# Thermodynamics
# ENGR360-MEP112

LECTURES 1&2

# INTRODUCTION AND BASIC CONCEPTS

## Objectives:

1. Identify the unique vocabulary associated with thermodynamics.
2. Review the metric SI and the English unit systems and dimensions.
3. Explain the basic concepts of thermodynamics such as system, state, state postulate, equilibrium, process, and cycle.
4. Review concepts of temperature, temperature scales, pressure, and absolute and gage pressure.

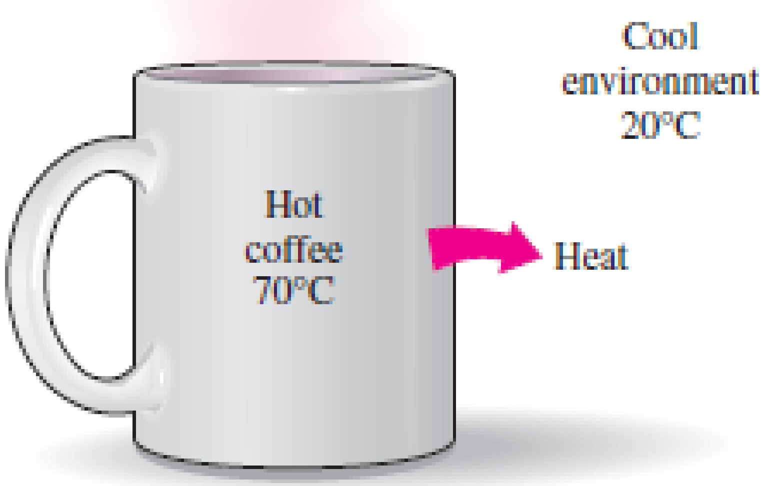
# 1. THERMODYNAMICS AND ENERGY

**Thermodynamics can be defined as the science of energy. It defines and explains the quantitative and qualitative transformation of energy.**

- Quantitative transformation ➔ First law of thermodynamics
- Qualitative transformation ➔ Second law of thermodynamics
- The name thermodynamics stems from the Greek words therme (heat) and dynamis (power), which is most descriptive of the early efforts to convert heat into power. Today the same name is broadly interpreted to include all aspects of energy and energy transformations, including power generation, refrigeration, and relationships among the properties of matter.

- **Actual processes occur in the direction of decreasing quality of energy.**

**Low quality of energy retained at the surrounding (less useful form)**




**High quality of energy in the form of hot tea (useful form)**

- **Classical thermodynamics:** study of thermodynamics that does not require a knowledge of the behavior of individual particles.

Example: the pressure of a gas in a container is the result of momentum transfer between the molecules and the walls of the container. However, one does not need to know the behavior of the gas particles to determine the pressure in the container. It would be sufficient to attach a pressure gage to the container.

- **Statistical thermodynamics:** A more elaborate approach, based on the average behavior of large groups of individual particles.

# Application Areas of Thermodynamics

Energy – matter interaction exists everywhere in nature. It is hard to imagine an area that does not relate to thermodynamics.

- Refrigerator
- Power plant
- Internal combustion engine (ICE)
- Rocket
- Human body

# 2. DIMENSIONS AND UNITS

Any physical quantity can be characterized by dimensions. The magnitudes assigned to the dimensions are called units.

- International system (SI)
- English system

***Fundamental (primary) dimensions and their units***

| Dimension | SI units | English units |
|---|---|---|
| **Length (L)** | **Meter (m)** | **Foot (ft)** |
| **Mass (M)** | **Kilogram (kg)** | **Pound mass (lbm)** |
| **Time (t)** | **Second (s)** | **Second (s)** |
| **Temperature (T)** | **Kelvin (K)** | **Rankine (R)** |

**1 m = 3.28 ft & 1 kg = 2.2 lbm & 1 K = 0.555 R**

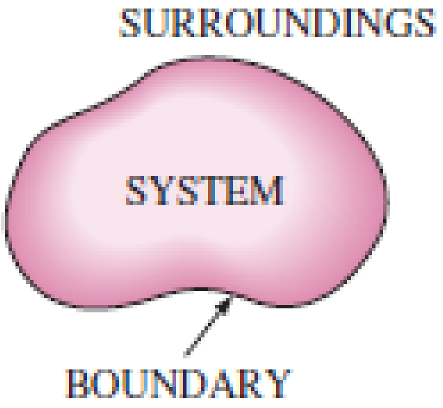
## Standard prefixes in SI units

Standard prefixes in SI units

| Multiple | Prefix |
|---|---|
| $10^{12}$ | tera, T |
| $10^{9}$ | giga, G |
| $10^{6}$ | mega, M |
| $10^{3}$ | kilo, k |
| $10^{2}$ | hecto, h |
| $10^{1}$ | deka, da |
| $10^{-1}$ | deci, d |
| $10^{-2}$ | centi, c |
| $10^{-3}$ | milli, m |
| $10^{-6}$ | micro, $\mu$ |
| $10^{-9}$ | nano, n |
| $10^{-12}$ | pico, p |

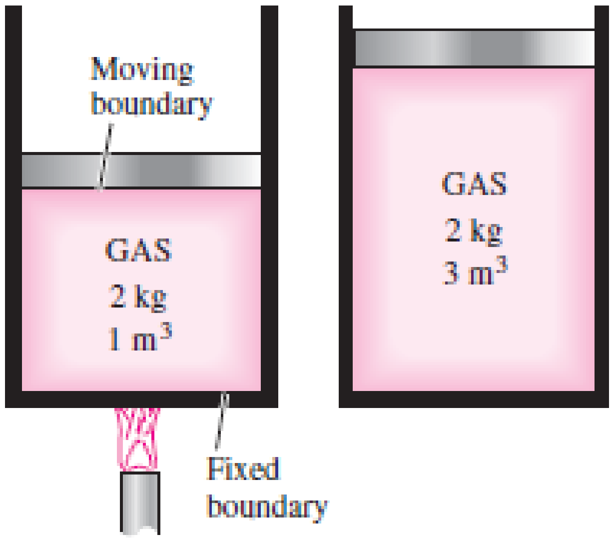
# 3. SYSTEMS AND CONTROL VOLUMES

- A **system** is defined as a quantity of matter or a region in space chosen for study.




- The mass or region outside the system is called the **surroundings**.

- The *real or imaginary* surface that separates the system from its surroundings is called the **boundary**.

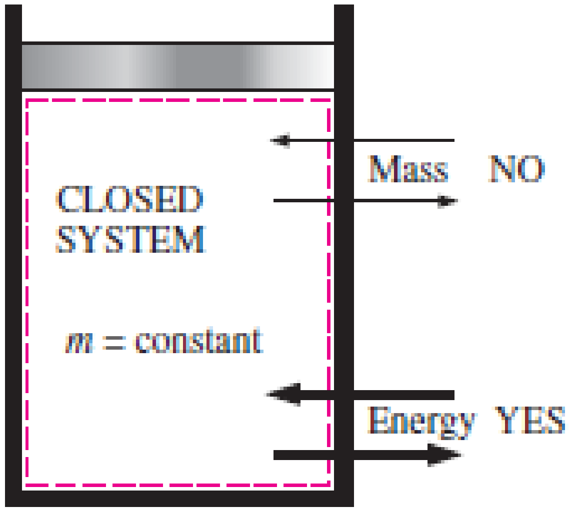



- The boundary of a system can be *fixed or movable*.

# 3. SYSTEMS AND CONTROL VOLUMES

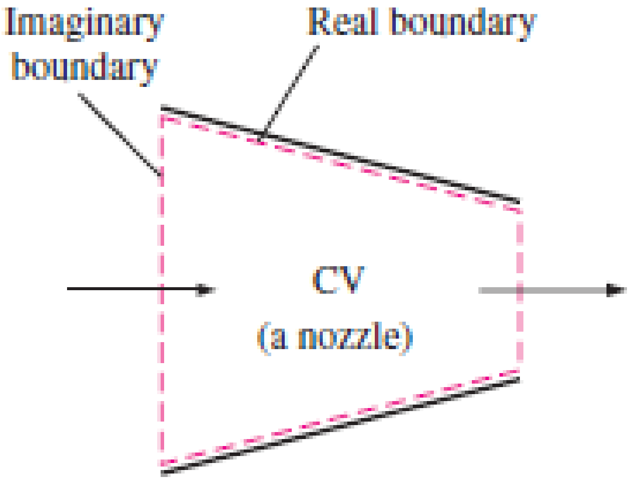
## Closed system (control mass)

Region Consists of a fixed amount of mass and no mass can enter or leave a closed system.




## Open system (control volume)

Region in space associated with fluid flow. Both mass and energy can cross the boundary of a control volume.



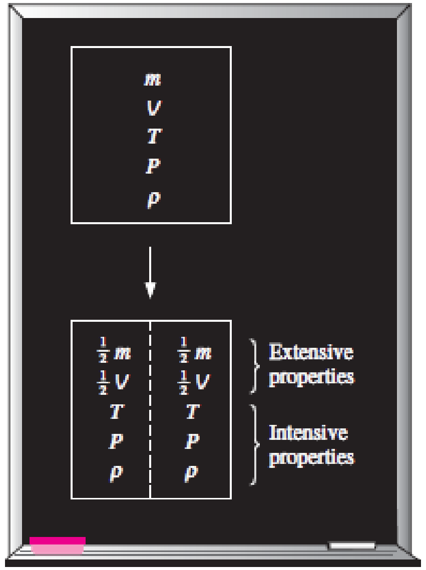

**If mass and energy are not allowed to cross the boundary, that system is called an *isolated system.***

# 4. PROPERTIES OF A SYSTEM

**Any characteristic of a system is called a property. Some familiar proper-ties are pressure P, temperature T, volume V, and mass m.**

- **Intensive properties ➔ Mass independent (P, T)**
- **Extensive properties ➔ Mass dependent (m, Total energy (E))**
- **Specific properties ➔ Extensive properties per unit mass**

**An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.**

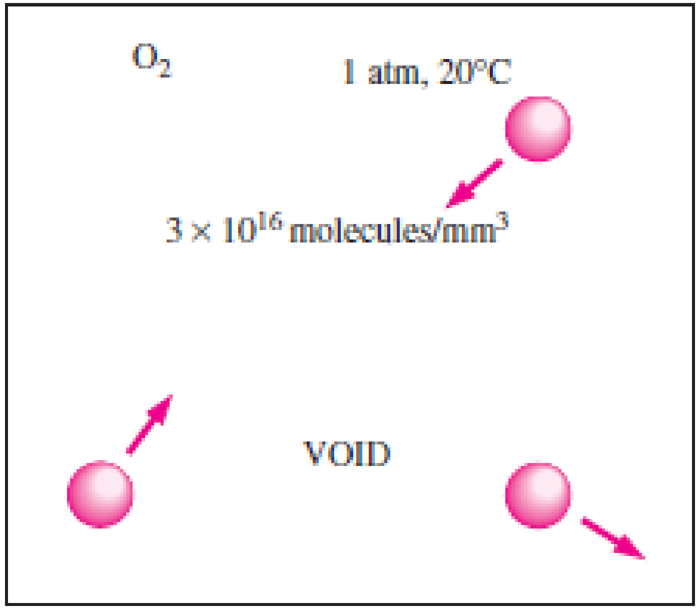


# Continuum

- Substance is considered continuous, homogeneous matter with no voids between atoms.

- The continuum idealization allows us to treat properties as point functions.

- The continuum model is applicable as long as the characteristic length scale of the system is much larger than the mean free path of the molecules.




Diameter = $3x10^{-10}$ m
Mean free path = $6.3x10^{-8}$ m

# 5. DENSITY AND SPECIFIC GRAVITY

- **Density ($\rho$) is the mass per unit volume** $= \frac{m}{V} \quad \frac{kg}{m^3}$
- **Specific volume ($v$) is the reciprocal of density** $= \frac{V}{m} \quad \frac{m^3}{kg}$
- **Specific gravity (SG) is the density of a substance relative to the density of a well-known substance**

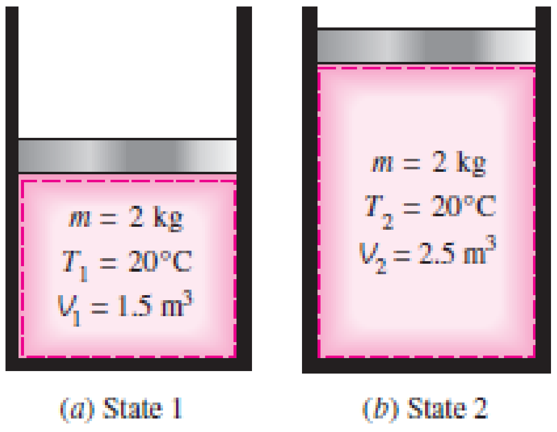
$$SG = \begin{cases} \dfrac{\rho}{\rho_{H_2O\ (at\ 4^oC)}} & \text{liquids} \\ \dfrac{\rho}{\rho_{air\ (at\ standard\ condition\ (1\ atm\ and\ 27^oC)}} & \text{Gases} \end{cases}$$

- **Specific weight ($\gamma$) is the weight of a unit volume of a substance** $= \rho g \quad \frac{N}{m^3}$

# 6. STATE AND EQUILIBRIUM

- **State:** All the properties of the system that completely describe its condition.

- **Equilibrium:** The state of balance, where no potential exist to change the state.




A system at two different states.

| | |
|---|---|
| **Thermal equilibrium** | **T = constant** |
| **Mechanical equilibrium** | **P = constant** |
| **Phase equilibrium** | **The mass of each phase does not change with time** |
| **Chemical equilibrium** | **Chemical composition does not change with time** |

# The State Postulate

**The number of properties required to fix the state of a system is given by the state postulate.**


The state of nitrogen is fixed by two independent, intensive properties.

**Example:**

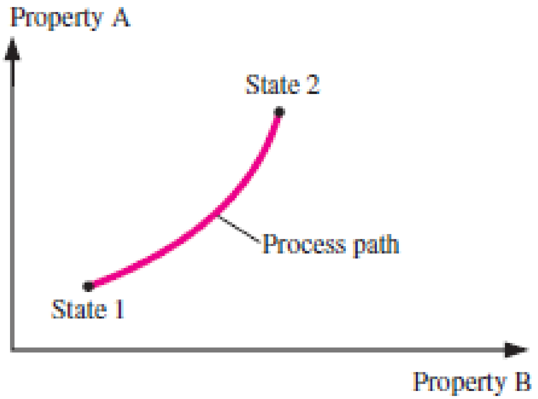
**At sea level (P = 1 atm), water boils at 100°C, but on a mountaintop where the pressure is lower, water boils at a lower temperature. That is, T = *f*(P) during a phase-change process; thus, temperature and pressure are not sufficient to fix the state of a two-phase system.**

# 7. PROCESSES AND CYCLES

- **Process:** any change that a system undergoes from one equilibrium state to another is called a process.

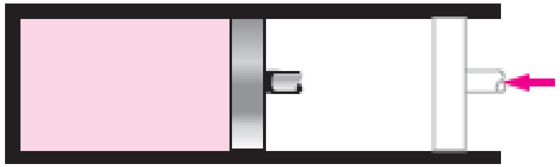
- **Path:** a series of states the system undergo during a process is called the path.

- **Quasi-equilibrium process:** it is a sufficiently slow process that occurs in such a way the system remains in equilibrium state at all times.




A process between states 1 and 2 and the process path.

(a) Slow compression (quasi-equilibrium)



(b) Very fast compression (nonquasi-equilibrium)

# 7. PROCESSES AND CYCLES

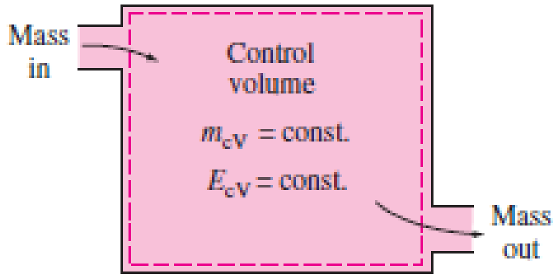
**The prefix *iso-* is often used to designate a process for which a particular property remains constant.**

| | |
|---|---|
| **Isothermal process** | **T = constant** |
| **Isobaric process** | **P = constant** |
| **Isochoric (isometric) process** | **V = constant** |

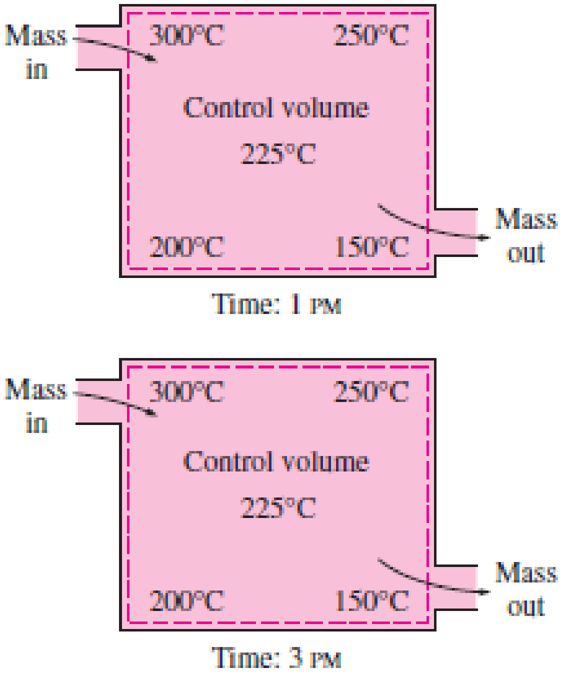
- **Cycle:** A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical.

# The Flow Process

| | |
|---|---|
| **Steady Flow** | **No change with time** |
| **Unsteady flow** | **Change with time** |
| **Uniform flow** | **No change with location** |
| **Non-uniform flow** | **Change with location** |




Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

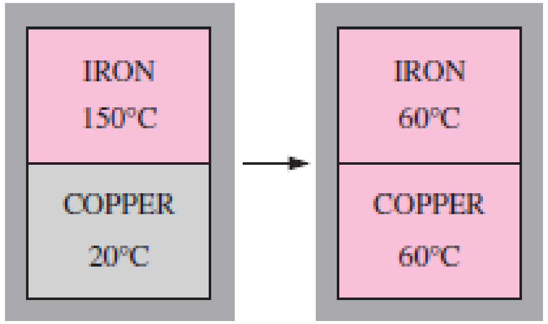



During a steady-flow process, fluid properties within the control volume may change with position but not with time.

# 8. TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

**Temperature is a measure of hotness or coldness.**

- **May be misleading sense. When we touch a metallic door handle, it feels much colder than a wooden or plastic one though they are at the same temperature.**
- **The zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other even they are not in contact.**
- **It serves as a basis for the validity of temperature measurement. 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

| Scale type | SI system | English system |
|---|---|---|
| Absolute | Kelvin (K) | Rankine (R) |
| Relative | Celsius (°C) | Fahrenheit (°F) |

$$T(R) = 1.8\,T(K)$$

$$T(°F) = 1.8\,T(°C) + 32$$

$$T(K) = T(°C) + 273$$

$$T(R) = T(°F) + 460$$

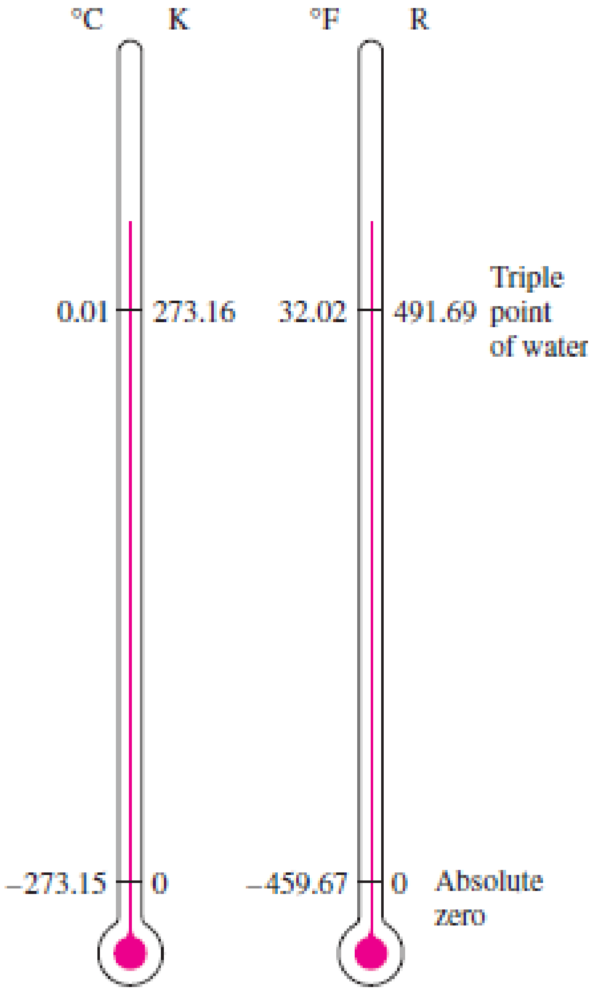
$$\boxed{Y = AX + B}$$

# Temperature Scales

$$\Delta T(K) = \Delta T(°C)$$

$$\Delta T(R) = \Delta T(°F)$$

**Raising the temperature of a substance by 1°C is the same as raising it by 1 K. Similarly in English system.**




Comparison of temperature scales.

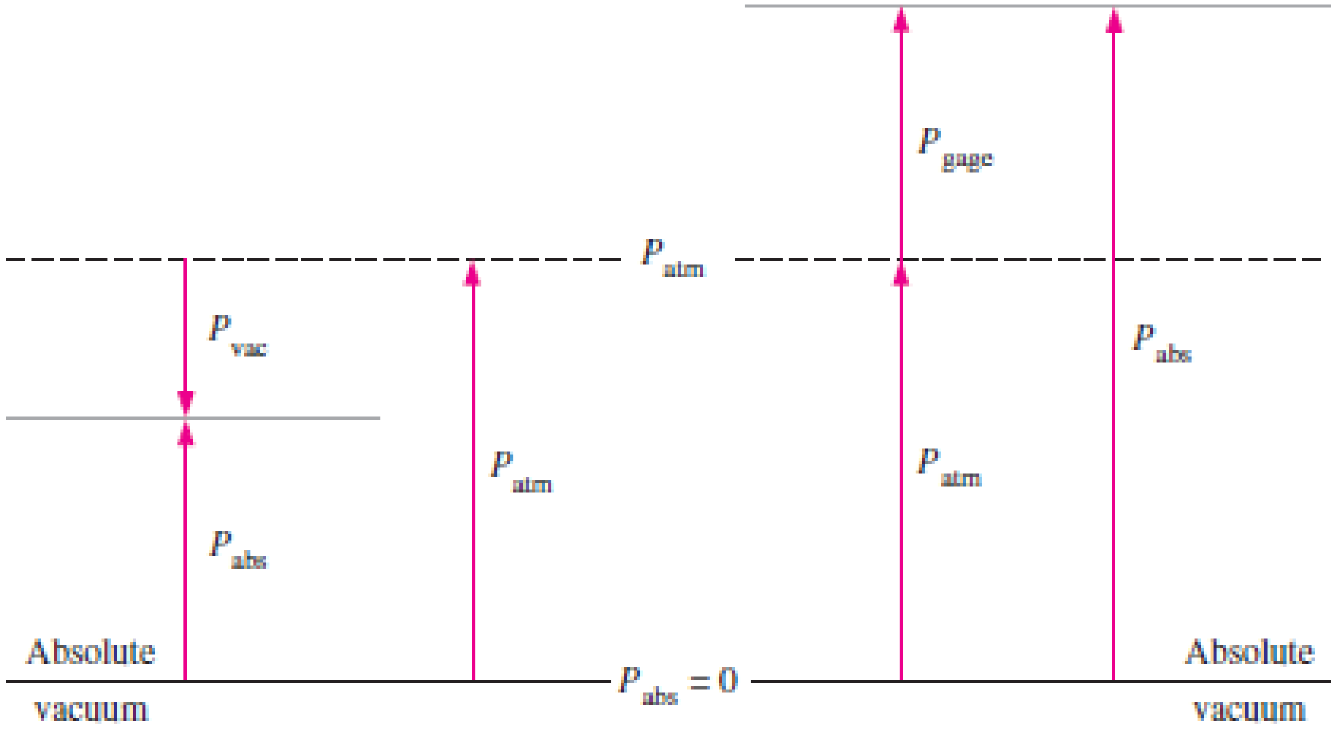
# 9. PRESSURE

**Pressure is defined as a normal force exerted by a fluid per unit area.**

- **SI units: Newton/square meters ($N/m^2$) = Pascal (Pa).**
- **1 bar = $10^5$ Pa = 0.1 MPa = 100 kPa**
- **The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure). Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the gage pressure. Pressure below atmospheric pressure are called vacuum pressure and is measured by vacuum gage that indicates the difference between the atmospheric pressure and the absolute pressure. *Absolute, gage, and vacuum pressures* are all positive quantities and are related to each other by**

# 9. PRESSURE

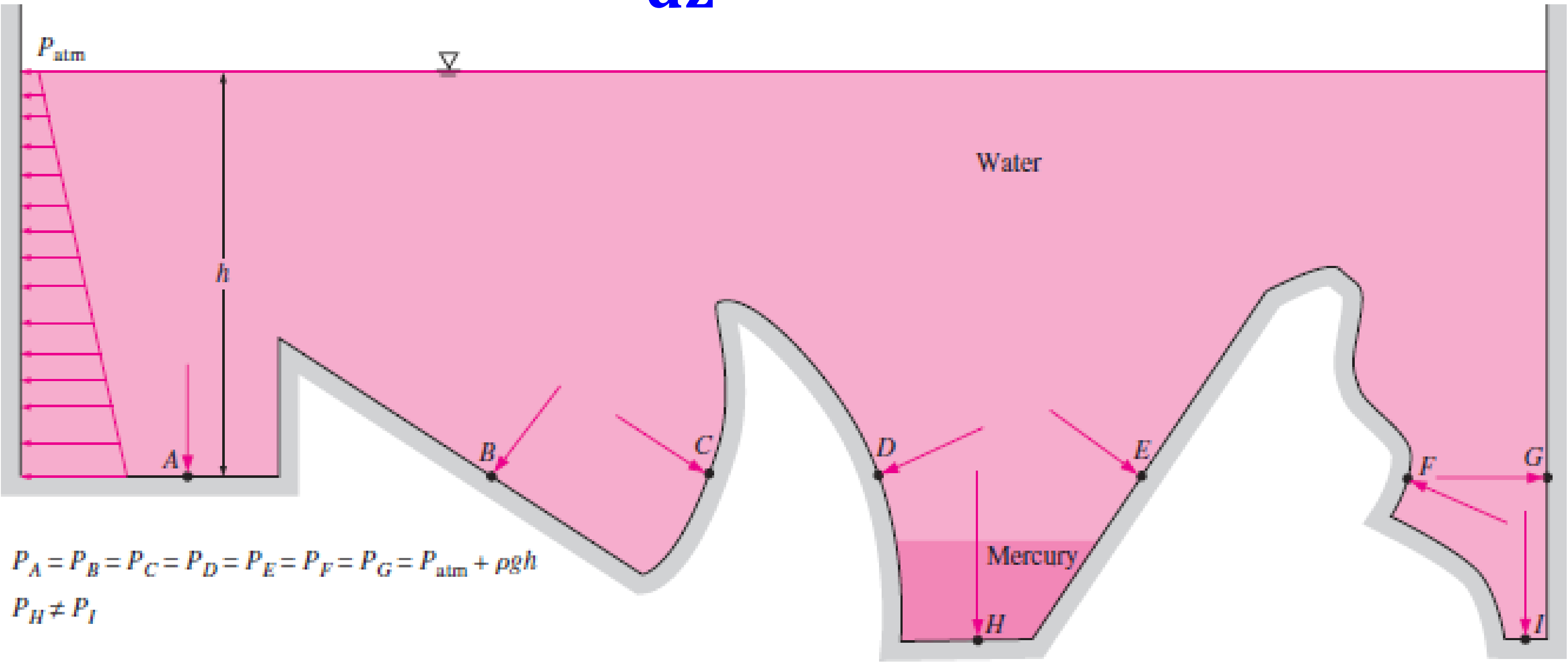
$$p_{gage} = p_{abs} - p_{atm}$$
$$p_{vac} = p_{atm} - p_{abs}$$




Absolute, gage, and vacuum pressures.

# Variation of Pressure with Depth

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



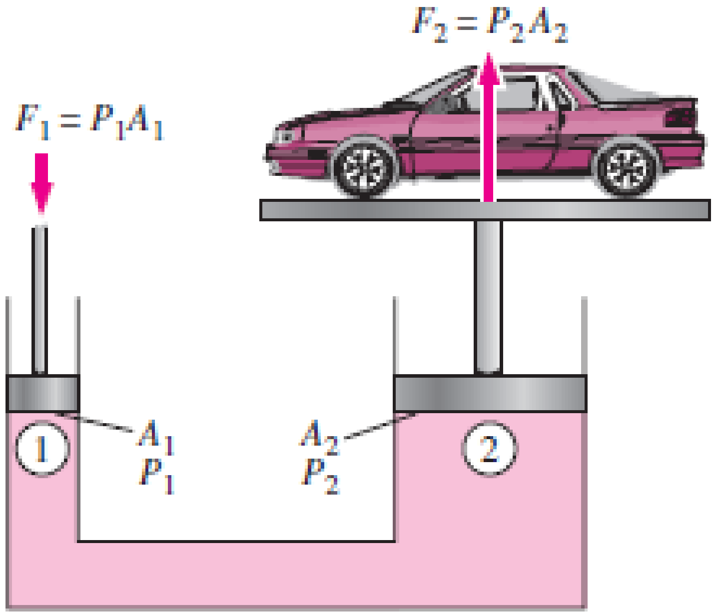

$P_A = P_B = P_C = P_D = P_E = P_F = P_G = P_{atm} + \rho g h$

$P_H \neq P_I$

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.

# Variation of Pressure with Depth

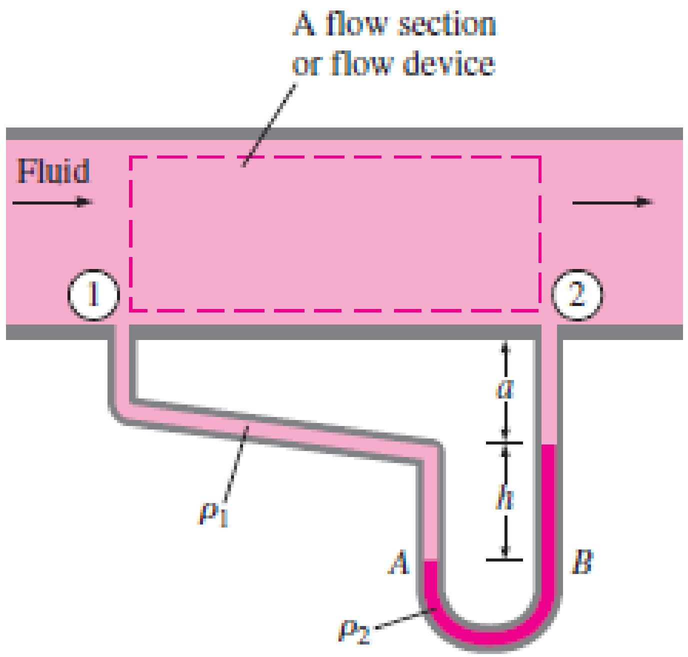
**A consequence of the pressure in a fluid remaining constant in the horizontal direction is that the pressure applied to a confined liquid increases the pressure throughout by the same amount. This is called Pascal's law**




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

# 10. THE MANOMETER

***A device used to measure the pressure difference.***




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

***Example:***

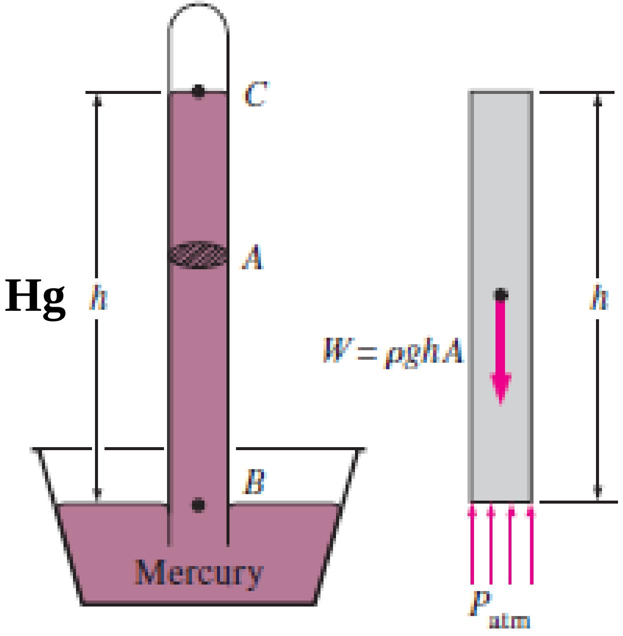
$$\mathbf{p_1 + \rho_1 g(a + h) - \rho_2 gh - \rho_1 ga = p_2}$$

$$\mathbf{\Delta p = p_1 - p_2 = gh(\rho_2 - \rho_1)}$$

# 11. THE BAROMETER AND ATMOSPHERIC PRESSURE

$$p_{atm} = \rho_{Hg} \cdot g \cdot h$$

760 mm Hg




The basic barometer.

## Remarks on significant digits:

**How can you tell the digit is significant or not? (problem # 7 – Sheet 1)**