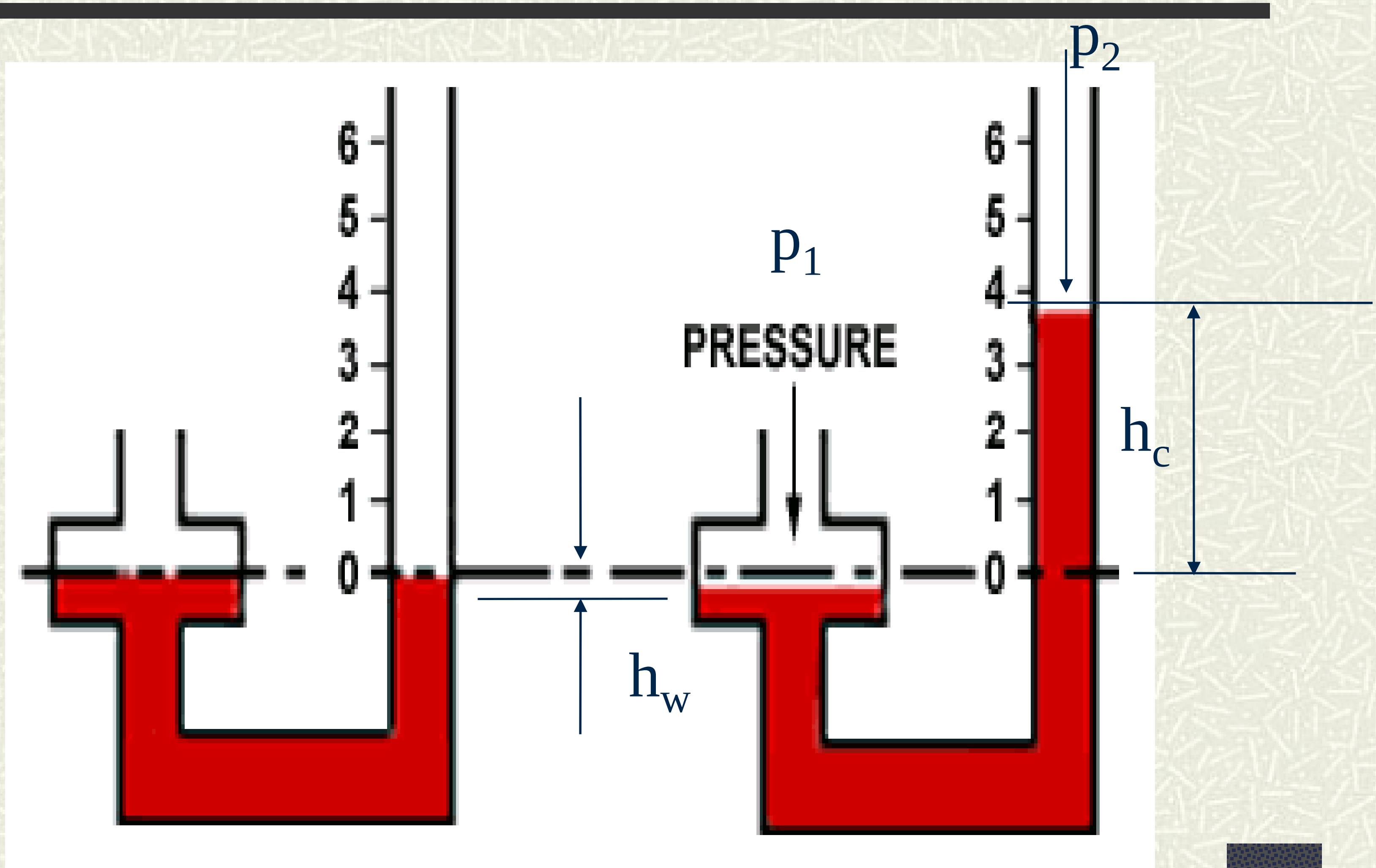
i.e. $P_1 - P_2 = (\rho_m - \rho)gh.$

LIQUID COLUMN – Well-Type Manometer

[redacted]

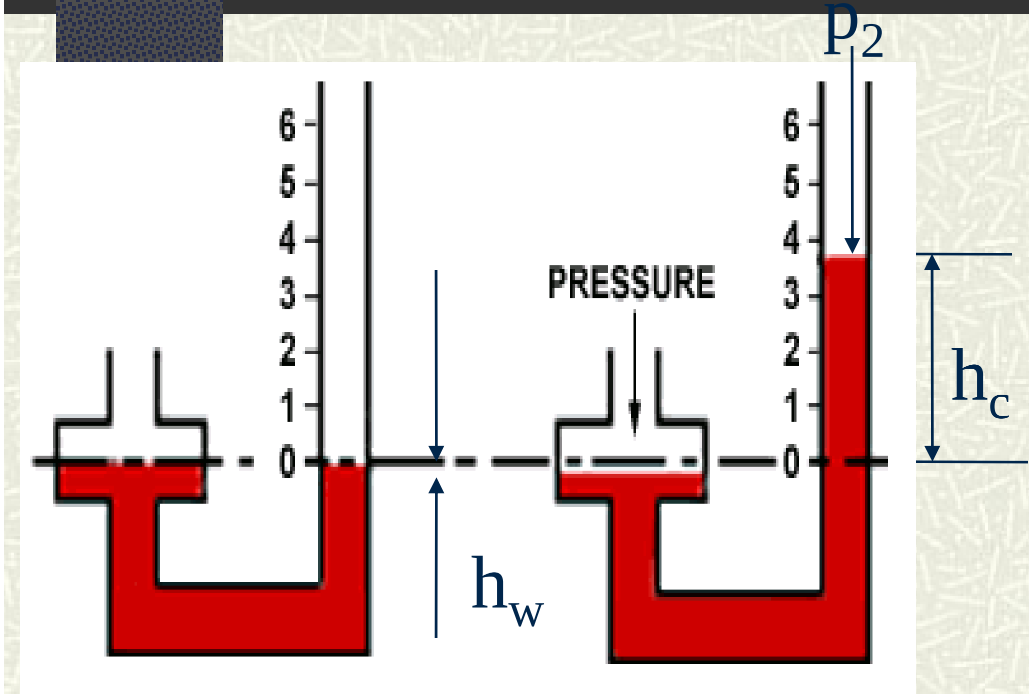


LIQUID COLUMN – Well-Type Manometer



LIQUID COLUMN –

Well-Type Manometer **(Measuring range = 1bar – 1.5bar)**



LHS: $p_1 - \rho g h_w$

RHS: $p_2 + \rho g h_c$

LHS = RHS

$p_1 - \rho g h_w = p_2 + \rho g h_c$

$p_1 - p_2 = \rho g h_c + \rho g h_w$

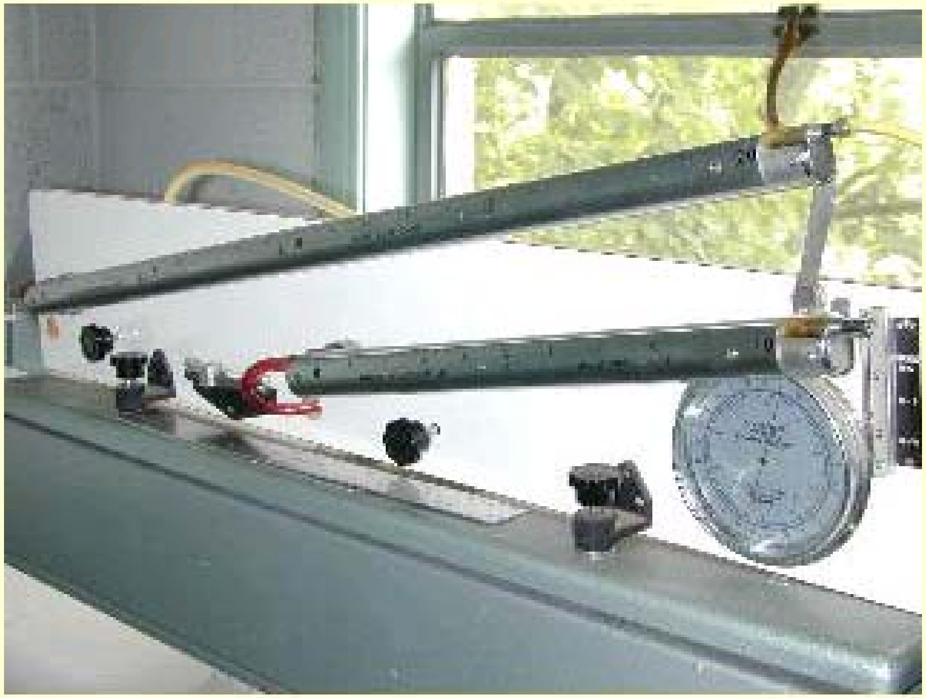
By constant volume, $h_w A_w = h_c A_c \Rightarrow h_w/h_c = A_c/A_w$

Therefore $p_1 - p_2 = \rho g h_c (1 + A_c/A_w)$

$= \rho g h_c$ when $A_w >> A_c$

LIQUID COLUMN – Inclined Manometer

Inclined tube manometers



LIQUID COLUMN – Inclined Manometer

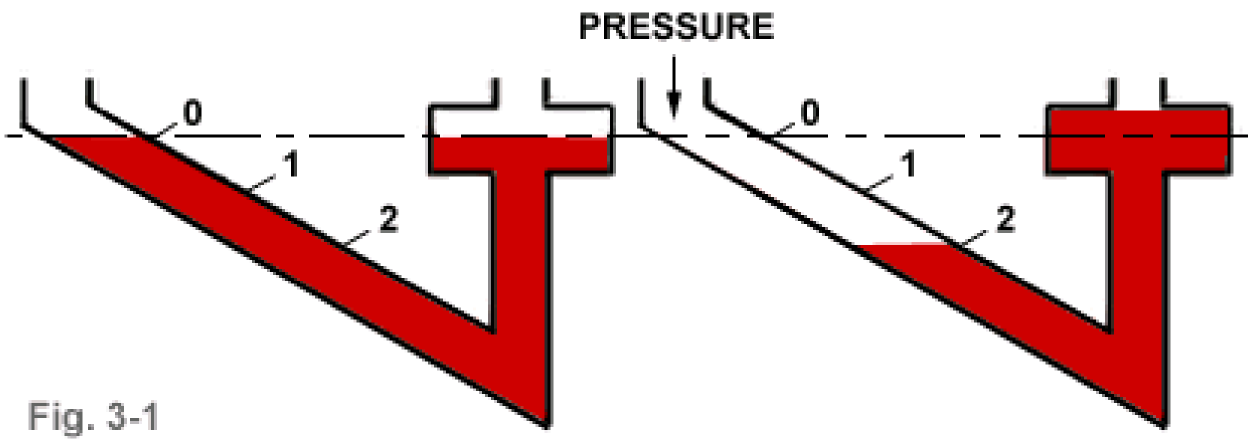
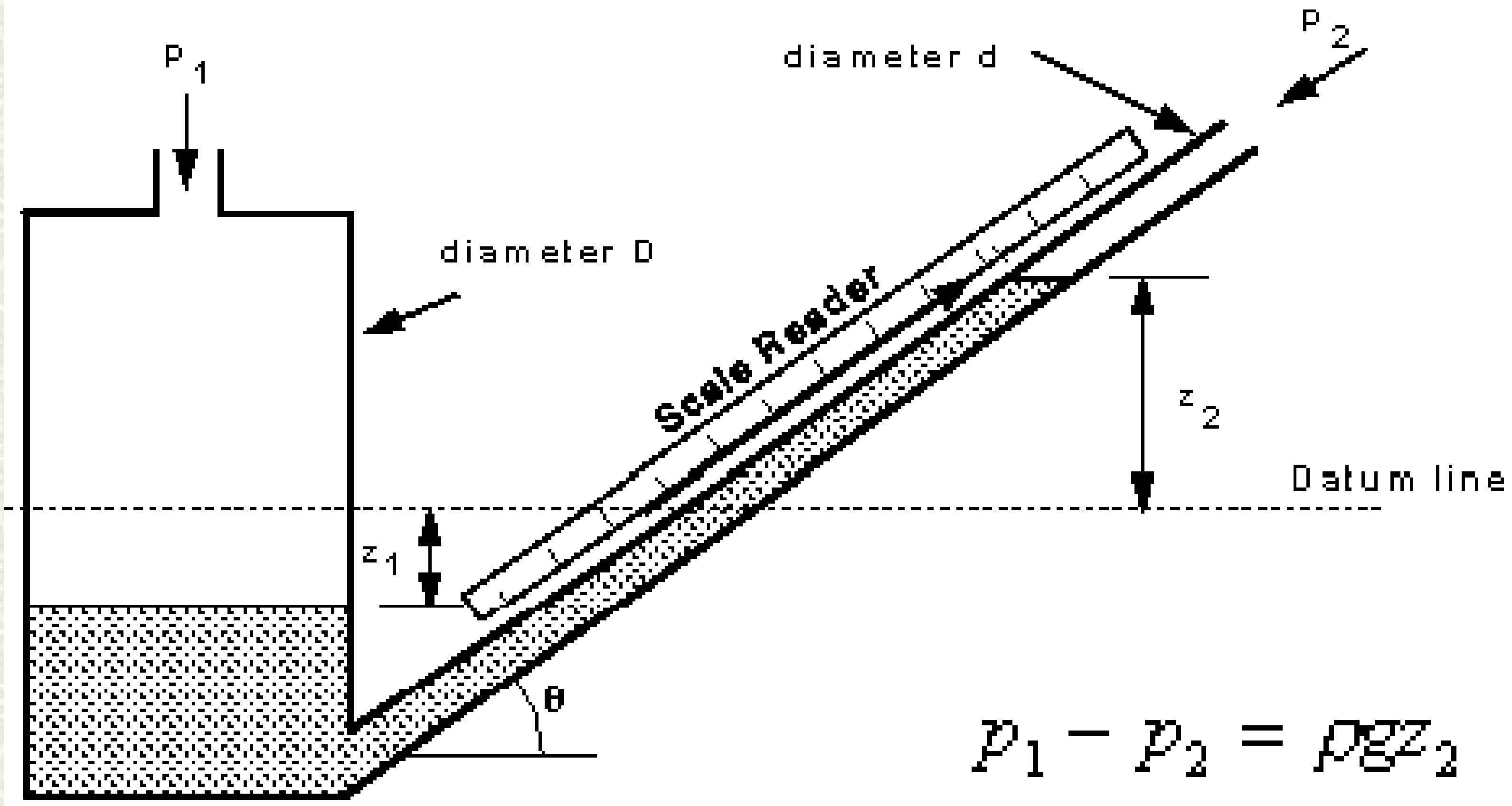


Fig. 3-1

LIQUID COLUMN – Inclined Manometer



Tilted manometer.

$$p_1 - p_2 = \rho g z_2$$
$$= \rho g x \sin\theta$$

LIQUID COLUMN – Inclined Manometer

The inclined version is used for better sensitivity.

Measuring range = 0.1bar – 30mbar

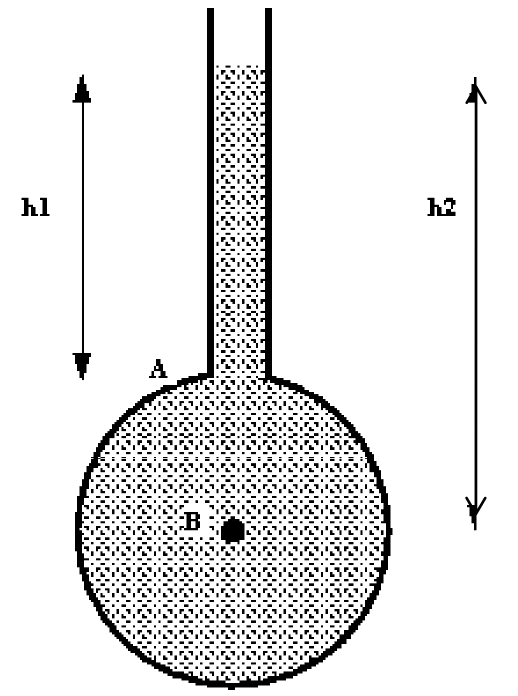
PIEZOMETER

pressure at A = pressure due to column of liquid above A

$$p_A = \rho g h_1$$

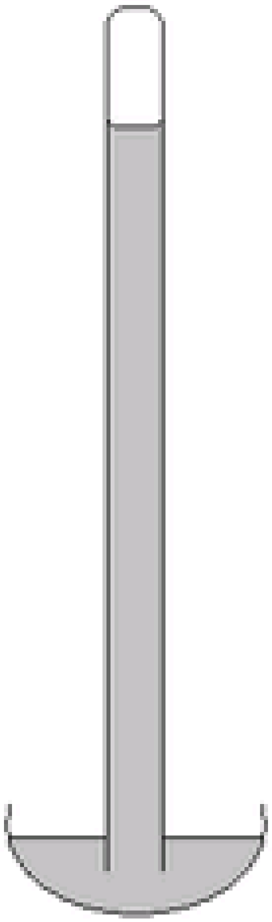
pressure at B = pressure due to column of liquid above B

$$p_B = \rho g h_2$$



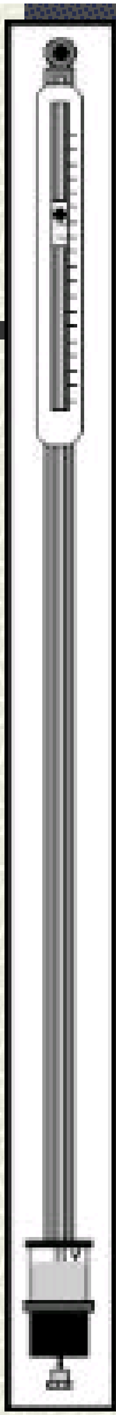
A simple piezometer tube manometer

MERCURY BAROMETER



A **barometer** is an instrument used to measure atmospheric pressure.

A standard mercury barometer has a glass column of about 30 inches (about 76 cm) in height, closed at one end, with an open mercury-filled reservoir at the base.



MERCURY BAROMETER

Mercury in the tube adjusts until the weight of the mercury column balances the atmospheric force exerted on the reservoir.

High atmospheric pressure places more force on the reservoir, forcing mercury higher in the column.

Low pressure allows the mercury to drop to a lower level in the column by lowering the force placed on the reservoir.

MERCURY BAROMETER

MANOMETER LIQUID SELECTION

- Low viscosity
- Low coefficient of expansion
- Low vapour pressure
- Low cohesiveness
- Non corrosive

MANOMETER LIQUID IN USE

- Mercury
- Water
- Kerosene
- Alcohol
- Ethyl
- Benzene

THE END