01 — The Nature Of Fluids & Pressure Measurement

Water Resources, CIVL318

Last revision on September 5, 2018

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- A liquid:
  - Tends to flow and conform to the shape of its container.
  - For the purpose of this course we consider a liquid to be incompressible:
    - We assume that the density of water at the bottom of the ocean is the same as the density near the surface (if at the same temperature)
    - Density is different from pressure: the pressure at the bottom of the ocean is much more than at the surface

Pressure

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Pressure is the force per unit area on a surface, where

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Blaise Pascal $(1623 - 1662)$ determined the following principles:

Wikimedia link

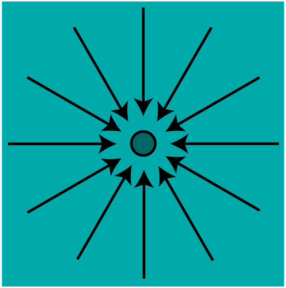
1. Pressure acts uniformly in all directions on a "small" volume of a fluid at rest
2. In a fluid confined by solid boundaries, pressure acts perpendicularly to the boundaries

Pascal's Laws

Pressure acts uniformly in all directions on a small volume of a fluid at rest.

The forces must balance out (i.e. $\Sigma F_x = \Sigma F_y = 0$); otherwise the volume of fluid will not be in equilibrium and cannot remain at rest.

Also, the volume must be sufficiently "small" that we do not have to consider the mass, and therefore the weight, W, of the volume of fluid.



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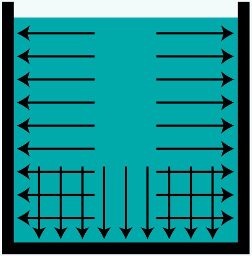

Example 1

A piston confines oil in a closed circular cylinder. The maximum operating pressure for the piston is 17.8 MPa. The piston has a diameter of 62.5 mm.

What is the maximum load that the piston can support?

Exercise 1

A press used to produce coins requires a force of 8.20 kN. The hydraulic cylinder has a diameter of 63.5 mm.

What is the oil pressure needed to generate this force?

Density

$$\rho = \frac{M}{V}$$

Density (denoted by ρ, 'rho') is mass per unit volume.

- The density of water between $0\,^{\circ}C$ and $15\,^{\circ}C$ is approximately 1000 kg/m^3.
- Water has a maximum density at $4\,^{\circ}C$.
- Above $15\,^{\circ}C$, the density drops steadily to a density of 958 kg/m^3 at $100\,^{\circ}C$.

There is a table of values for the properties of water attached to this module's handout.

Specific Weight

$$\boxed{\gamma = \frac{W}{V}}$$

Specific weight is weight per unit volume.

Water has a specific weight of approximately 9.81 $\mathrm{kN/m^3}$ between $0\,^\circ C$ and $15\,^\circ C$.

Since $w = mg$, it follows that:

$$\gamma = \frac{w}{V} = \frac{mg}{V} = \rho g$$

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Example 2

An empty barrel with an inside diameter of 900 mm weighs 205 N.

What does the barrel weigh when it is filled to a depth of 750 mm with water at $25°C$?

Specific Gravity

Specific gravity, **sg**, is the ratio of the density (or specific weight) of a substance to the density (or specific weight) of water at $4\,^{\circ}C$.

The specific gravity of a substance s is given by:

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The density of gasoline at $25\,^{\circ}C$ is 680 kg/m^3 and the density of water at $4\,^{\circ}C$ is 1000 kg/m^3. Therefore, the specific gravity of gasoline at $25\,^{\circ}C$ is $sg = 680/1000 = 0.68$.

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The specific weight of mercury at $25\,^{\circ}C$ is 132.8 kN/m^3 and the specific weight of water at $4\,^{\circ}C$ is 9.81 kN/m^3 so the specific gravity of mercury at $25\,^{\circ}C$ is $sg = 13.54$.

Example 3

Calculate the density and the specific weight of benzene which has a specific gravity of 0.876.

Example 4

An open cylindrical tank with diameter 5.75 m and depth 3.30 m is filled to the top with water at $10℃$.

The water is then heated to $55℃$. Assume that the tank dimensions remain constant and there are no losses due to evaporation

Calculate the mass of water that overflows.

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- Pressure relative to a perfect vacuum is called **absolute pressure**
- Pressure relative to the surrounding atmosphere is called **gauge pressure**
- Absolute, atmospheric and gauge pressures are related by the following expression:

$$\boxed{p_{abs} = p_{atm} + p_{gauge}}$$

Absolute and Gauge Pressure

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- Normal pressure at sea-level is 101.3 kPa (or 14.7 psi) but changes with the weather. The highest recorded pressure (adjusted to sea-level) of 110.0 kPa was measured in the middle of Siberia and the lowest of 89.1 kPa in a typhoon in the South Pacific.

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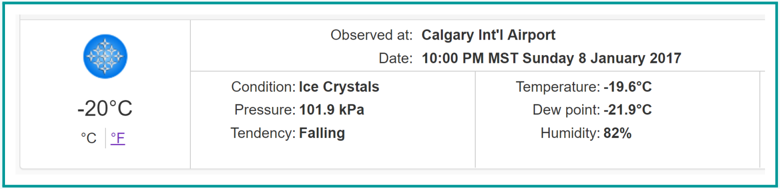
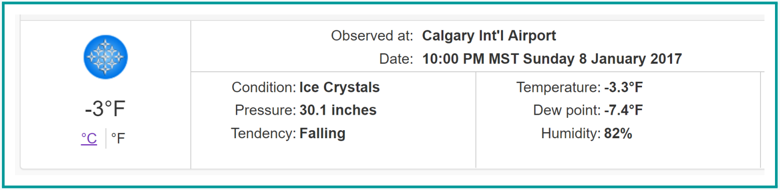
- Atmospheric pressure also varies with altitude. The pressure at the top of Everest is approximately one-third of that at sea-level (and contains one-third of the oxygen available at sea-level).

Atmospheric Pressure

In January, 2017, the atmospheric pressure at Calgary International Airport was reported by Environment Canada to be 101.9 kPa:



The US measures pressure in inches of mercury:



http://weather.gc.ca/city/pages/ab-52_metric_e.html

Pressure and Elevation

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- Weather stations do not normally display this difference due to elevation; the stations adjust the pressure for elevation. Thus, 103.1 kPa was the reported pressure in Leh on Monday 9th January, 2017, at 12.05pm. This adjustment enables us to know something about the weather conditions in a particular location without knowing the elevation and making calculations.

  http://www.worldweatheronline.com/Leh-weather/Jammu-and-Kashmir/IN.aspx

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- Elevation relative to some reference level is usually denoted by z.
  A difference in elevation between two points is usually denoted by h.

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Pressure and Elevation

The change in pressure in a homogeneous liquid at rest due to change in elevation is given by:

$$\boxed{\Delta p = \gamma h}$$

where

$$\begin{aligned} \Delta p &= \text{change in pressure} \\ \gamma &= \text{specific weight of liquid} \\ h &= \text{change in elevation} \end{aligned}$$

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Note:

1. This equation does not apply to gases
2. Points at the same elevation (same horizontal level) have the same pressure (see Pascal's Paradox)
3. This equation is stated for absolute values of change in pressure. Pressure increases with increased depth.

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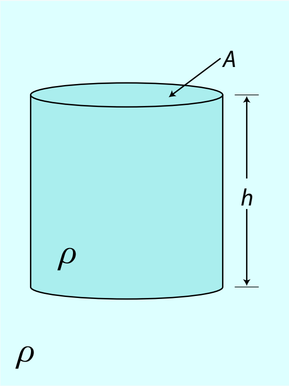
Derivation of $\Delta p = \gamma h$



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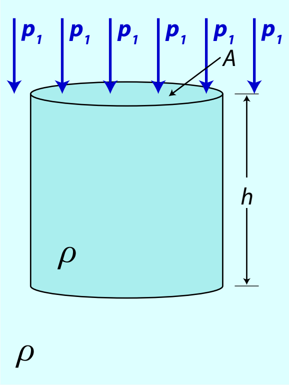

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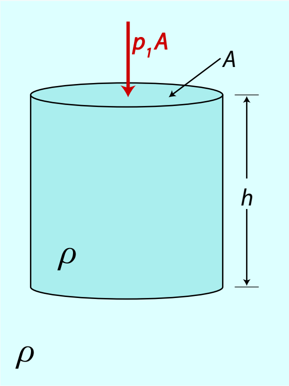

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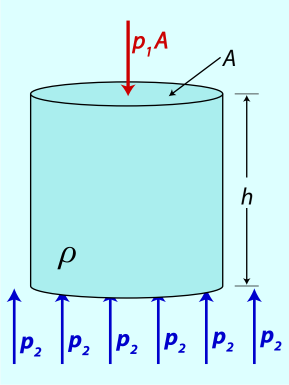

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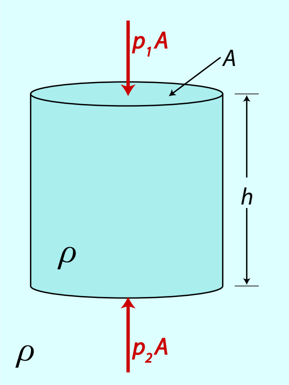

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- The force exerted on the top surface is $F_{down} = p_1 A$.
- Similarly the pressure, p_2, on the bottom surface of the cylinder is uniform ...
- ... and $F_{up} = p_2 A$.

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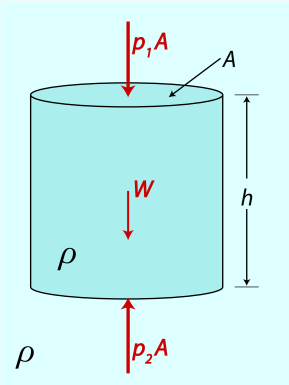

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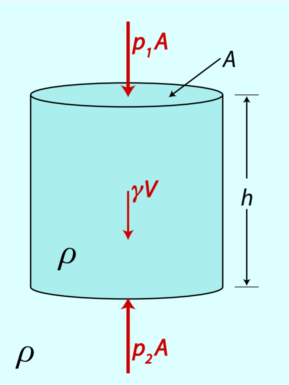

- The other force to be considered is the weight, W, of the cylindrical volume
- $W = \gamma \cdot V$

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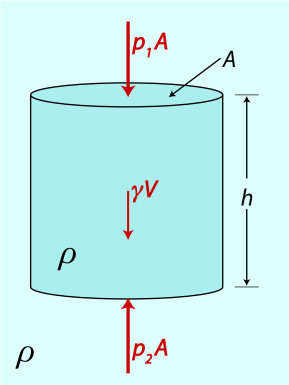

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$$\Sigma F_y = p_2 A - \gamma V - p_1 A = 0$$

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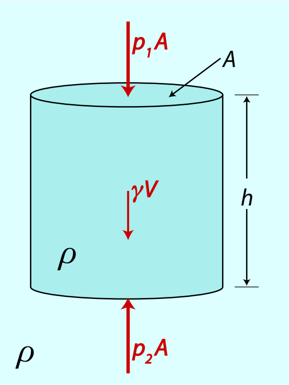

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- $W = \gamma \cdot V$
- The cylinder is in equilibrium so
$$\Sigma F_y = p_2 A - \gamma V - p_1 A = 0$$
- $V = Ah$ so
$$\begin{aligned} p_2 A - \gamma \cdot Ah - p_1 A &= 0 \\ p_2 - \gamma h - p_1 &= 0 \\ p_2 - p_1 &= \gamma h \\ \Delta p &= \gamma h \end{aligned}$$

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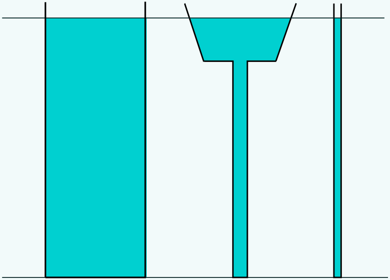
Pascal's Paradox



Pascal's Paradox

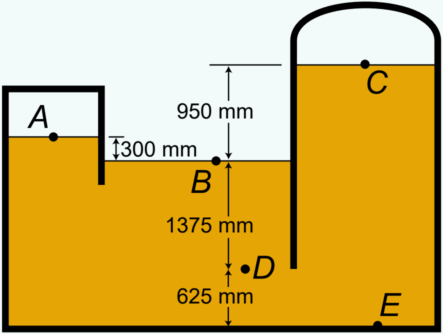
All three vessels contain the same liquid. The pressure at the bottom of each vessel is the same because pressure is due only to the depth of liquid.

Water Tower

Water Tower

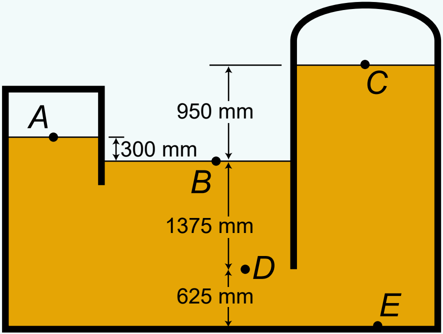
Example 5

A tank, open to the atmosphere in the centre, contains medium fuel oil. Atmospheric pressure is 102.1 kPa. Calculate the gauge pressure and the absolute pressure for locations A, B and D.

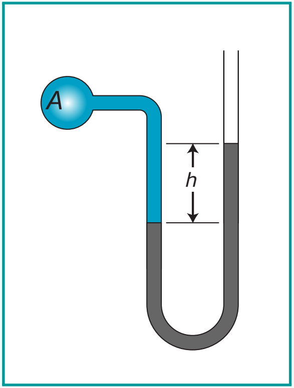


Exercise 2

A tank, open to the atmosphere in the centre, contains medium fuel oil. Atmospheric pressure is 102.1 kPa. Calculate the gauge pressure and the absolute pressure for locations C and E.



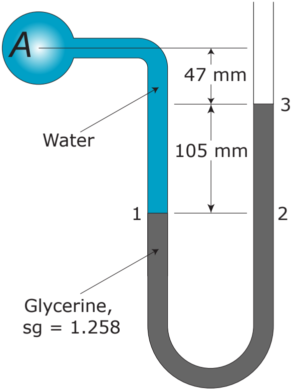
Manometers



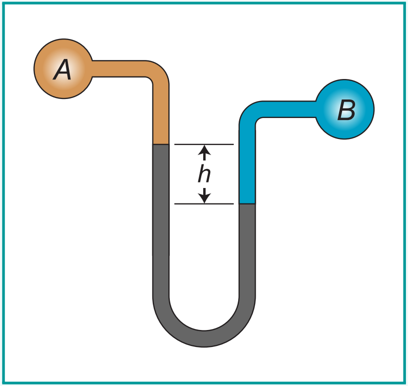
- A manometer is a pressure-measuring instrument.
- It uses the height of a liquid column, h, to measure the pressure difference between two locations.
- This manometer is open to the atmosphere at one end; it is used to measure the difference in pressure between A and the atmosphere (that is, it measures gauge pressure at A).

Example 6

Determine the pressure at A given that the temperature of the water is 25°C.



Differential Manometers



- The **differential manometer** illustrated is used to measure the difference in pressure between A and B.

Example 7

Determine the pressure difference between A and B.