PHYSICS 2: FLUID MECHANICS AND THERMODYNAMICS

Phan Hiền Vũ

Department of Physics - IU VNU-HCM

Office: A1.503

Email: phvu@hcmiu.edu.vn

- No of credits: 02 (30 teaching hours)
- Textbook: Halliday/Resnick/Walker (2018) entitled Principles of Physics, 11th edition, John Willey & Sons, Inc.

Course Requirements

- Progressing: Attendance (5%) + Homework (5%) + Discussion (10%) + Quiz (10%)
- Mid-term exam: 30%
- Final exam: 40%
- Absence more than 20% → not allowed to attend the Final exam

Preparation for each class

- Read text ahead of time
- Finish homework

Questions, Discussion

- Via email and/or make an appointment to meet at A1.503

Content

(Chapters 14, 18, 19, 20 of Principles of Physics, Halliday et al.)

CHAPTER 1 FLUID MECHANICS

1.1. Fluids at Rest

1.2. Ideal Fluids in Motion

1.3. Bernoulli's Equation

Question: What is a fluid?

A fluid is a substance that can flow (liquids, gases)

Physical parameters:

Density: (the ratio of mass to volume for a material)

$$\rho = \frac{\Delta m}{\Delta V}$$

- Δm and ΔV are the mass and volume of the element, respectively.
- Density has no directional properties (a scalar property)

Unit: kg/m^3 or g/cm^3; $1\ g/cm^3 = 1000\ kg/m^3$

Uniform density:

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

Fluid Pressure:

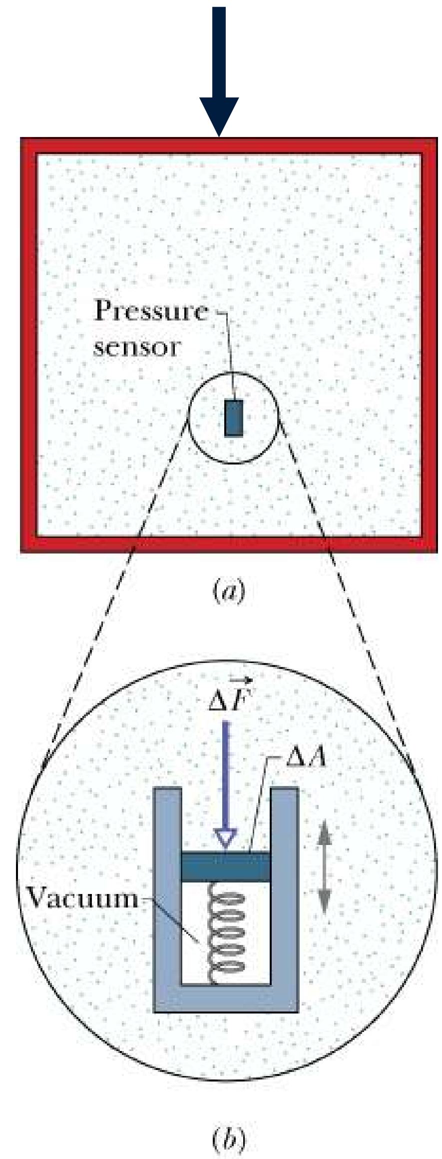
- Pressure is the ratio of normal force to area
  - Pressure is a scalar property
  - Unit:
    - SI: N/m^2 = Pa (Pascal)
    - Non-SI: atm = 1.01×10^5 Pa
- Fluid pressure is the pressure at some point within a fluid:

$$p = \frac{\Delta F}{\Delta A}$$

- Uniform force on flat area:

$$p = \frac{F}{A}$$

A fluid-filled vessel



Fluid Properties:

- Fluids conform to the boundaries of any container containing them.
- Gases are compressible but liquids are not, e.g., see Table 14-1:
  - Air at 20^0C and 1 atm pressure: density (kg/m^3)=1.21

    20^0C and 50 atm: density (kg/m^3)=60.5

  → The density significantly changes with pressure

  - Water at 20^0C and 1 atm: density (kg/m^3)=0.998×10^3

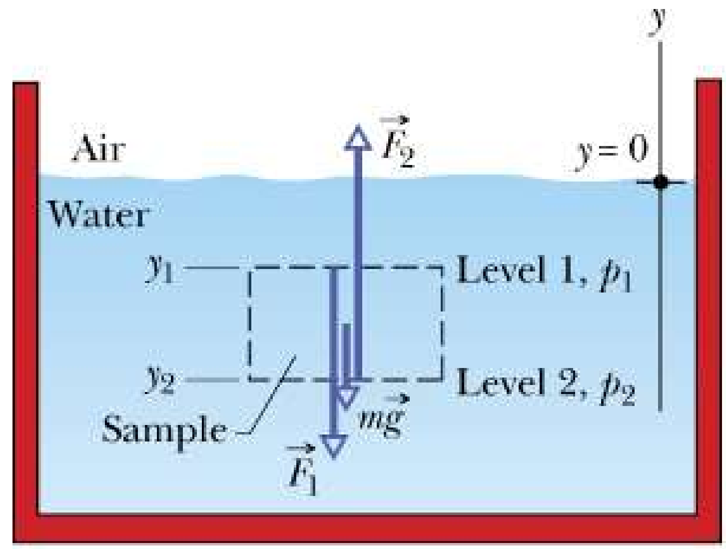
    20^0C and 50 atm: density (kg/m^3)=1.000×10^3

  → The density does not considerably vary with pressure

1.1. Fluids at Rest

The pressure at a point in a non-moving (static) fluid is called the hydrostatic pressure, which only depends on the depth of that point.

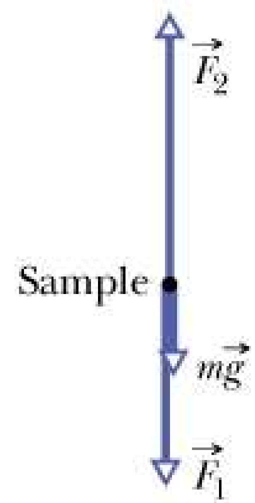
Problem: We consider an imaginary cylinder of horizontal base area A



$$F_2 = F_1 + mg$$

$$F_1 = p_1 A$$

$$F_2 = p_2 A$$



$$\longrightarrow \quad p_2 A = p_1 A + \rho A (y_1 - y_2) g$$

$$\boxed{p_2 = p_1 + \rho (y_1 - y_2) g}$$

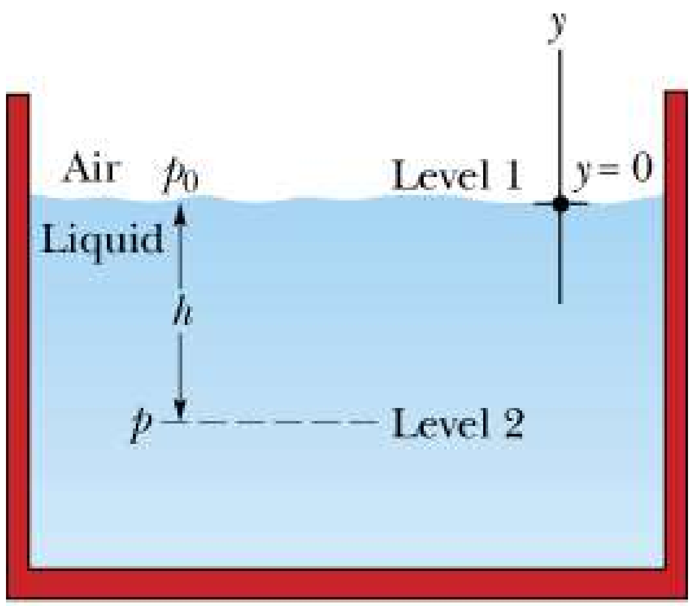
- If $y_1 = 0$, $p_1 = p_0$ (on the surface) and $y_2 = -h$, $p_2 = p$:

$$p = p_0 + \rho g h$$

gauge pressure

absolute pressure

atmospheric pressure

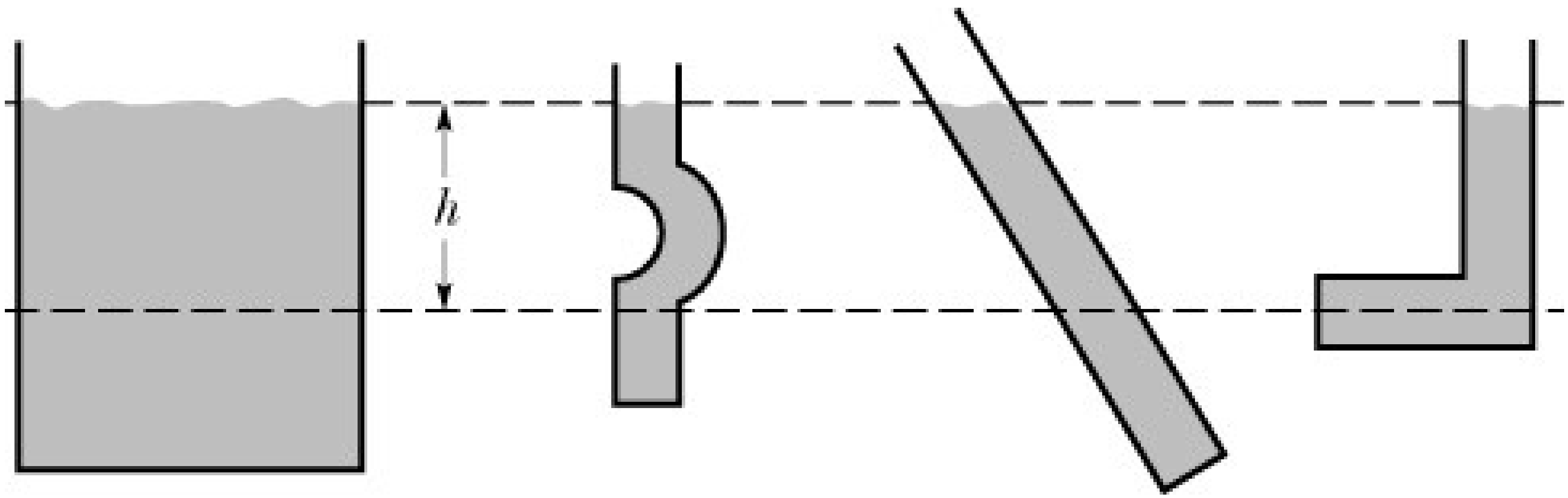


- Calculate the atmospheric pressure at d above level 1:

$$p = p_0 - \rho_{air} g d$$

Question:

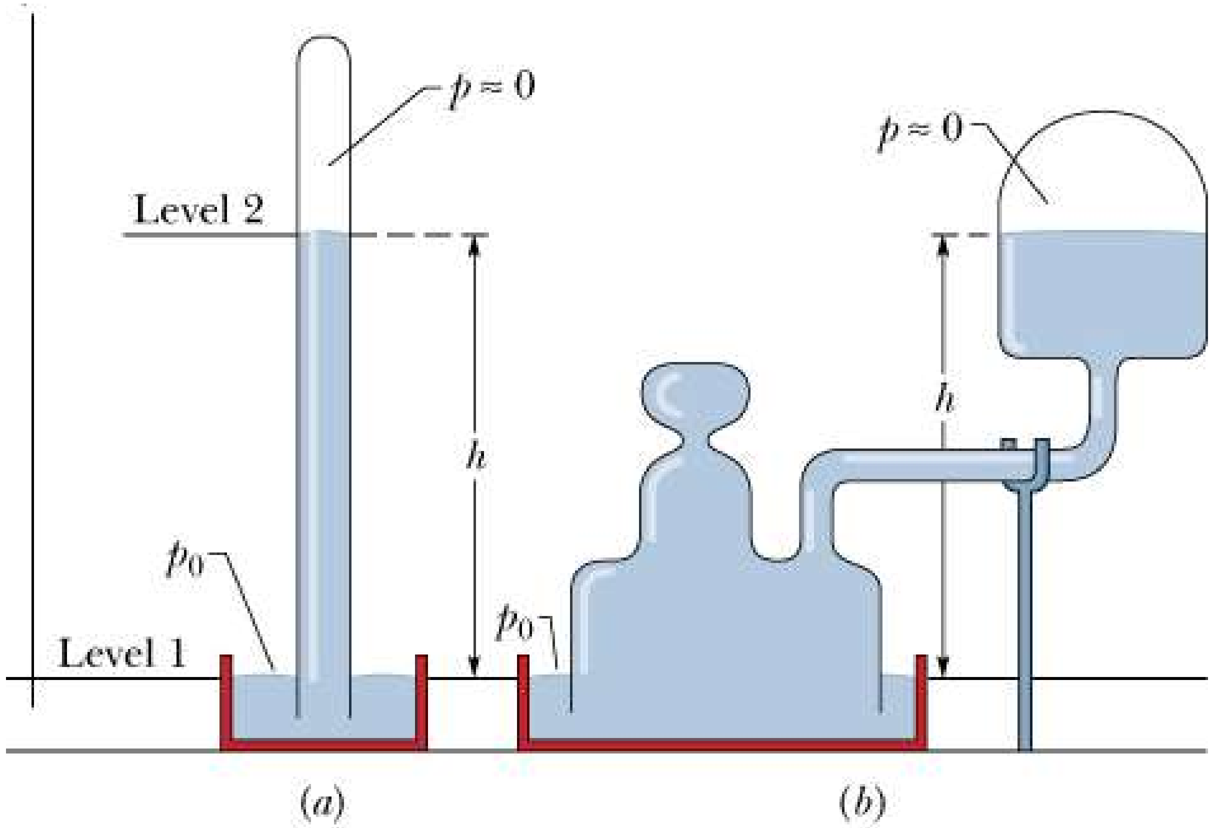
There are four containers of water. Rank them according to the pressure at depth h, greatest first.



(a) (b) (c) (d)

A. Measuring pressure:

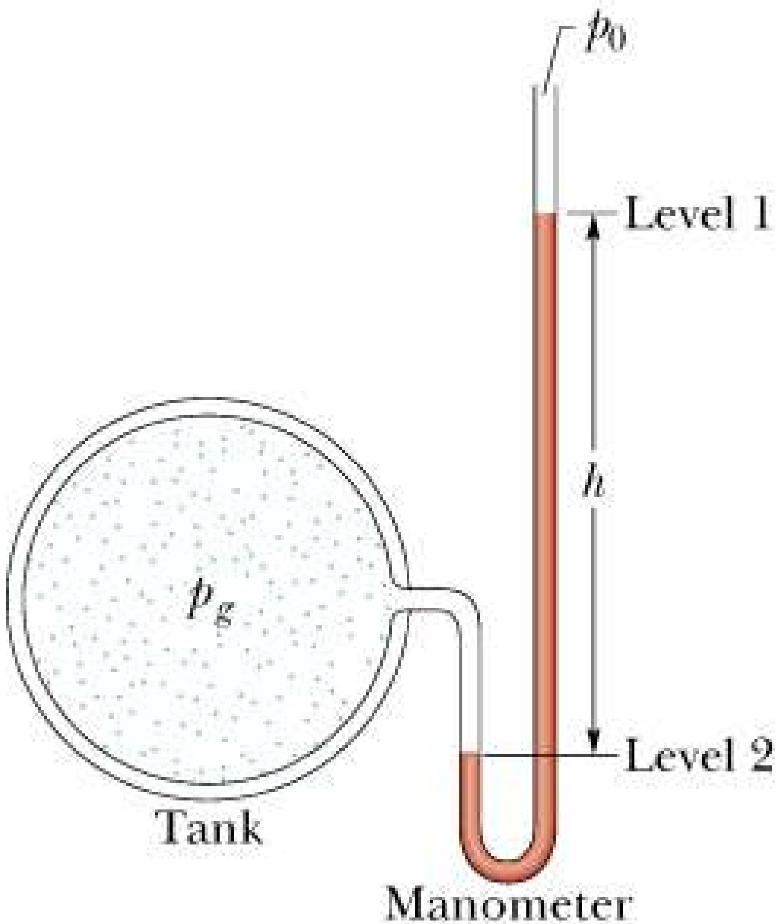
Mercury barometers (atmospheric pressure)



$$p_0 = \rho g h$$

ρ is the density of the mercury

An open-tube manometer (gauge pressure)

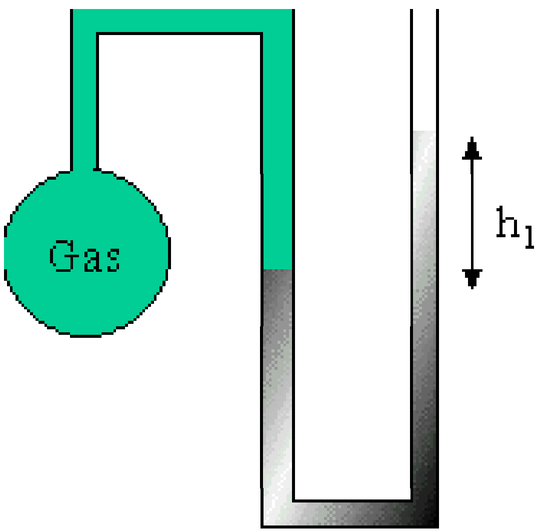


$$p_g = \rho g h$$

ρ is the density of the liquid

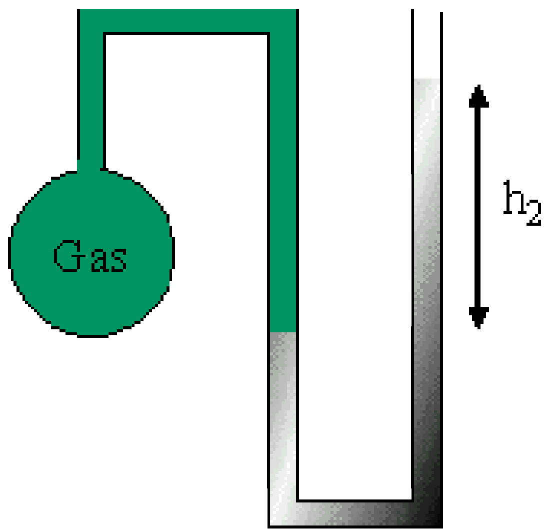
The gauge pressure can be positive or negative:

closed tube



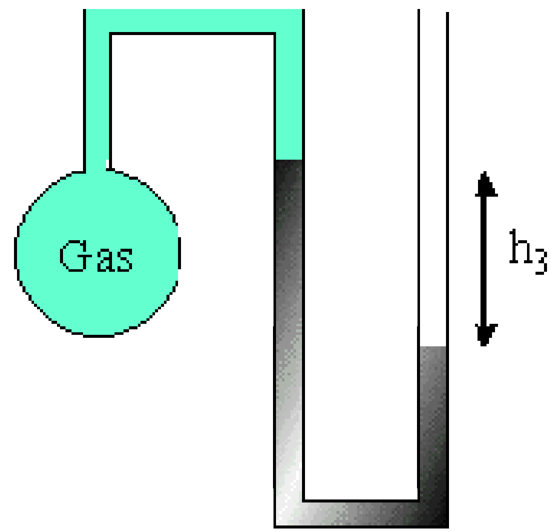
$$p_{gas} = \rho g h_1$$
$$p_{gauge} = p_{gas} - p_0 = \rho g h_1 - p_0$$

open tube



$$p_{gas} = \rho g h_2 + p_0$$
$$p_{gauge} = p_{gas} - p_0 = \rho g h_2 > 0$$

open tube



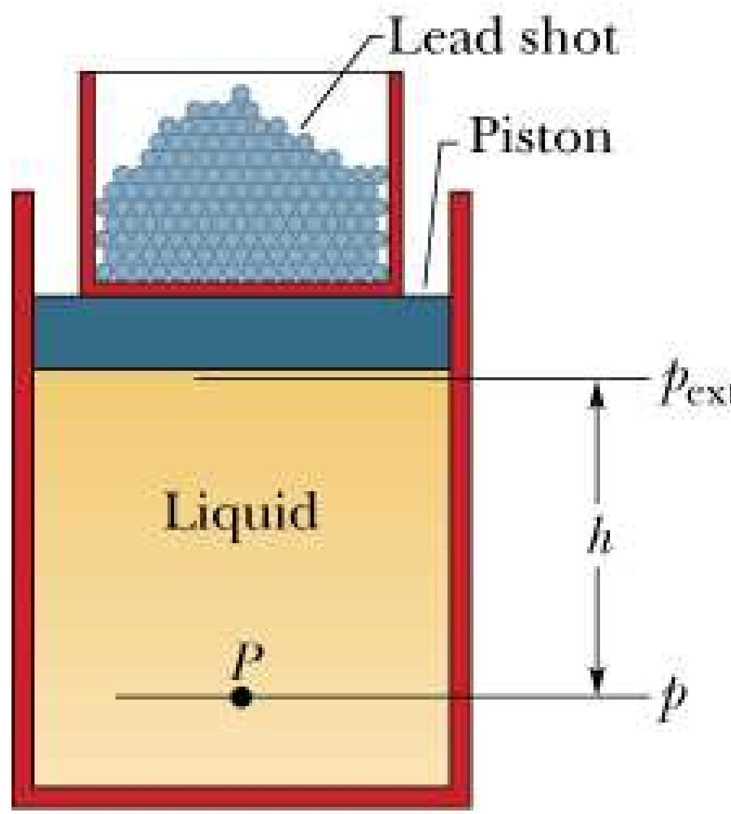
$$p_{gas} + \rho g h_3 = p_0$$
$$p_{gauge} = p_{gas} - p_0 = -\rho g h_3 < 0$$

B. Pascal’s Principle:

A change in the pressure applied to an enclosed incompressible fluid is transmitted undiminished to every part of the fluid, as well as to the walls of its container.

$$p = p_{ext} + \rho g h$$

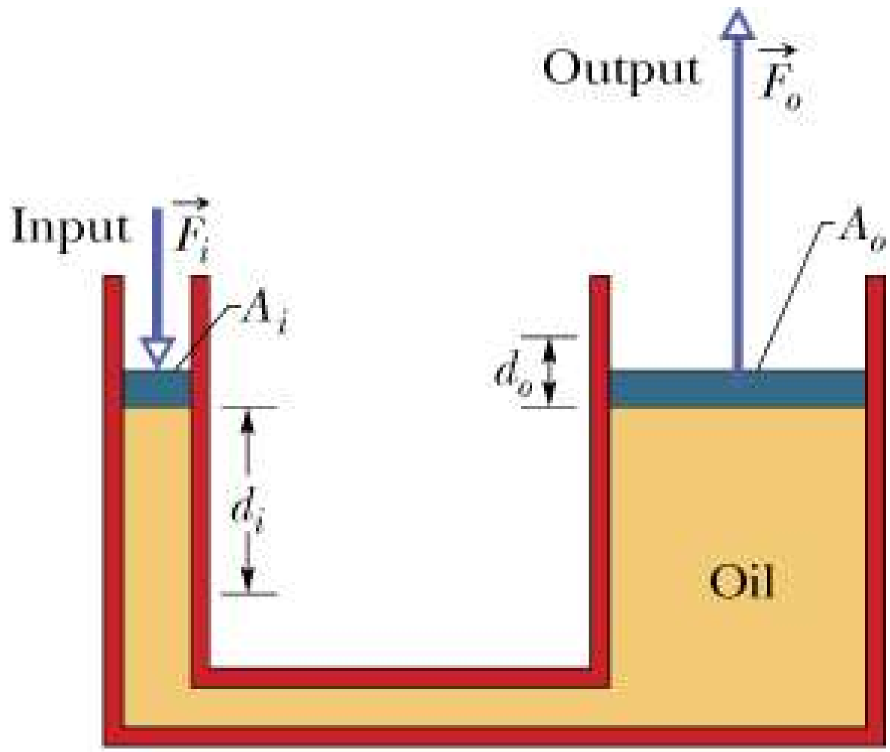
$$\Delta p = \Delta p_{ext}$$



- Application of Pascal's principle:

$$\Delta p = \frac{F_i}{A_i} = \frac{F_0}{A_0}$$

$$F_0 = F_i \frac{A_0}{A_i}$$



A Hydraulic Lever

$A_0 > A_i \rightarrow F_0 > F_i$

The output work:

$$W = F_i d_i = F_0 d_0$$

https://www.youtube.com/watch?v=hV5IEooHqIw

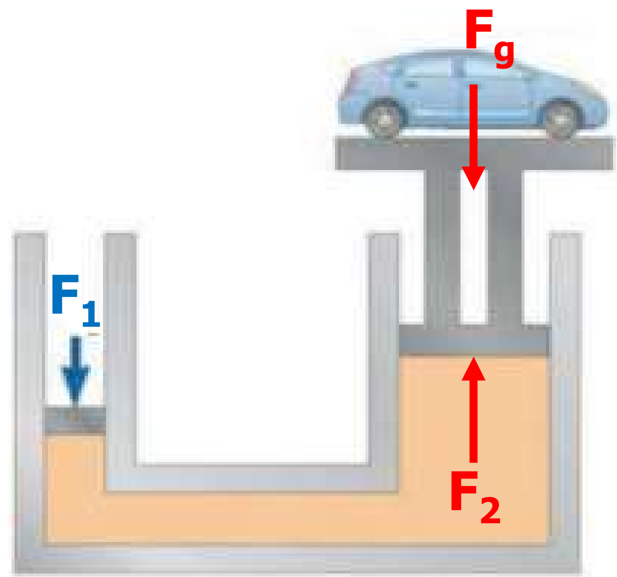
Sample: What force must be exerted on the master cylinder of a hydraulic lift to support the weight of a 2000 kg car (a large car) resting on the slave cylinder, see Figure? The master cylinder has a 2.0 cm diameter and the slave has a 24.0 cm diameter.

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_1 = F_2 \frac{A_1}{A_2} = m_2 g \frac{\pi r_1^2}{\pi r_2^2}$$

$$F_1 = (2000)(9.8) \frac{\left(\frac{0.02}{2}\right)^2}{\left(\frac{0.24}{2}\right)^2}$$

$F_1 = 136.11$ N



C. Archimedes's Principle:

We consider a plastic sack of water in static equilibrium in a pool:

$$\vec{F}_g + \vec{F}_b = 0$$

The net upward force is a buoyant force $\vec{F}_b$
$F_b = F_g = m_f\, g$ (m_f is the mass of the sack)

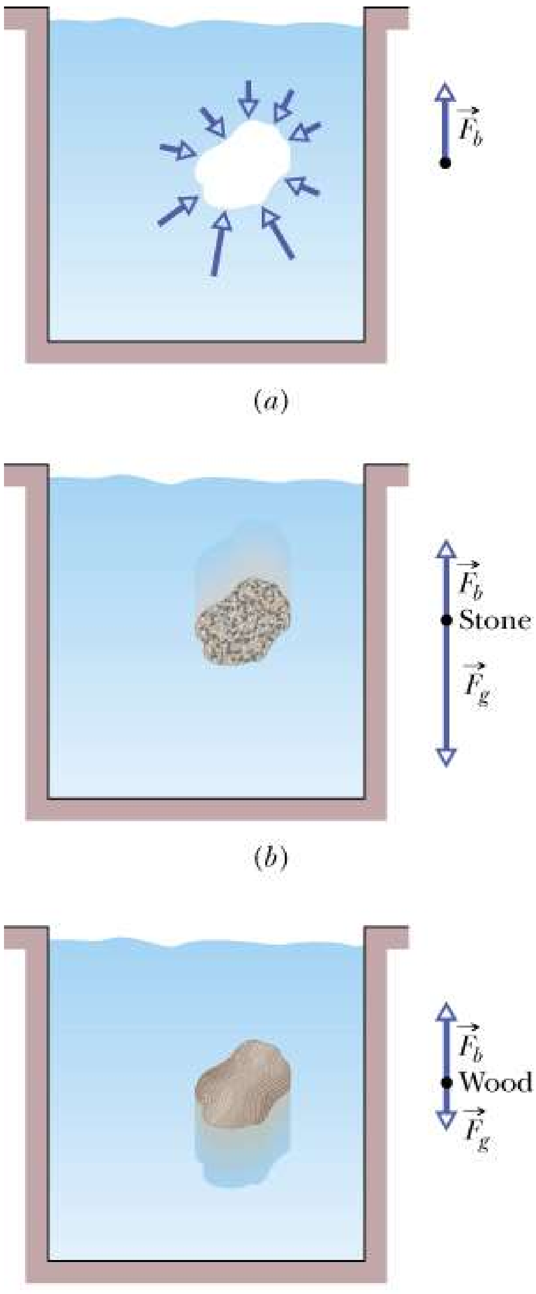
$$\boxed{F_b = \rho_{fluid}\, g V}$$

V: volume of water displaced by the object, if the object is fully submerged in water, $V = V_{object}$

If the object is not in static equilibrium, see figures (b) and (c):

$$F_b < F_g \text{ (case b: a stone)}$$

$$F_b > F_g \text{ (case c: a lump of wood)}$$



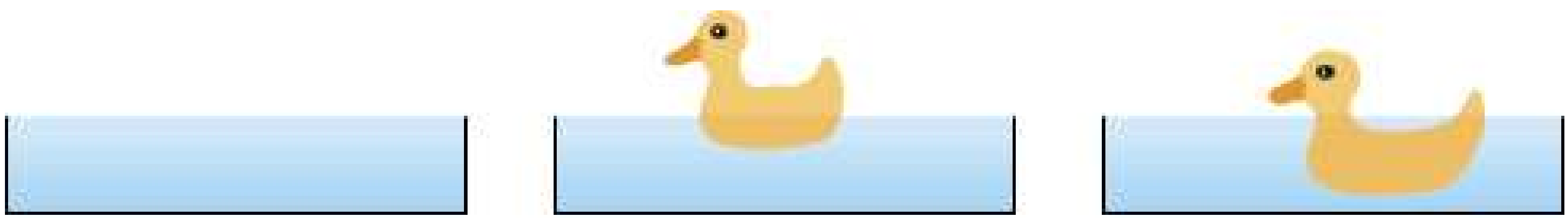
(a) (b) (c)

The buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object.

Apparent weight in a Fluid:

$$\mathbf{weight_{app} = weight_{actual} - F_b}$$

Question: Three identical open-top containers filled to the brim with water; toy ducks float in 2 of them (b & c). Rank the containers and contents according to their weight, greatest first.



(a) (b) (c)

1.2. Ideal Fluids in Motion

We do only consider the motion of an ideal fluid that matches four criteria:

- Steady flow: the velocity of the moving fluid at any fixed point does not vary with time.
- Incompressible flow: the density of the fluid has a constant and uniform value.
- Non-viscous flow: no resistive force due to viscosity.
- Irrotational flow.

The Equation of Continuity

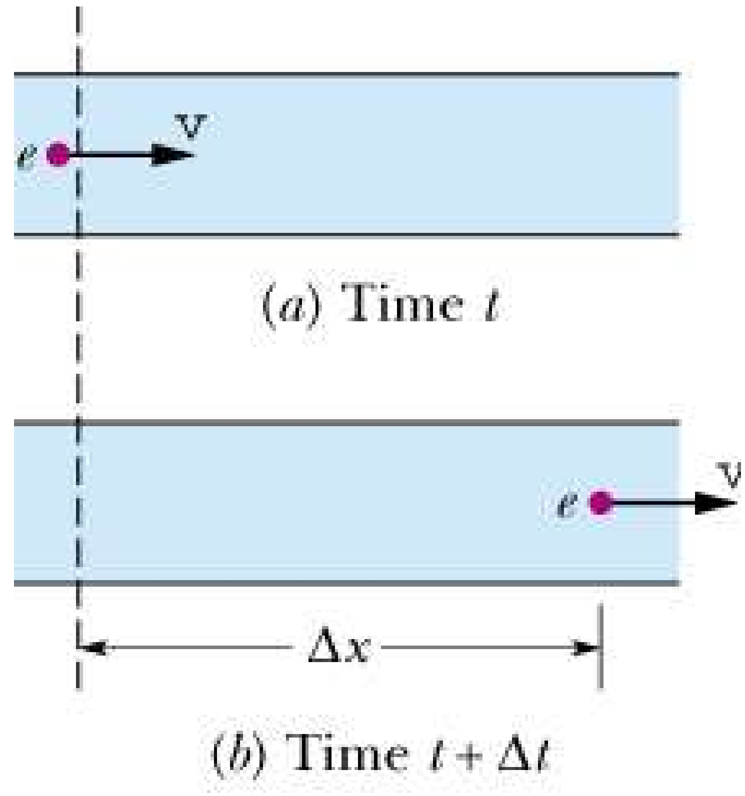
(the relationship between speed and cross-sectional area)

We consider the steady flow of an ideal fluid through a tube. In a time interval Δt, a fluid element e moves along the tube a distance:

$$\Delta x = v\Delta t$$

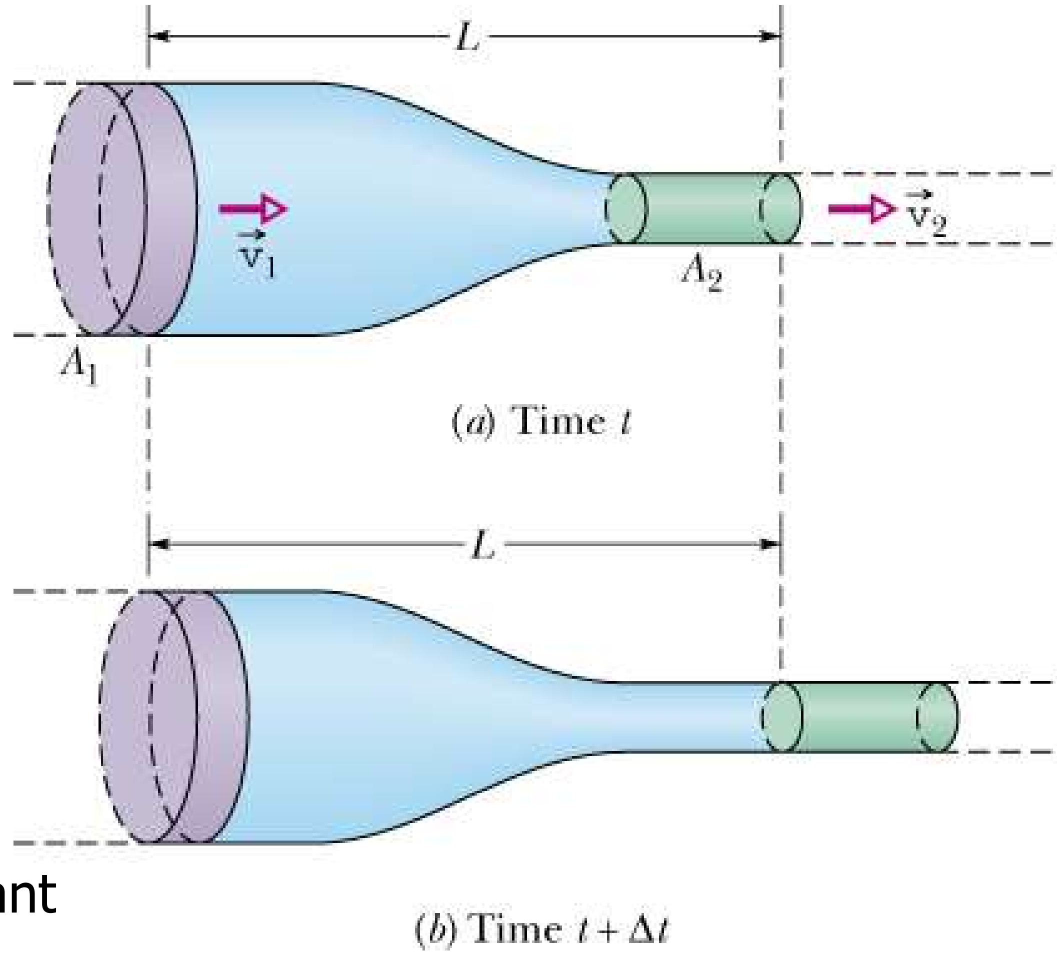
$$\Delta V = A\Delta x = Av\Delta t$$

$$\Delta V = A_1 v_1 \Delta t = A_2 v_2 \Delta t$$



The Equation of continuity

$$\boxed{A_1 v_1 = A_2 v_2}$$



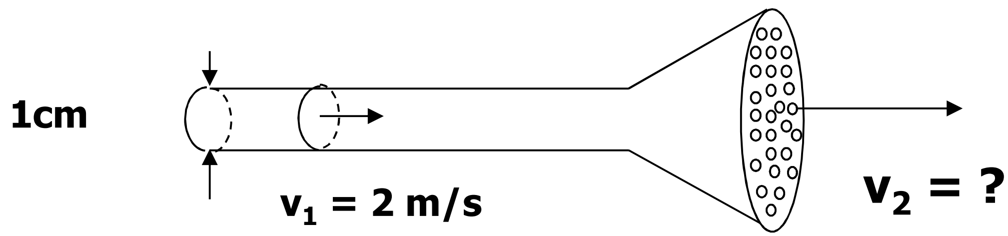
- Volume flow rate:

$$R_V = Av = \text{a constant}$$

- Mass flow rate:

$$R_m = \rho\, R_V = \rho\, Av = \text{a constant}$$

Sample: A sprinkler is made of a 1.0 cm diameter garden hose with one end closed and 40 holes, each with a diameter of 0.050 cm, cut near the closed end. If water flows at 2.0 m/s in the hose, what is the speed of the water leaving a hole?



Using the equation of continuity, the speed v_2 is:

$$v_1 A_1 = v_2 A_2 = v_2 (40 a_0)$$

a_0 is the area of one hole

$$v_2 = \frac{v_1 A_1}{40 a_0} = \frac{2.0 \times \pi \left(\frac{1.0}{2}\right)^2}{40 \times \pi \left(\frac{0.05}{2}\right)^2} = 20 \text{ (m/s)}$$

1.3. Bernoulli's Equation

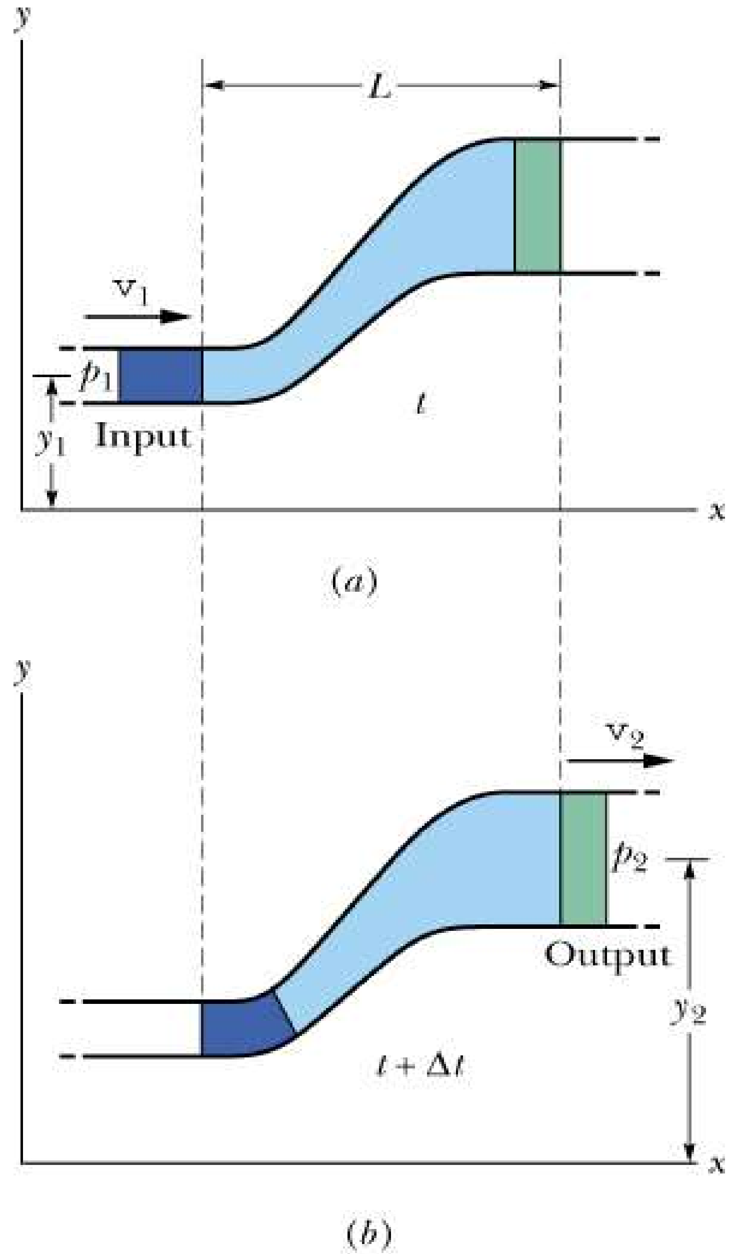
- An ideal fluid is flowing at a steady rate through a tube.
- Applying the principle of conservation of energy (work done = change in kinetic energy):

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

$$\boxed{p + \frac{1}{2}\rho v^2 + \rho g y = \text{a constant}}$$

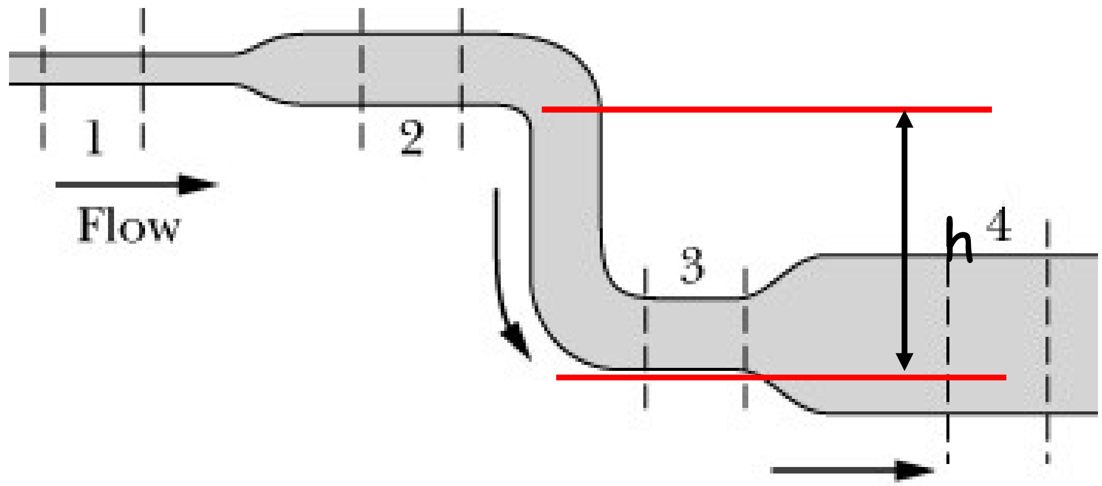
- If y=0: $p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$

→ As the velocity of a horizontally flowing fluid increases, the pressure exerted by that fluid decreases, and conversely.



https://www.youtube.com/watch?v=UJ3-Zm1wbIQ

Question: Water flows smoothly through a pipe (see the figure below), descending in the process. Rank the four numbered sections of pipe according to (a) the volume flow rate R_V, (b) the flow speed v, and (c) the water pressure p, greatest first.



Conclusion:

1. Pressure (N/m^2 = Pa): the ratio of normal force to area

$$p = \Delta F/\Delta A$$

2. Gauge pressure and Absolute pressure:

$$p_g = \rho g h$$

$$p = p_0 + p_g \quad (p_0\text{: atmospheric pressure})$$

3. Pascal's principle

$$\Delta p = \frac{F_i}{A_i} = \frac{F_o}{A_o}$$

4. Bouyant force (Archimedes' principle):

$$F_b = \rho g V$$

5. Volume flow rate (m^3/s) and Mass flow rate (kg/s):

$$R_V = Av$$

$$R_m = \rho R_V$$

6. Bernoulli's Equation :

$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{a constant}$$

Homework:

(1) Read “Proof of Bernoulli’s Equation”

(2) Problems 1, 2, 17, 28, 38, 39, 48, 58, 65, 71 in Chapter 14 Textbook