L 13 Fluids [2]:
Fluid Statics \(\rightarrow\) fluids at rest

- More on fluids at rest
- How is atmospheric pressure measured?
- Buoyancy: How can a steel boat float?

Review: Pressure = force per unit area

Example: A large rectangular box having a mass of 4.8 kg has dimensions of 2 m x 3 m x 4 m. What pressure would this box exert on the floor depending on which side it is set on?

\[ P = \frac{F}{A} \]

the force exerted by the box is equal to its weight: \( w = mg \) = 4.8 kg \( \times \) 10 m/s\(^2\) = 48 N. There are 3 possible values of the area A depending on which side rests on the floor:

\[ A_1 = 2 \text{ m} \times 3 \text{ m} = 6 \text{ m}^2, \quad A_2 = 2 \text{ m} \times 4 \text{ m} = 8 \text{ m}^2, \quad A_3 = 3 \text{ m} \times 4 \text{ m} = 12 \text{ m}^2. \]

\[ P_1 = \frac{w}{A_1} = \frac{48 \text{ N}}{6 \text{ m}^2} = 8 \text{ Pa} \]
\[ P_2 = \frac{w}{A_2} = \frac{48 \text{ N}}{8 \text{ m}^2} = 6 \text{ Pa} \]
\[ P_3 = \frac{w}{A_3} = \frac{48 \text{ N}}{12 \text{ m}^2} = 4 \text{ Pa} \]

Pressure in a fluid increases with depth \(h\)

The pressure at the surface is atmospheric pressure \((1 \text{ atm})\)

\[ P_0 = P_{\text{atm}} = 1.013 \times 10^5 \text{ N/m}^2 = 1.013 \times 10^5 \text{ Pa} \]

\[ P(h) = P_0 + \rho g h \]

\( \rho = \text{density (kg/m}^3\) \)

\( \approx 1000 \text{ kg/m}^3 \) for water

\( \rho g h = 1000 \times 10 \times h = 10^4 h \)

Pressure is always perpendicular to the surface of an object

Pressure depends only on depth

\[ P = P_0 = 1 \text{ atm} = 10^5 \text{ Pa} \]

\[ P = P_0 + 2 \text{ atm} = 2 \times 10^5 \text{ Pa} \]

\[ P = P_0 + 3 \text{ atm} = 3 \times 10^5 \text{ Pa} \]

All 3 objects experience same pressure

Pascal’s Vases

- The fluid levels are the same in all each tube irrespective of their shape
Pressure increases with depth, so the speed of water leaking from the bottom hole is larger than that from the higher ones.

Measuring atmospheric pressure - Barometers

- The column of liquid is held up by the pressure of the liquid in the tank.
- \( P_{\text{liquid}} = P_{\text{ATM}} \) at surface, \( \rho \) the atmosphere holds the liquid up.

Barometric pressure

Atmospheric pressure can support a column of water 10.3 m high, or a column of mercury (which is 13.6 times as dense as water) 30 inches high → the mercury barometer

http://forecast.weather.gov/MapClick.php?zoneid=IAZ064

Pascal’s Principle

- If you apply pressure to an enclosed fluid, that pressure is transmitted equally to all parts of the fluid
- If I exert extra pressure on the fluid with a piston, the pressure in the fluid increases everywhere by that amount
- Cartesian diver

Pascal’s Principle

A change in pressure in an enclosed fluid at rest is transmitted undiminished to all points in the fluid

A hydraulic car lift

- Pressure is \( F/A \)
- At the same depth the pressures are the same
- so \( F_1/A_1 = F_2/A_2 \), or
  \[ F_2 = F_1 \left( \frac{A_1}{A_2} \right) \]
- with a little force you can lift a heavy object!
- the jack
Water pumps and drinking straws

- A ground level pump can only be used to cause water to rise to a certain maximum height since it uses atmospheric pressure to lift the water.
- For deeper wells, the pump must be located at the bottom.
- When you use a straw, you create a vacuum in your mouth and atmospheric pressure pushes the liquid up.

Pressure depends only on depth

- The pressure at the bottom of the lake is higher than at the top.
- The dam must be thicker at its base.
- The pressure does not depend on how far back the lake extends.

Blood Pressure

- Sphygmomanometer.
- The blood pressure in your feet can be greater than the blood pressure in your head depending on whether a person is standing or reclining.

Buoyancy – why things float

- The trick is to keep the water on the outside, and avoid hitting icebergs (which also float), which are easy to miss since 90% of it is submerged.
- The hole in the hull was only about 1 m².

Buoyant Force

- The water pushes down on the top of the object, and pushes up on the bottom of the object.
- The difference between the upward force and the downward force is the buoyant force $F_B$.
- Since the pressure is larger on the bottom, the buoyant force is UP.
- There is a buoyant force even if the object does not float.
Archimedes principle

The buoyant force on an object in a fluid equals the weight of the fluid which it displaces.
- water weighs 10N/liter → each liter of displaced water provides 10 N of buoyant force
  - this works for objects in water
  - helium balloons (density of He = 0.18 kg/m³)
  - hot air balloons → the density of hot air is lower than the density of cool air so the weight of the cool air that is displaced is larger than the weight of the balloon

Will it float?

- The object will float if the buoyant force is enough to support the object’s weight
- The object will displace just enough water so that the buoyant force = its weight
- If it displaces as much water as possible and this does not match its weight, it will sink.
- Objects that have a density less than water will always float in water, e.g., oil
- A steel bolt will float in mercury ($\rho = 13.6$ g/cm³)

Floating objects

lighter object

heavier object

Floating in a cup of water

Only a thin layer of water around the hull is needed for the ship to float!

Oil Tankers

empty tanker

full tanker