ESO 201A: Thermodynamics

2016-2017-I semester

Introduction: part 3

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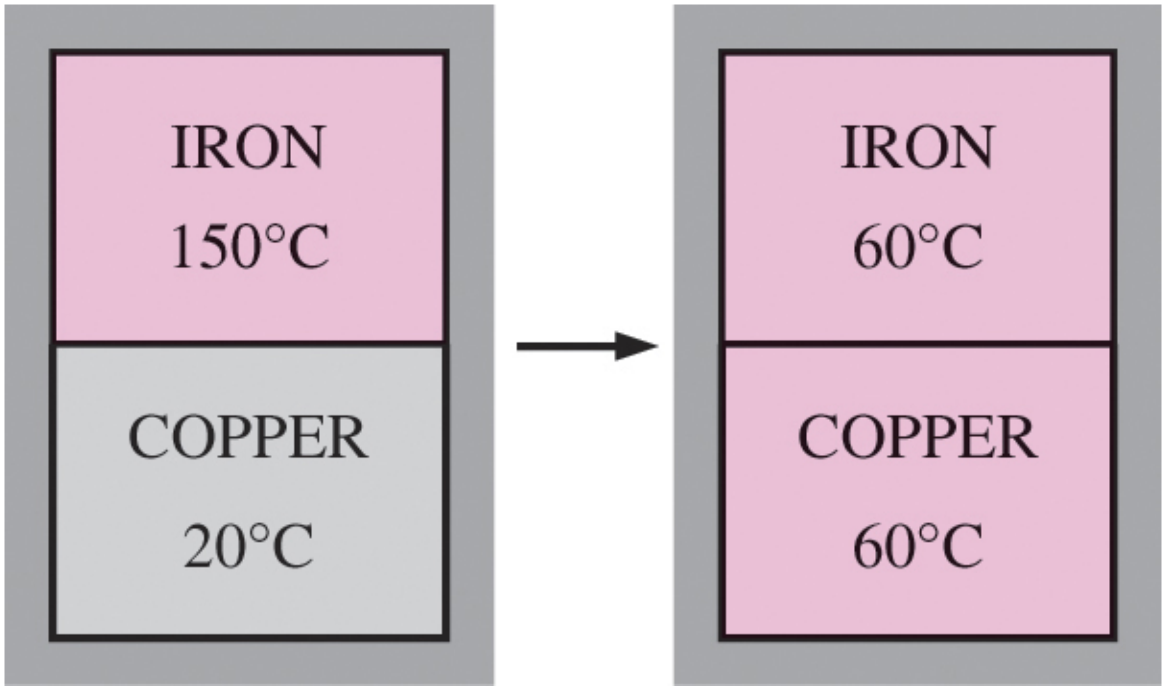
Learning objectives

1. Review of metric SI
2. Explain basic concept of :
   - *system, state, state postulate, equilibrium, and process*
3. Define intensive and extensive properties of system
4. Define density, specific gravity, and specific weight
5. Discuss temperature scale
6. Understanding pressure, barometer, manometer

Temperature and zeroth law of thermodynamics

- **The zeroth law of thermodynamics**: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.
- By replacing the third body with a thermometer, the zeroth law can be restated as *two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact*.



Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

Temperature scales

- All temperature scales are based on some easily reproducible states
  - freezing and boiling points of water: the *ice point* and the *steam point*.
- **Ice point**: A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure (0°C or 32°F).
- **Steam point**: A mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure (100°C or 212°F).
  - **Celsius scale**: in SI unit system (two point scale)
  - **Fahrenheit scale**: in English unit system
- **Thermodynamic temperature scale**: A temperature scale that is independent of the properties of any substance.
  - **Kelvin scale** (SI) **Rankine scale** (E)

Temperature scales

$$T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273.15$$

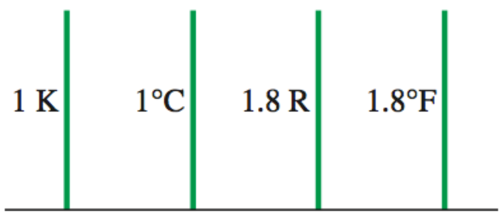
$$T(\mathrm{R}) = T(^\circ\mathrm{F}) + 459.67$$

$$T(\mathrm{R}) = 1.8T(\mathrm{K})$$

$$T(^\circ\mathrm{F}) = 1.8T(^\circ\mathrm{C}) + 32$$

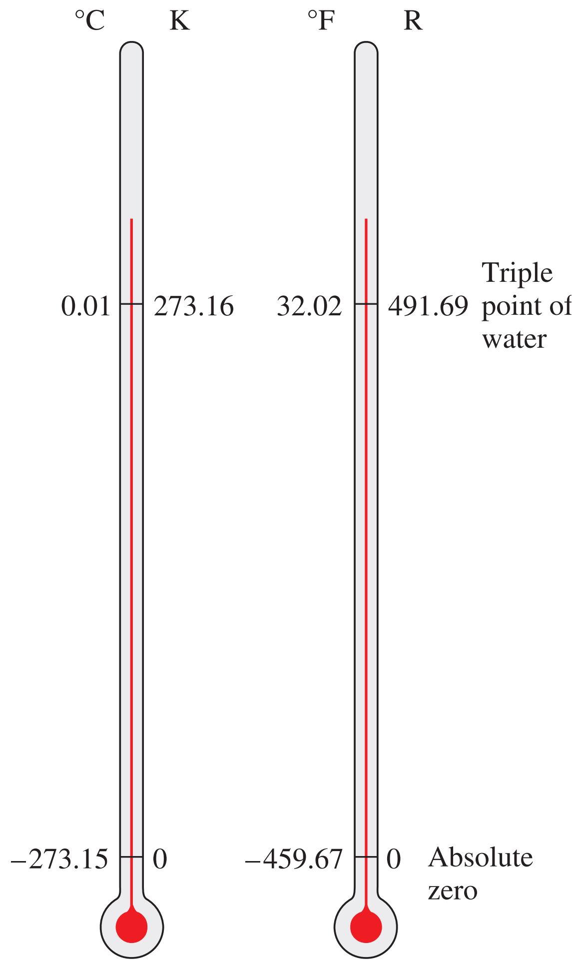
$$\Delta T(\mathrm{K}) = \Delta T(^\circ\mathrm{C})$$

$$\Delta T(\mathrm{R}) = \Delta T(^\circ\mathrm{F})$$



Comparison of magnitudes of various temperature units.

Comparison of temperature scales.



- The reference temperature in the original Kelvin scale was the ***ice point***, 273.15 K
- The reference point was changed to a much more precisely reproducible point, the ***triple point*** of water (the state at which all three phases of water coexist in equilibrium), which is assigned the value 273.16 K.

Pressure

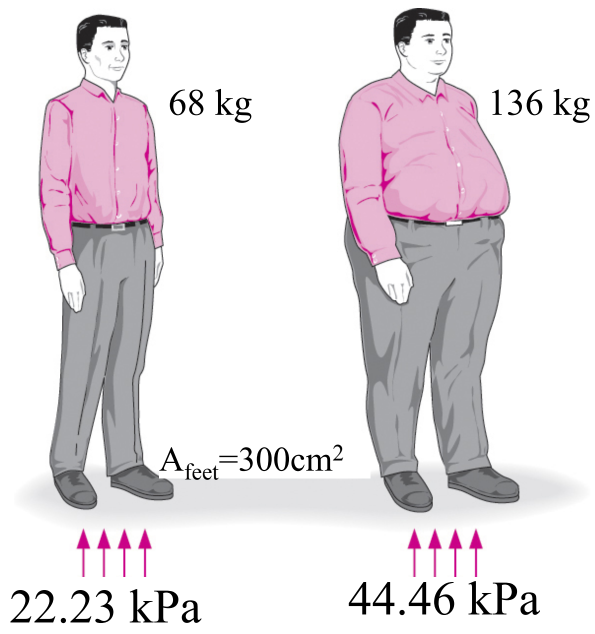
Pressure: Normal force per unit area – used for gas and liquid
Normal stress – solid

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$1 \text{ atm} = 101{,}325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

$$\begin{aligned}1 \text{ kgf/cm}^2 &= 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa} \\ &= 0.9807 \text{ bar} \\ &= 0.9679 \text{ atm}\end{aligned}$$



$P=68*9.807/300*(0.01)^2=22.3$ kPa

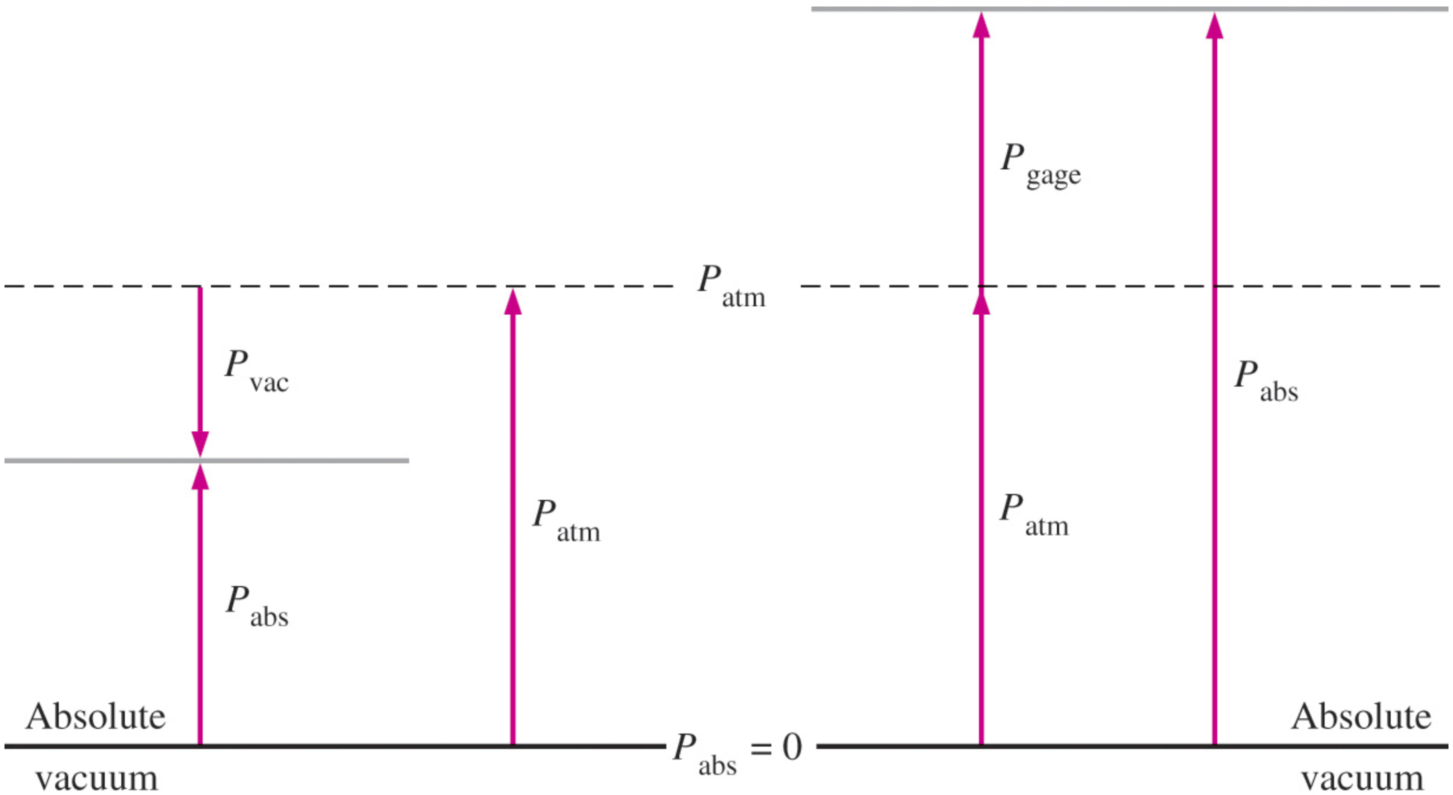
The normal stress (or "pressure") on the feet of a chubby person is much greater than on the feet of a slim person.

Pressure

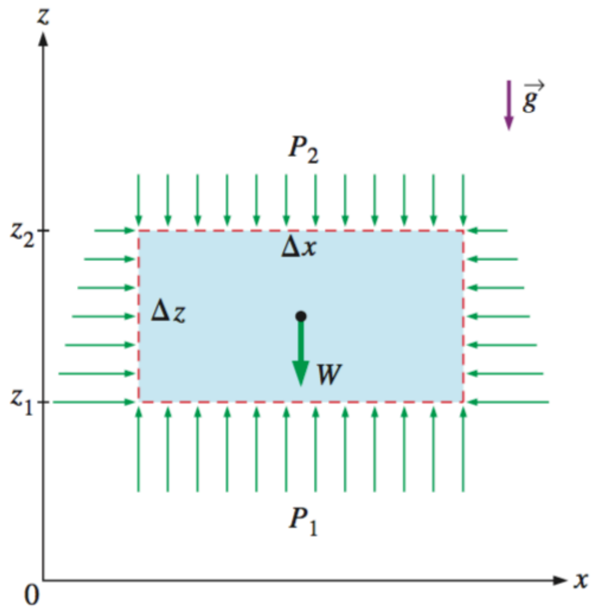
- **Absolute pressure**: The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure).
- **Gage pressure**: The difference between the absolute pressure and the local atmospheric pressure. Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure.
- **Vacuum pressures**: Pressures below atmospheric pressure.

$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$



Variation of Pressure



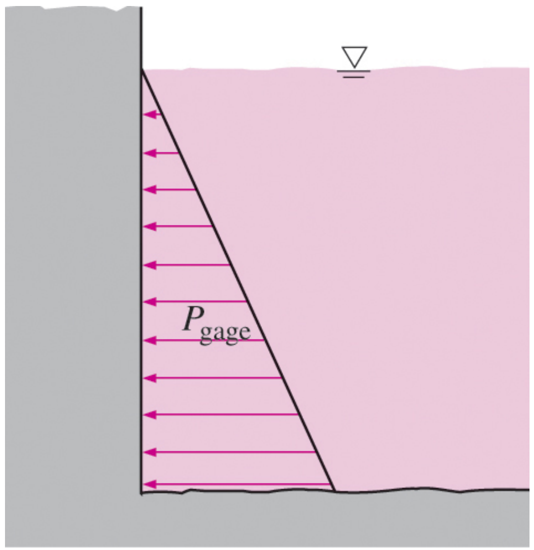
- Pressure of fluid at rest does not change in the horizontal direction.

Consider rectangular element, and assume *constant density*
Force balance in the z direction,

$$\sum F_z = ma_z = 0: \quad P_1\,\Delta x\,\Delta y - P_2\,\Delta x\,\Delta y - \rho g\,\Delta x\,\Delta y\,\Delta z = 0$$

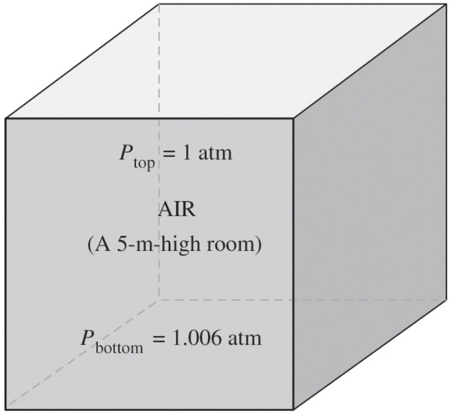
$$\Delta P = P_2 - P_1 = -\rho g\,\Delta z$$

$$P_{\text{below}} = P_{\text{above}} + \rho g|\Delta z|$$



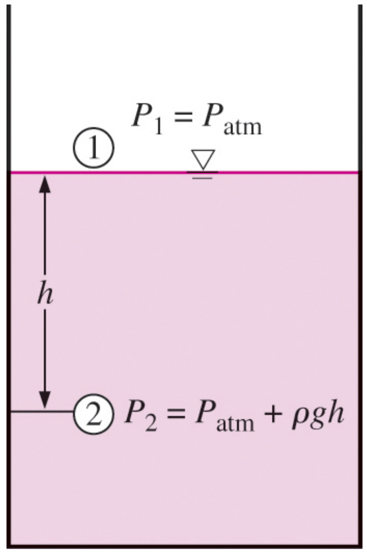
The pressure of a fluid at rest increases with depth (as a result of added weight).

Pressure



In a room filled with a gas, the variation of pressure with height is negligible

Pressure in a liquid at rest increases linearly with distance from the free surface.



$$P = P_{atm} + \rho g h \quad \text{or} \quad P_{gage} = \rho g h$$

For fluids with density variation with height

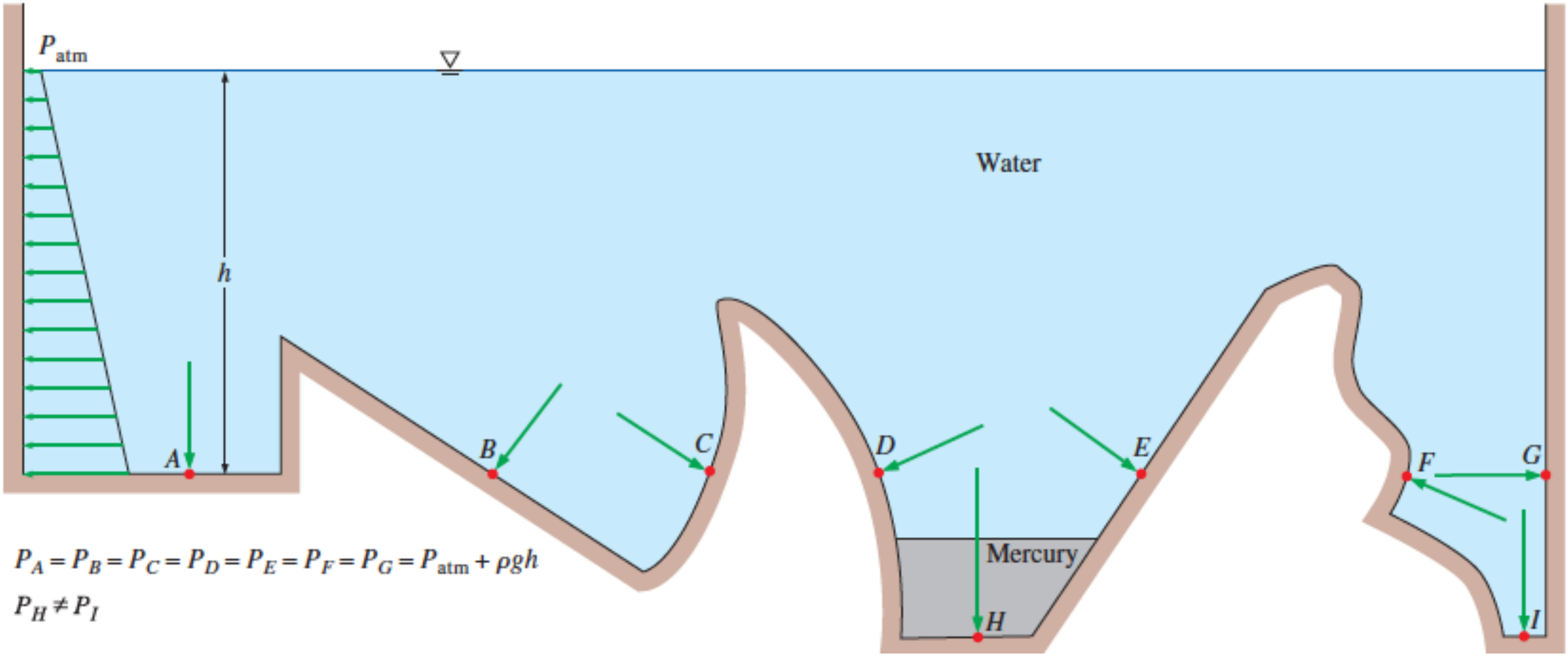
$$\Delta P = P_2 - P_1 = -\rho g \, \Delta z$$

$$\frac{dP}{dz} = -\rho g$$

Note dP is -ve, when dz is +ve

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g \, dz$$

Pressure



The pressure is the same at all points on a horizontal plane in a given fluid regardless of geometry, provided that the points are interconnected by the same fluid.

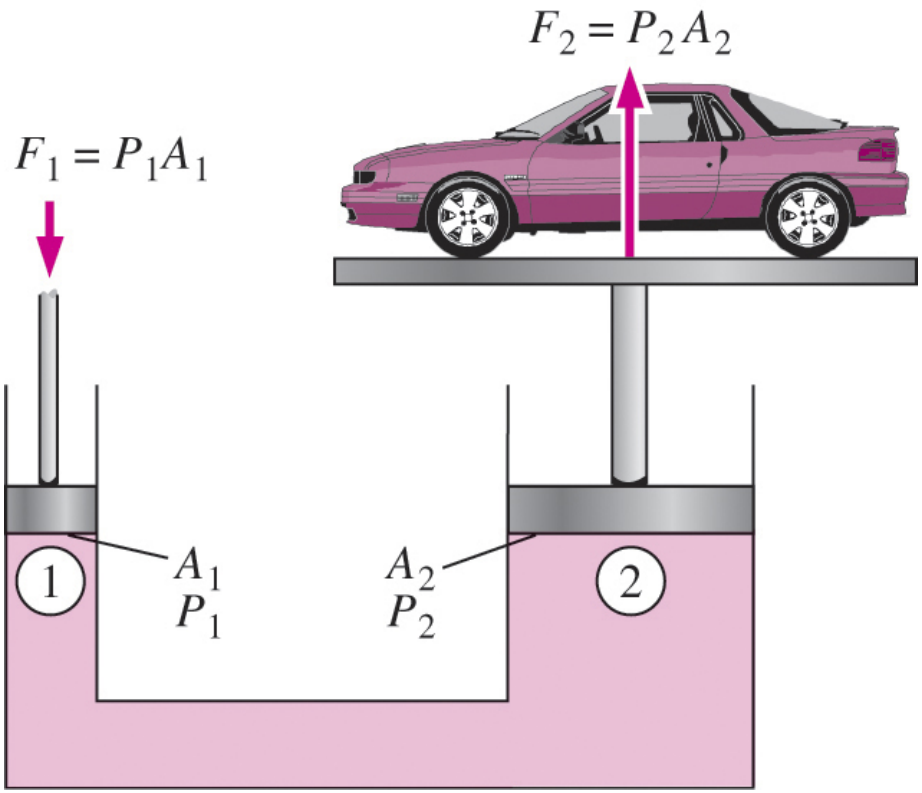
Pressure

Pascal's law: The pressure applied to a confined fluid increases the pressure throughout by the same amount.

Hydraulic jack

Lifting of a large weight by a small force by the application of Pascal's law.

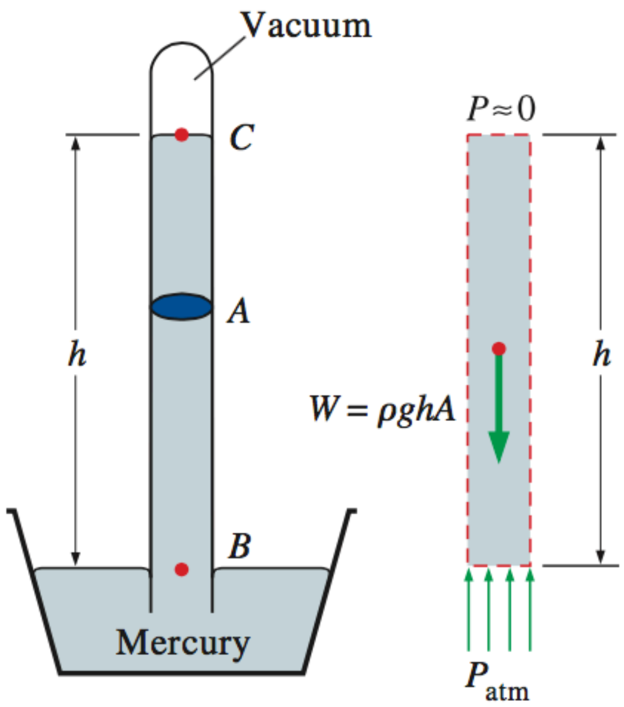
$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \rightarrow \quad \frac{F_2}{F_1} = \frac{A_2}{A_1}$$



The area ratio A_2/A_1 is called the *ideal mechanical advantage* of the hydraulic lift.

Pressure Measurement Devices

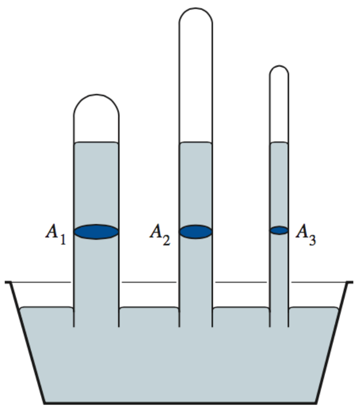
Atmospheric pressure- measured by
- barometer



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

Standard atmosphere, 1 atm = 760 mm Hg, 0 ^{o}C = 760 torr

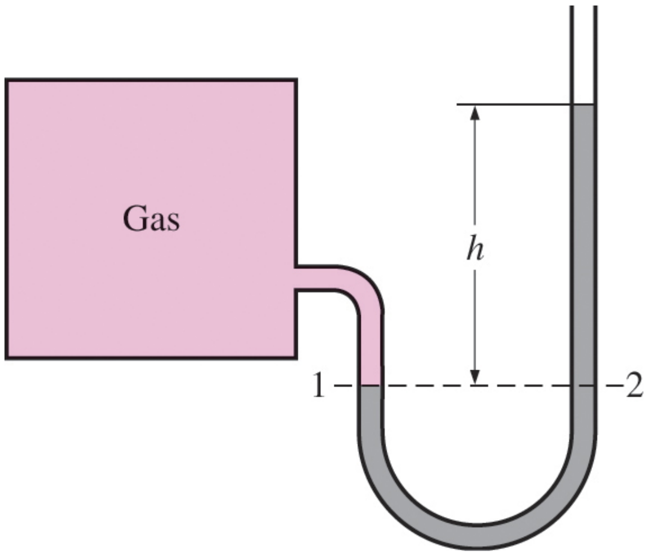
Length and cross-section area have no effect on the height of the fluid column of a barometer.



Manometer

Fluid column to measure the pressure difference

- used to measure small and moderate pressure differences
- contains one or more fluids such as mercury, water, alcohol, or oil.

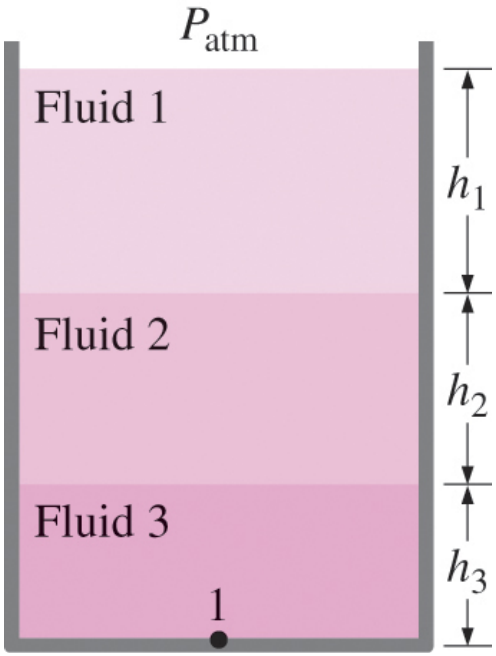


The basic manometer.

$$P_2 = P_{atm} + \rho g h$$

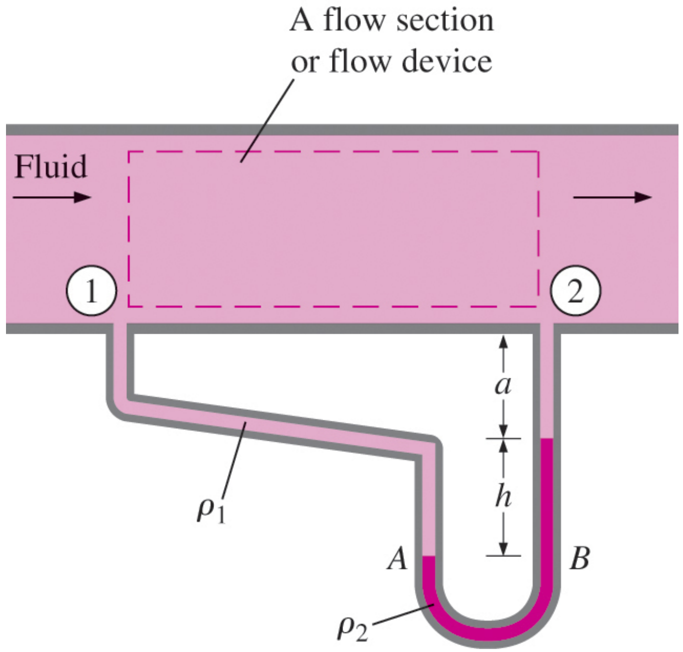
P_2=P_1 =pressure of gas (since g has less effect on gas)

Manometer



In stacked-up fluid layers, the pressure change across a fluid layer of density ρ and height *h* is ρ***gh***.

$$P_{atm} + \rho_1 g h_1 + \rho_2 g h_2 + \rho_3 g h_3 = P_1$$



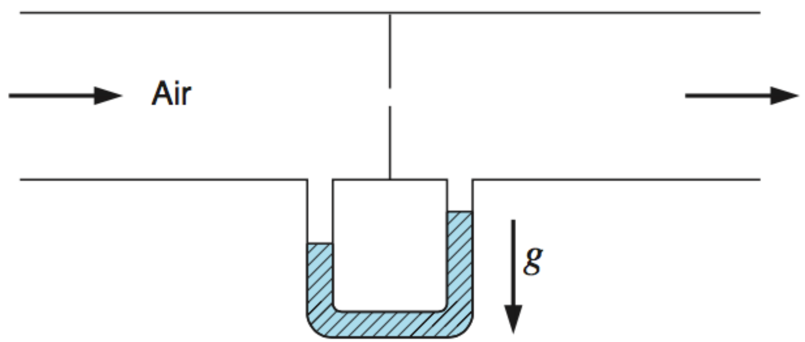
$$P_1 + \rho_1 g(a + h) - \rho_2 g h - \rho_1 g a = P_2$$

$$P_1 - P_2 = (\rho_2 - \rho_1) g h$$

Measuring the pressure drop across a flow section or a flow device by a differential manometer.

Example

A piece of experimental apparatus, as shown in figure below, is located where g = 9.5 m/s^2 and the temperature is 5°C. Air flow inside the apparatus is determined by measuring the pressure drop across an orifice with a mercury manometer (density of mercury is 13600 kg/m^3) showing a height difference of 200 mm. What is the pressure drop in kPa.



$$\Delta P = \rho_2 g h = \rho_{\mathrm{Hg}} g h$$

$$= 13600\mathrm{kg/m}^3 \times 9.5\ \mathrm{m/s}^2 \times 0.2\ \mathrm{m}$$

$$= 25840\ \mathrm{Pa} = 25.84\ \mathrm{kPa}$$

Problem-solving technique

- Step 1: Problem Statement
- Step 2: Schematic
- Step 3: Assumptions and Approximations
- Step 4: Physical Laws
- Step 5: Properties
- Step 6: Calculations
- Step 7: Reasoning, Verification, and Discussion

Summary

- Thermodynamics and energy
  - Application areas of thermodynamics
- Importance of dimensions and units
  - SI units, Dimensional homogeneity
- Systems and control volumes
- Properties of a system
- Density and specific gravity
- State and equilibrium
  - The state postulate
- Processes and cycles
  - The steady-flow process
- Temperature and the zeroth law of thermodynamics
  - Temperature scales
- Pressure
  - Variation of pressure with depth
- The manometer and the atmospheric pressure
- Problem solving technique