Irreversible Cartesian Diver

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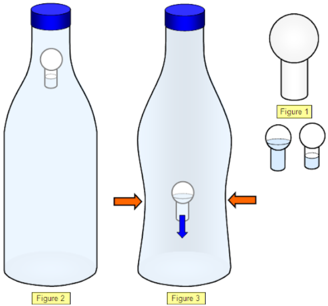
IYPT preparatory seminar

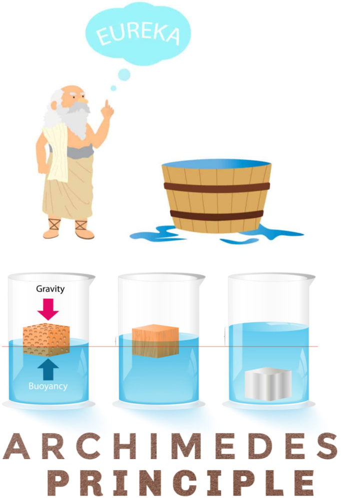
(Irreversible) Cartesian Diver: the phenomenon



- **Diver**: prepared filled with some water and some air.
- **Diver Floats**: when released into water container.
- **Diver Sinks**: on increasing pressure inside the container.
- 1. **Diver Bounce back**: on removing the (excess) pressure.
  2. **Diver remains sunk**: on removing the (excess) pressure.

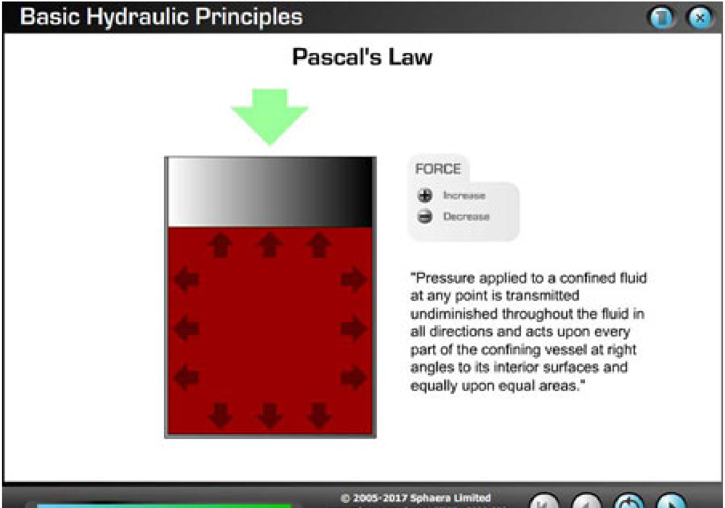
The physical principles governing Cartesian Diver

Archimedes' principle: Any object, totally or partially immersed in a fluid or liquid, is buoyed up by a force equal to the weight of the fluid displaced by the object.



Pascal's principle

A pressure change at any point in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere.



Cartesian Diver: first we note that:

1. Diver has non homogeneous density:
   (i) of her/his body,
   (ii) of water inside the body, and
   (iii) density of air inside the body.
   Let average density be ρ_D.

2. Diver has a fixed volume (V_D), and therefore a limiting value of Buoyancy: $F_B^{max} = \rho_{water}\ V_D\ g$.

3. The average density of the Diver ρ_D is a variable quantity (we will see how !).

Cartesian Diver: what is going on?

- Initially, $F_B^i = \rho_D^i \; V_D \; g$, so diver floats.
- When pressure is increased, volume of air inside the Diver decreases and more water fills into the Diver. As a result the average density (so weight) of Diver increases to a value greater than F_B^{max} and the Diver starts sinking, i.e., when
$$\rho_D \; V_D \; g > F_B^{max}$$
.
- As the Diver sinks, pressure further increases due to increasing depth h, and as a result the air inside the Diver is compressed further and even more water fills into the Diver. Weight of Diver increases, and he sinks faster.

Cartesian Diver: what is going on?

- If the excess pressure applied to make the Diver sink is removed quickly, the phenomenon is reversible. I.e., the air inside the Diver expands, s/he loses some water, and therefore weight of the Diver reduces below F_B^{max}. The Diver starts moving upwards and after sometime floats on the surface again.

- However, if the Diver sinks beyond a certain critical depth $h \geq h_{critical}$, even after removing the excess pressure the motion is irreversible, and s/he sinks to the bottom. Why? How to find $h_{critical}$!

Irreversible Cartesian Diver

- We noted before that as the Diver sinks deeper, also the non-external static water pressure increases due to the depth: $P_h = \rho_{water}\ gh$.
- We can derive weight of the Diver as a function of non-external static pressure $\rho_D(h)\ V_D g$.
- Then, $\rho_D(h_{critical})\ V_D g = F_B^{max}$.
- We can solve for $h_{critical}$.
- If the Diver sinks to a depth $h \geq h_{critical}$, even the maximum possible Buoyancy force is not enough to propel her/him upwards; s/he sinks further!

Irreversible Cartesian Diver: Realistic models and Experiments

- We measure density of water, body of the Diver, and mass of air inside the Diver.
- We measure volume of the Diver.
- We derive average density (and thus weight) of the Diver as a function pressure.
- Then we compute $h_{critical}$.

THANK YOU