Thermodynamics: An Engineering Approach, **6th Edition**

Yunus A. Cengel, Michael A. Boles

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Chapter 1

INTRODUCTION AND BASIC CONCEPTS

SUMMARY

DR. MUNZER EBAID

THERMODYNAMICS AND ENERGY

- **Thermodynamics**: The science of *energy.*
- **Conservation of energy principle**:

The first law of thermodynamics:

During an interaction, energy can change from one form to another but the total amount of energy remains constant.

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

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

Unity Conversion Ratios

All non primary units (secondary units) can be formed by combinations of primary units. Force units, for example, can be expressed as

$$N = kg\,\frac{m}{s^2} \quad \text{and} \quad lbf = 32.174\ lbm\,\frac{ft}{s^2}$$

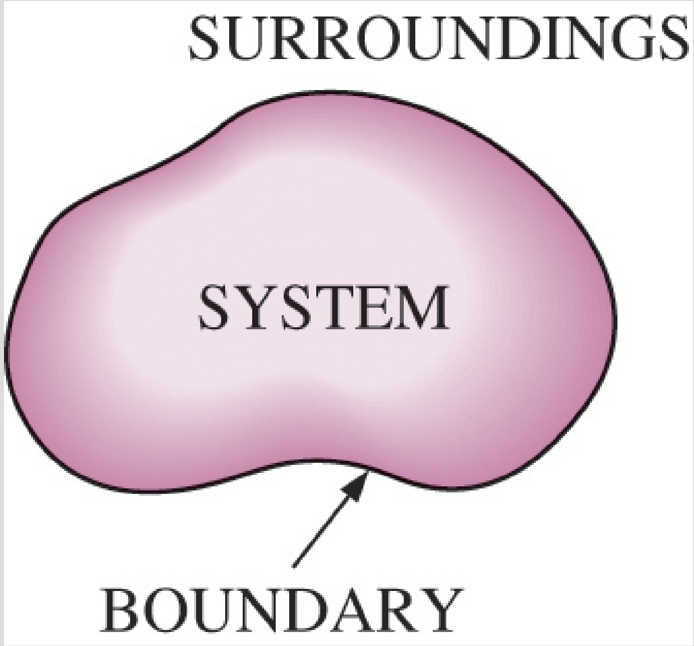
They can also be expressed more conveniently as **unity conversion ratios** as

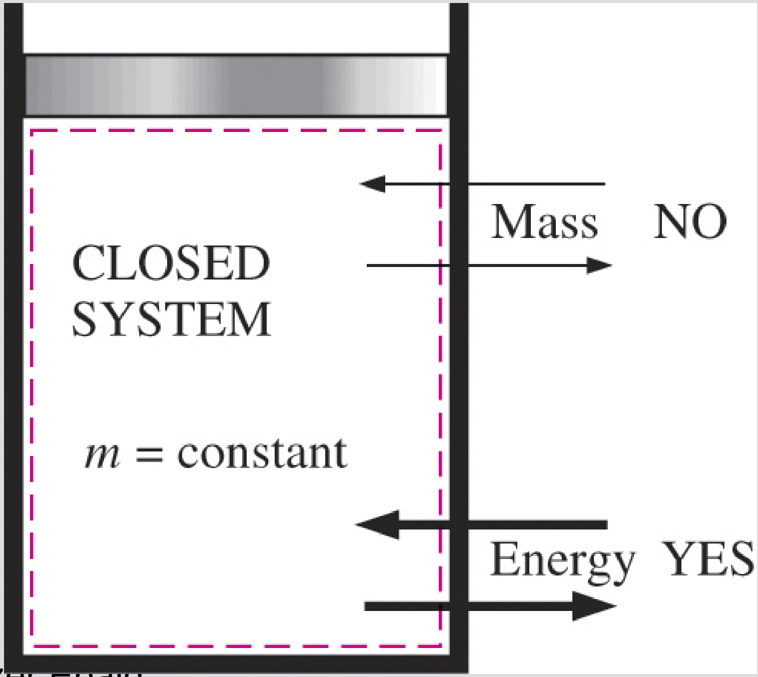
$$\frac{N}{kg \cdot m/s^2} = 1 \quad \text{and} \quad \frac{lbf}{32.174\ lbm \cdot ft/s^2} = 1$$

SYSTEMS AND CONTROL VOLUMES

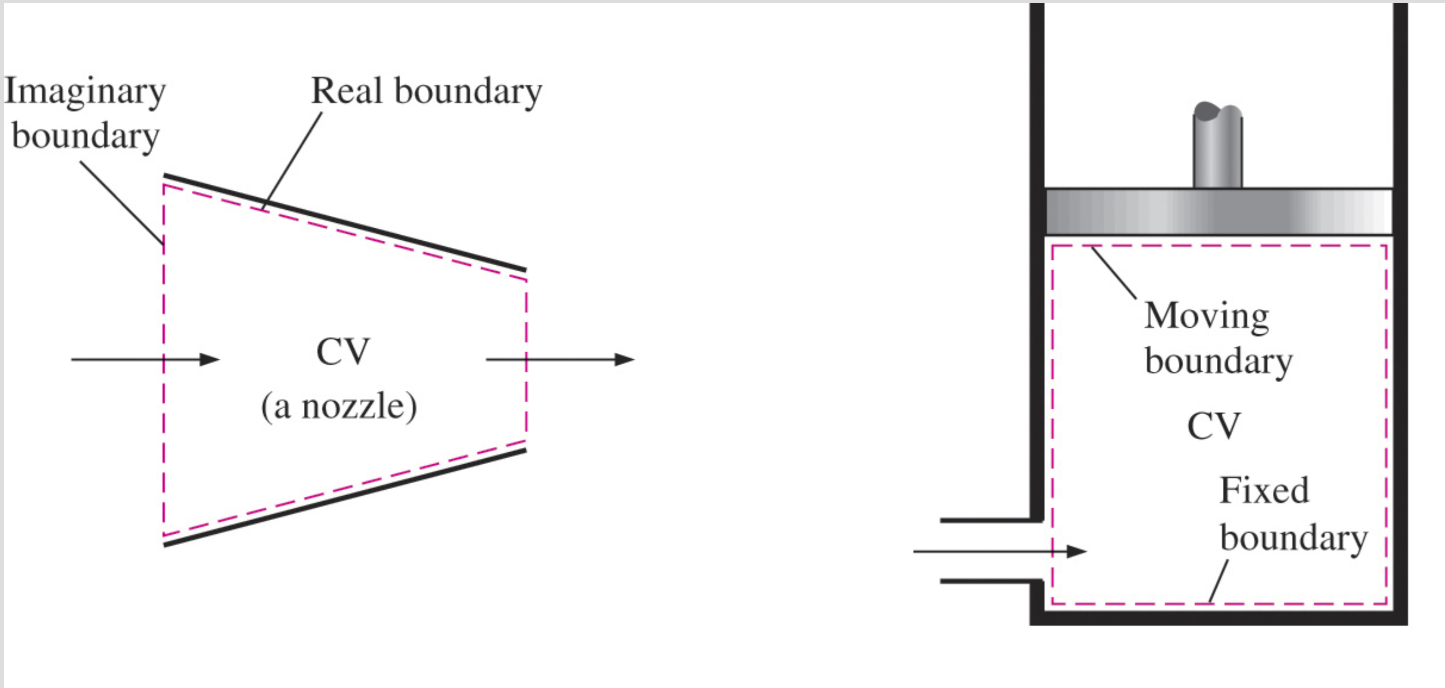
- **System**: A quantity of matter or a region in space chosen for study.

  Systems may be considered to be *closed* or *open*
- **Surroundings**: The mass or region outside the system
- **Boundary**: The real or imaginary surface that separates the system from its surroundings.
- The boundary of a system can be *fixed* or *movable.*





- **Open system (control volume):** A properly selected region in space.
- It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.
- Both mass and energy can cross the boundary of a control volume.
- **Control surface:** The boundaries of a control volume. It can be real or imaginary.

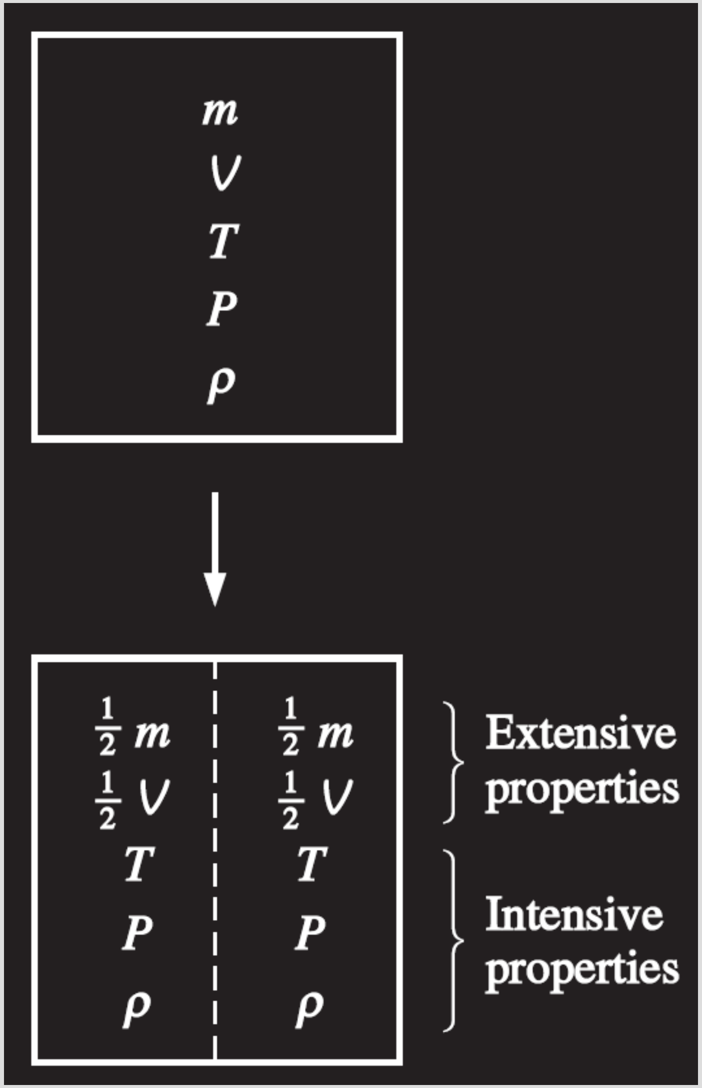


(*a*) A control volume with real and imaginary boundaries

(*b*) A control volume with fixed and moving boundaries

PROPERTIES OF A SYSTEM

- **Property:** Any characteristic of a system.
- Some familiar properties are pressure *P*, temperature *T*, volume *V*, and mass *m*.
- Properties are considered to be either *intensive* or *extensive*.
- **Intensive properties:** Those that are independent of the mass of a system, such as temperature, pressure, and density.
- **Extensive properties:** Those whose values depend on the size—or extent—of the system.
- **Specific properties:** Extensive properties per unit mass.



Criterion to differentiate intensive and extensive properties.

DENSITY AND SPECIFIC GRAVITY

Density: $$\rho = \frac{m}{V} \qquad (\mathrm{kg/m^3})$$

$$V = 12\ \mathrm{m^3}$$
$$m = 3\ \mathrm{kg}$$
$$\downarrow$$
$$\rho = 0.25\ \mathrm{kg/m^3}$$
$$v = \frac{1}{\rho} = 4\ \mathrm{m^3/kg}$$

Specific Volume: $$v = \frac{V}{m} = \frac{1}{\rho}$$

Specific Gravity :

The ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C).

$$\mathrm{SG} = \frac{\rho}{\rho_{\mathrm{H_2O}}}$$

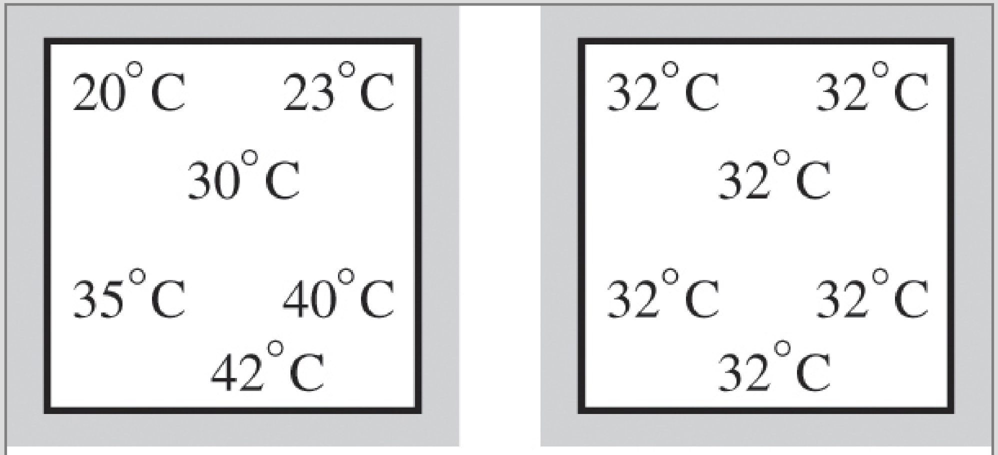
Specific Weight: **The weight of a unit volume of a substance.**

$$\gamma_s = \rho g \qquad (\mathrm{N/m^3})$$

STATE AND EQUILIBRIUM

- **Thermal equilibrium**:
  If the temperature is the same throughout the entire system.
- **Mechanical equilibrium:**
  If there is no change in pressure at any point of the system with time.
- **Phase equilibrium:**
  If a system involves two phases and when the mass of each phase reaches an equilibrium level and stays there.
- **Chemical equilibrium:**
  If the chemical composition of a system does not change with time, that is, no chemical reactions occur.

A closed system reaching thermal equilibrium



(*a*) Before (*b*) After

The State Postulate

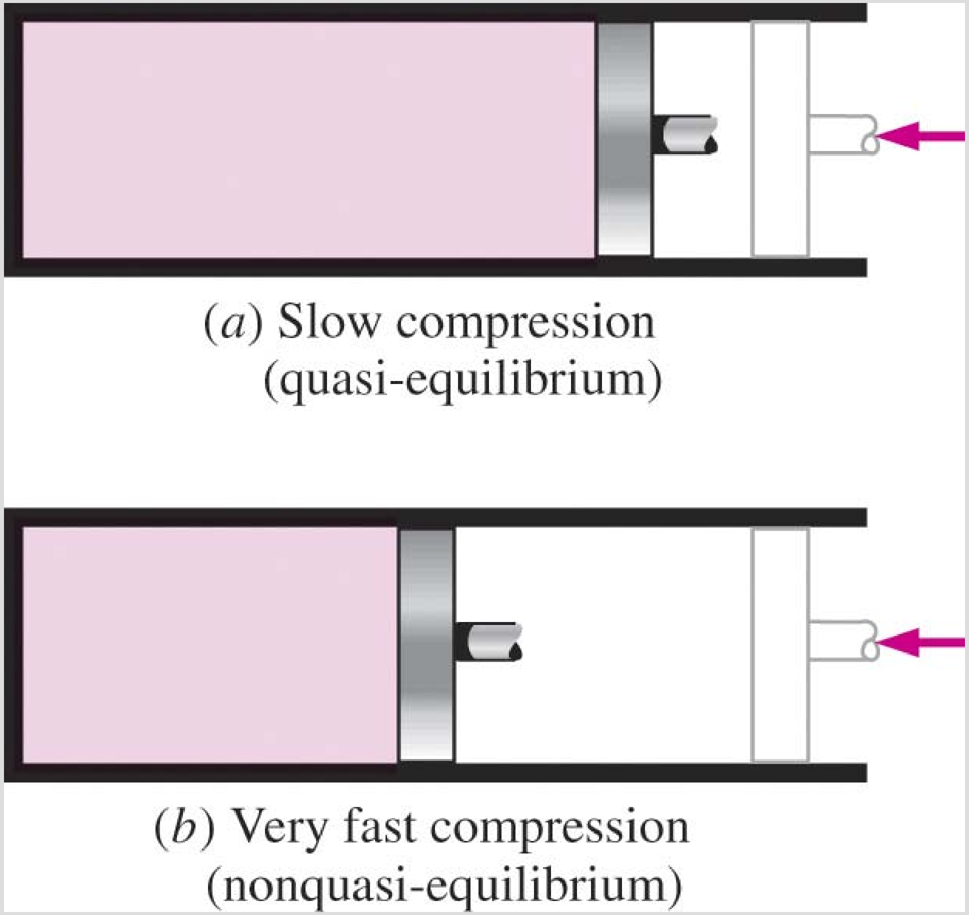
- The number of properties required to fix the state of a system is given by the **state postulate**:
  - ✓ *The state of a simple compressible system is completely specified by two independent, intensive properties.*
- **Simple compressible system:** If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.

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

PROCESSES AND CYCLES

Quasistatic or quasi-equilibrium process:

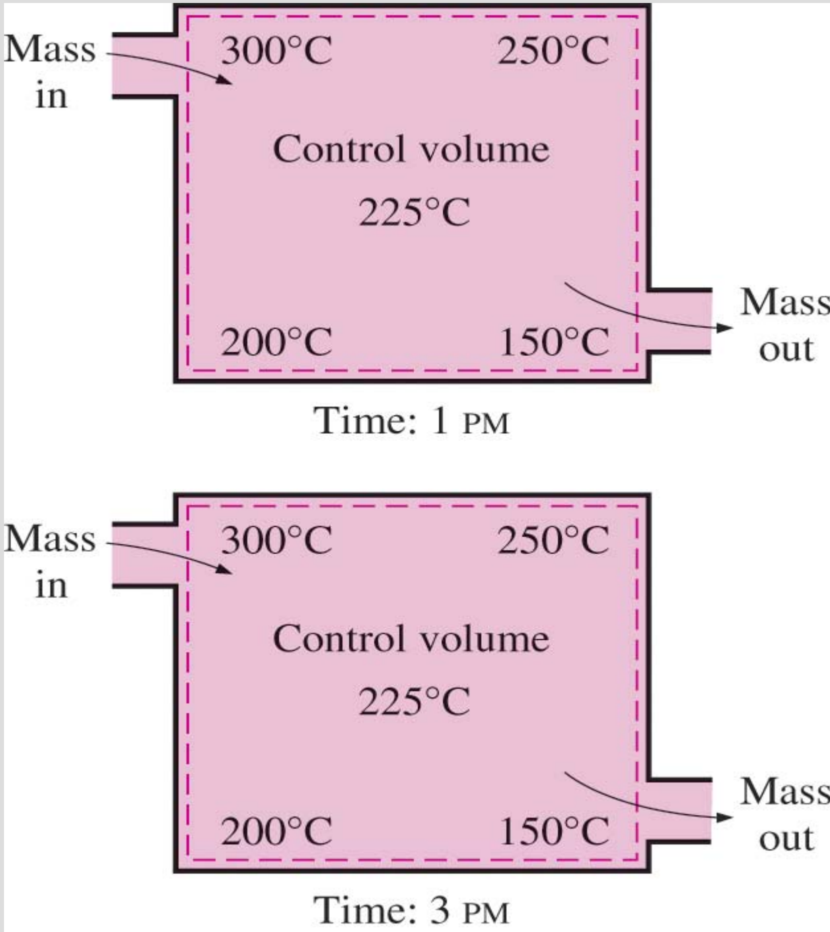
When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times.



- The prefix *iso-* is often used to designate a process for which a particular property remains constant.
- **Isothermal process**: A process during which the temperature *T* remains constant.
- **Isobaric process**: A process during which the pressure *P* remains constant.
- **Isochoric (or isometric) process**: A process during which the specific volume *v* remains constant.
- **Cycle**: A process during which the initial and final states are identical.

The Steady-Flow Process

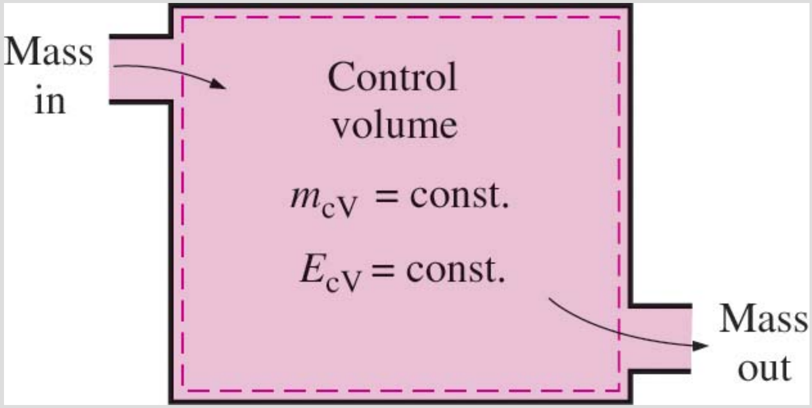
The term ***steady*** implies ***no change with time***. The opposite of steady is ***unsteady***, or ***transient***.



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

The Steady-Flow Process

- A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as *steady-flow devices*.
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily.
- Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.

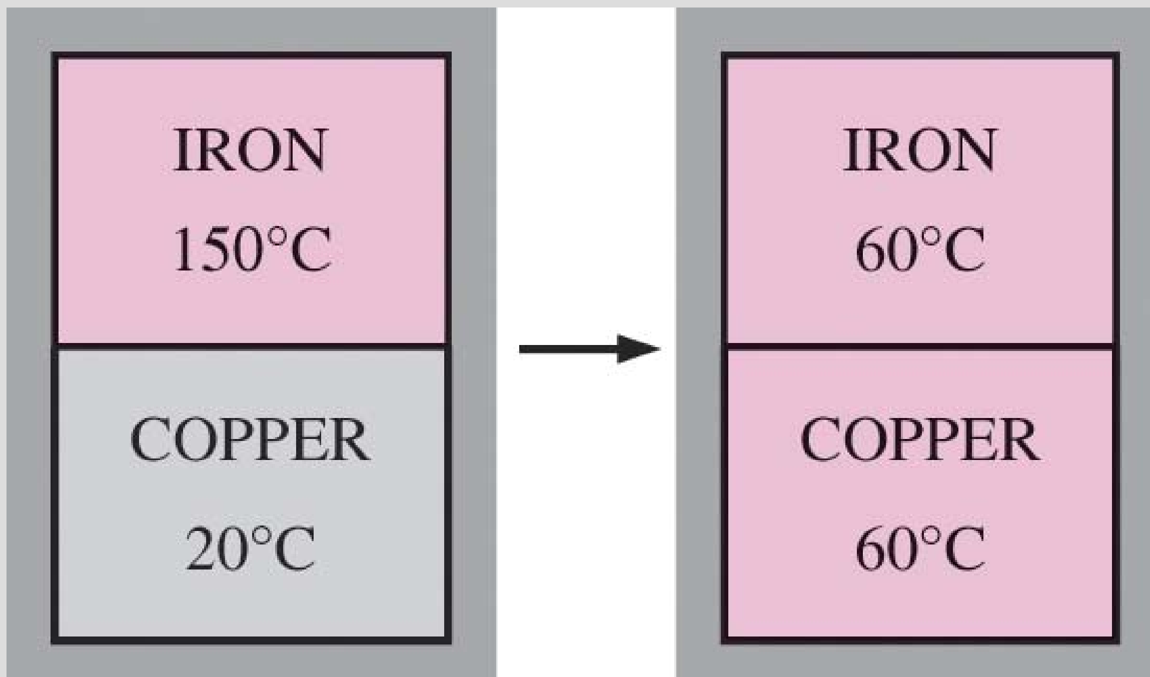


Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

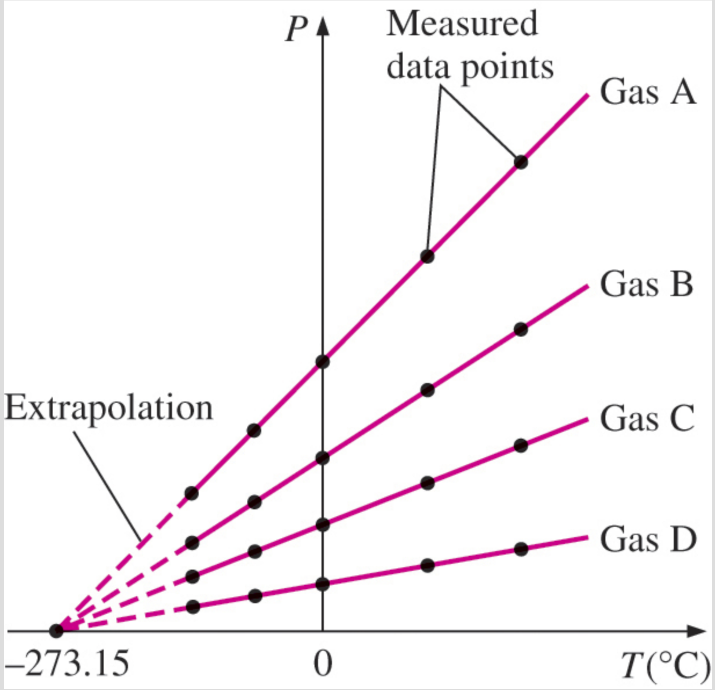
- **The zeroth law of thermodynamics**: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.
- By replacing the third body with a thermometer, the zeroth law can be restated as *two bodies are in thermal equilibrium if both have the same temperature 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 such as the 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).



P versus *T* plots of the experimental data obtained from a constant-volume gas thermometer using four different gases at different (but low) pressures.

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

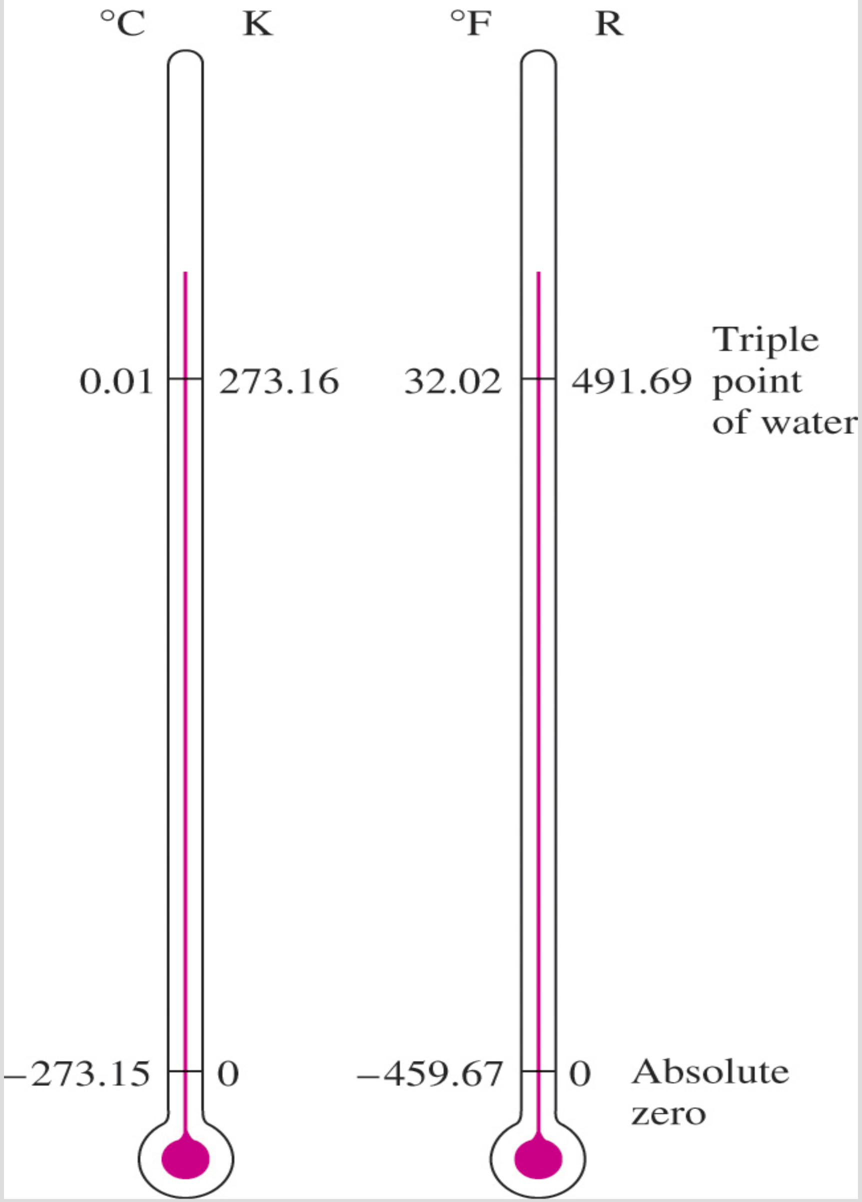
$$T(\text{R}) = 1.8T(\text{K})$$

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

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

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

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



Comparison of temperature scales.

PRESSURE

Pressure: A normal force exerted by a fluid per unit area

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

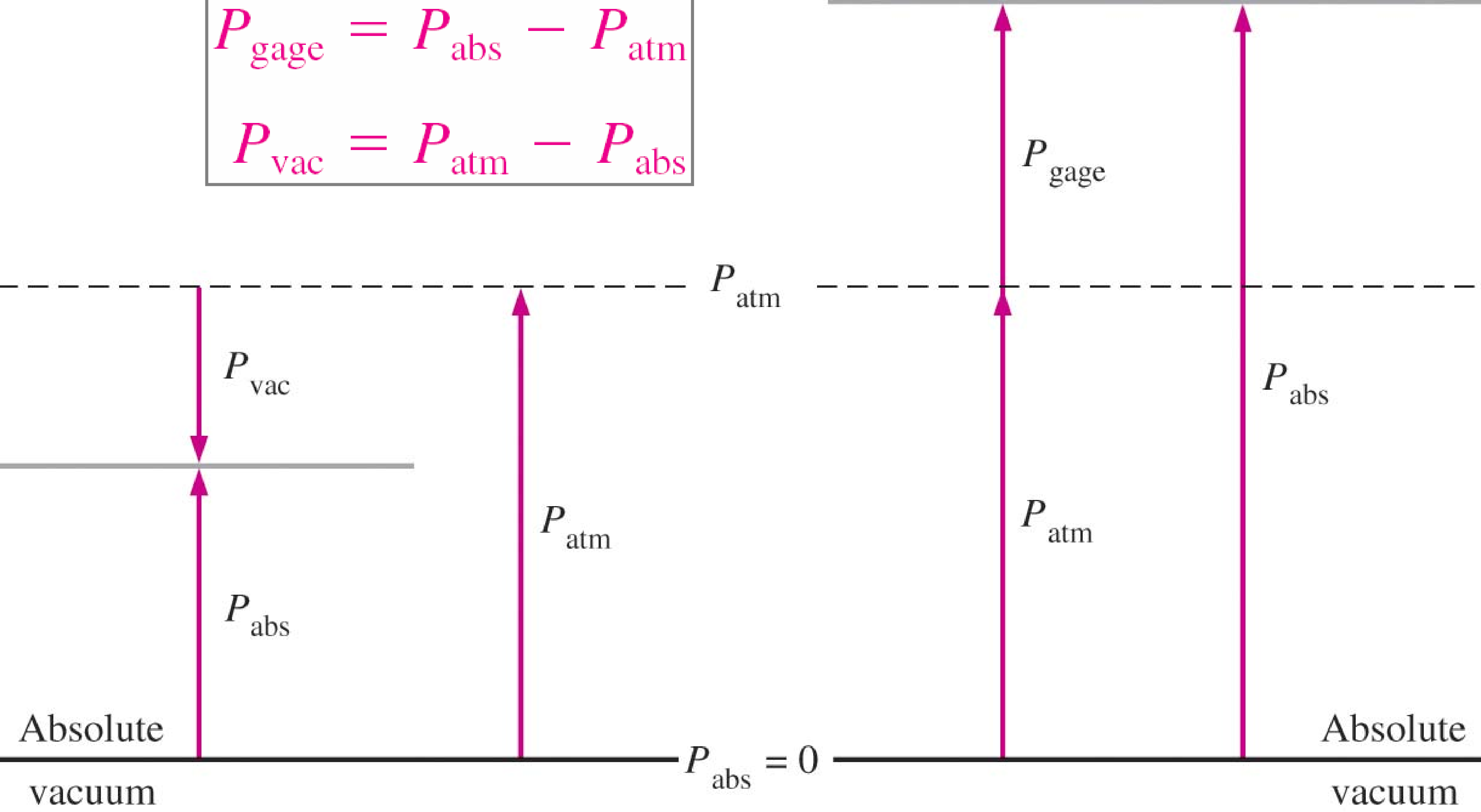
$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

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

$$1 \text{ kgf/cm}^2 = 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa}$$

$$= 0.9807 \text{ bar}$$

$$= 0.9679 \text{ atm}$$



Throughout this text, the pressure *P* will denote *absolute pressure* unless specified otherwise.

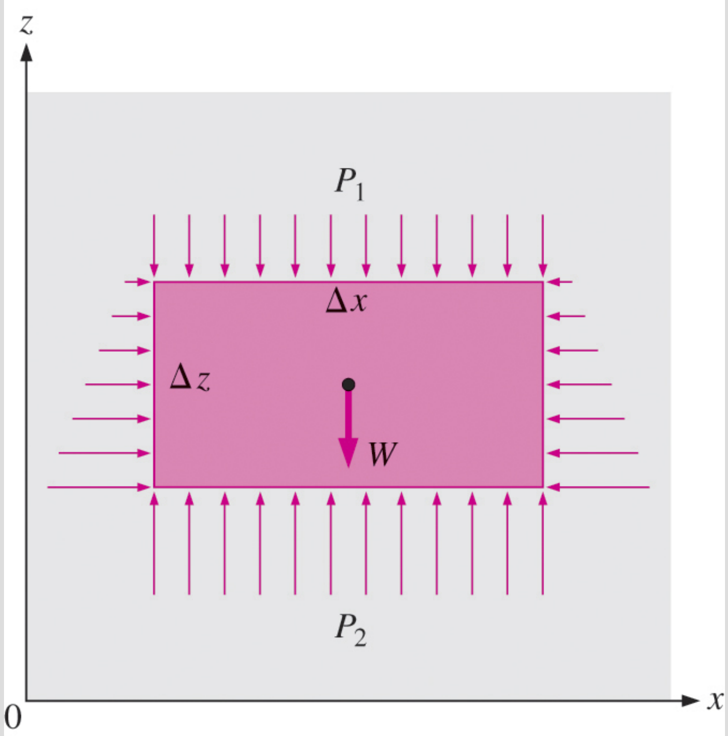
Variation of Pressure with Depth

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

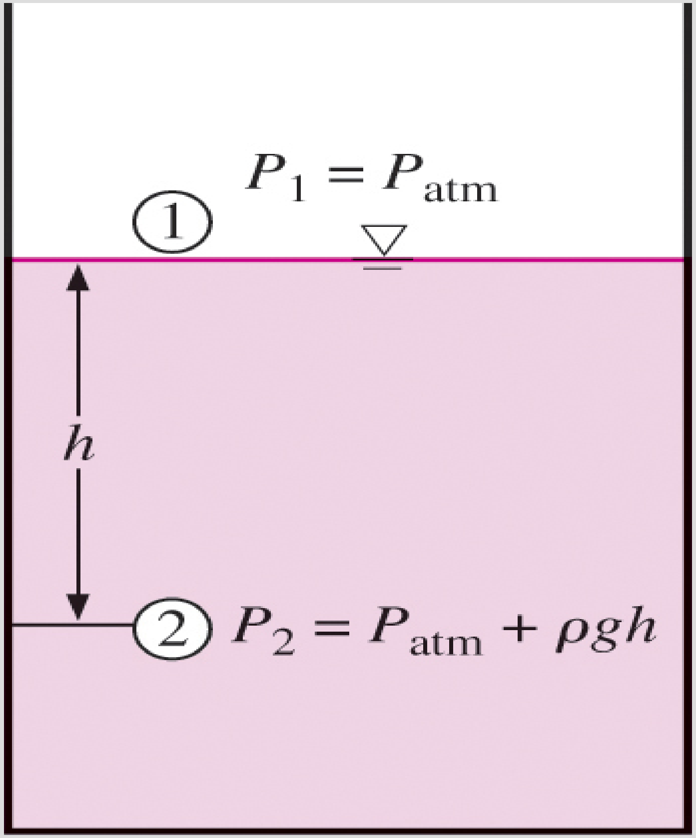
$$P = P_{atm} + \rho g h \quad \text{or} \quad P_{gage} = \rho g h$$

When the variation of density with elevation is known

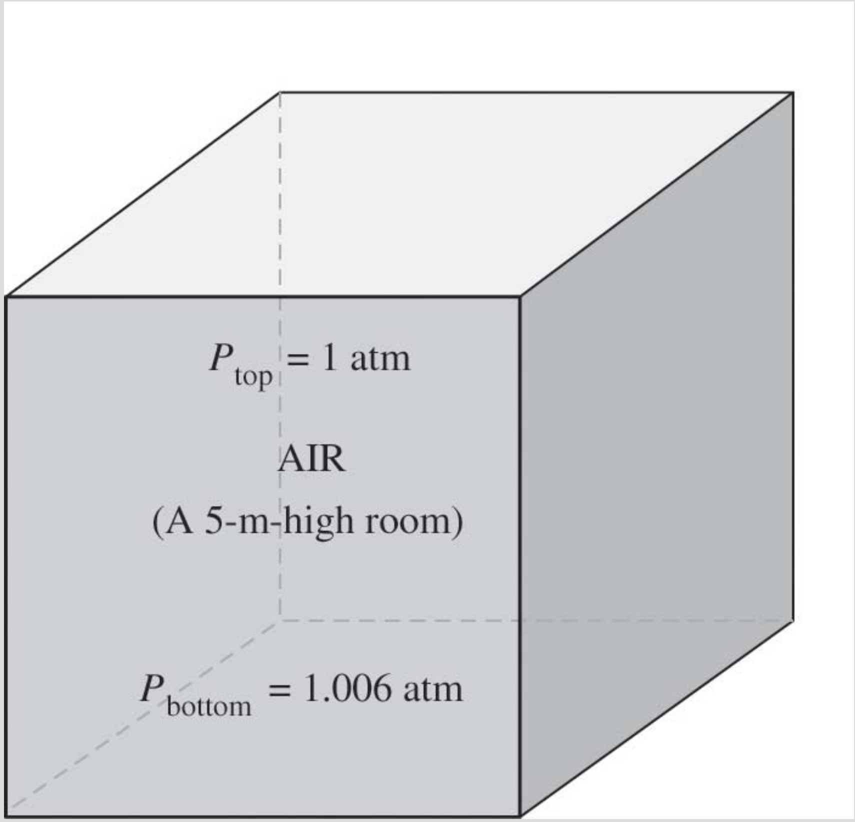
$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g \, dz$$



Free-body diagram of a rectangular fluid element in equilibrium



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



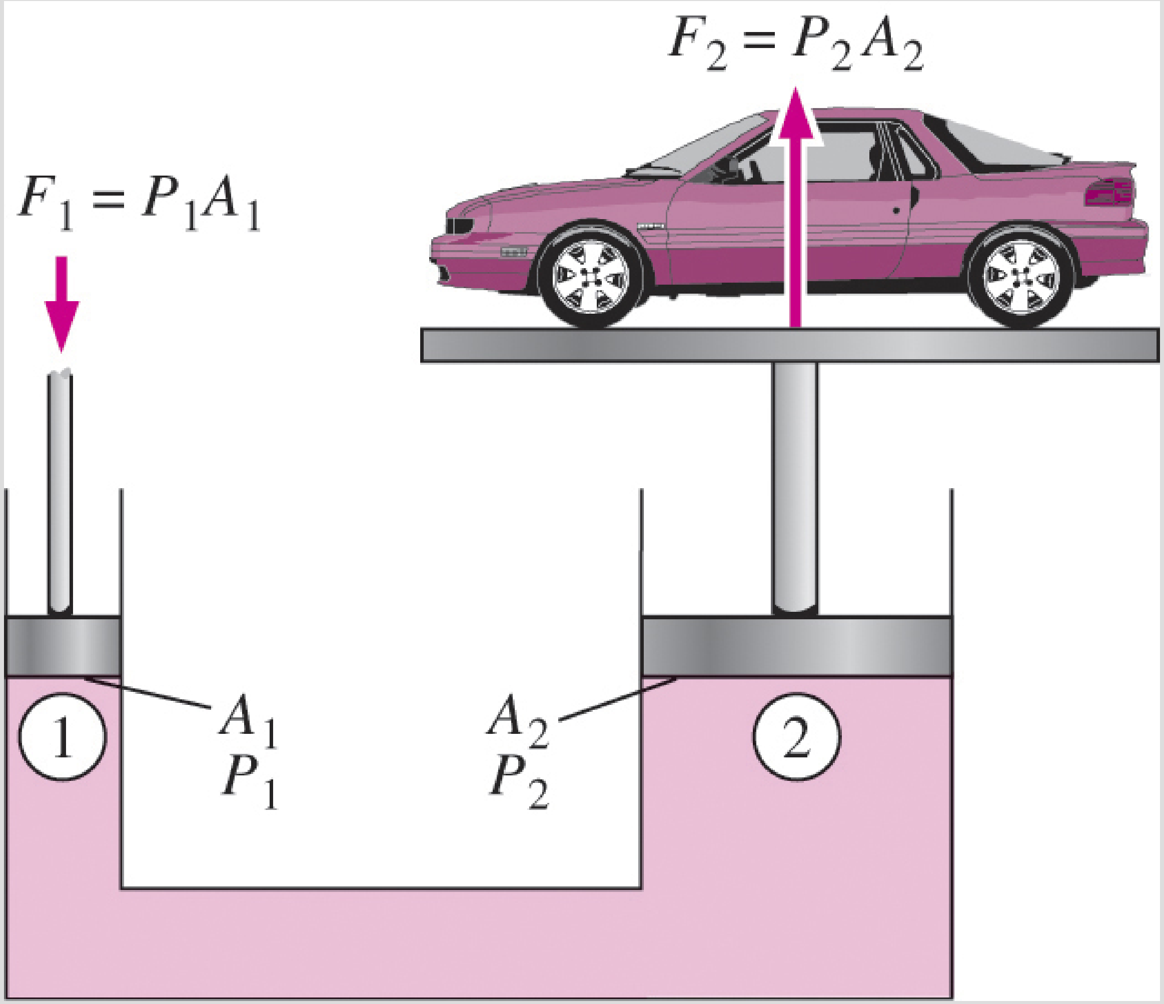
In a room filled with a gas, the variation of pressure with height is negligible.

Pascal's law:

The pressure applied to a confined fluid increases the pressure throughout by the same amount.

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

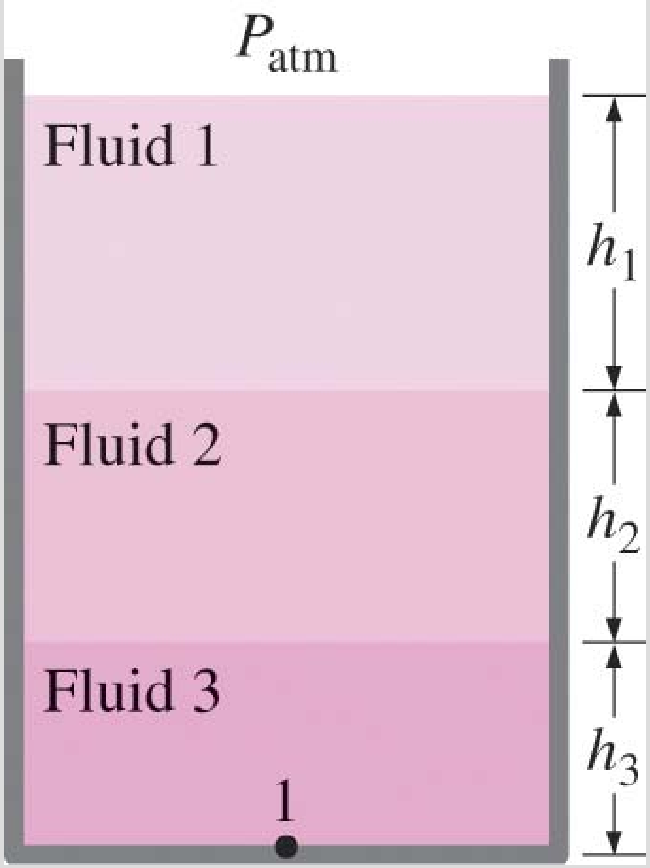
The area ratio A_2/A_1 is called the *ideal mechanical advantage* of the hydraulic lift.



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

The Manometer

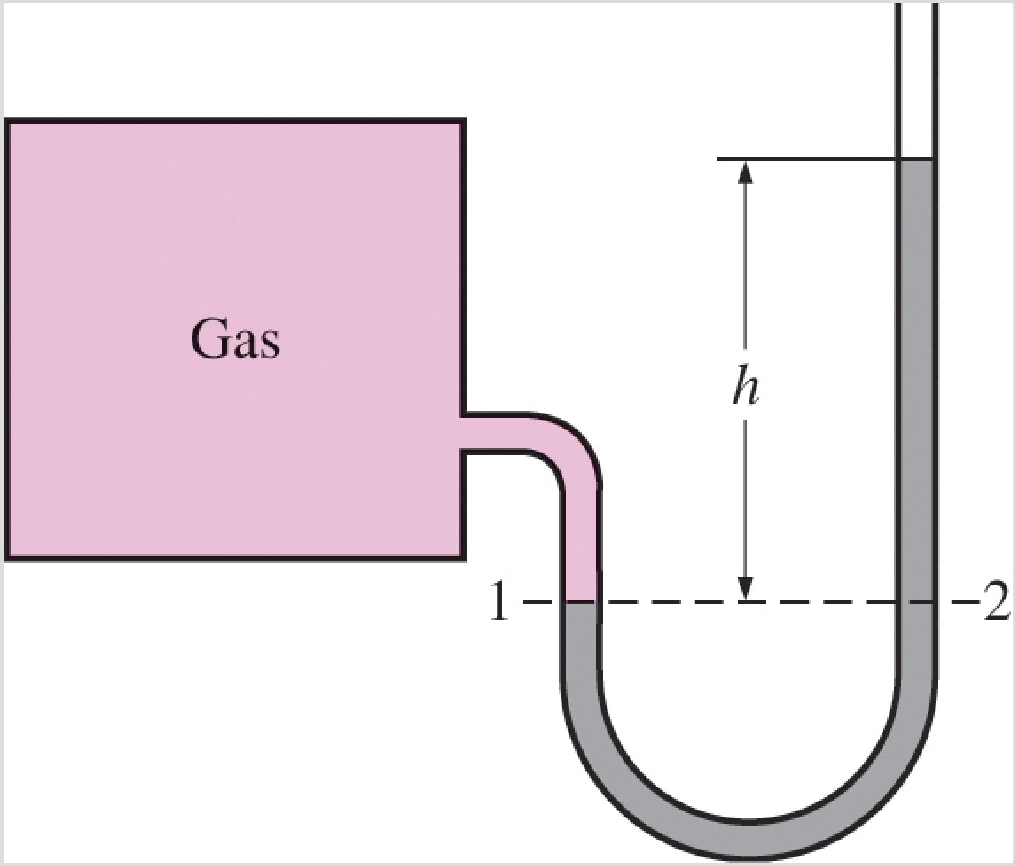
It is commonly used to measure small and moderate pressure differences. A manometer contains one or more fluids such as mercury, water, alcohol, or oil.



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

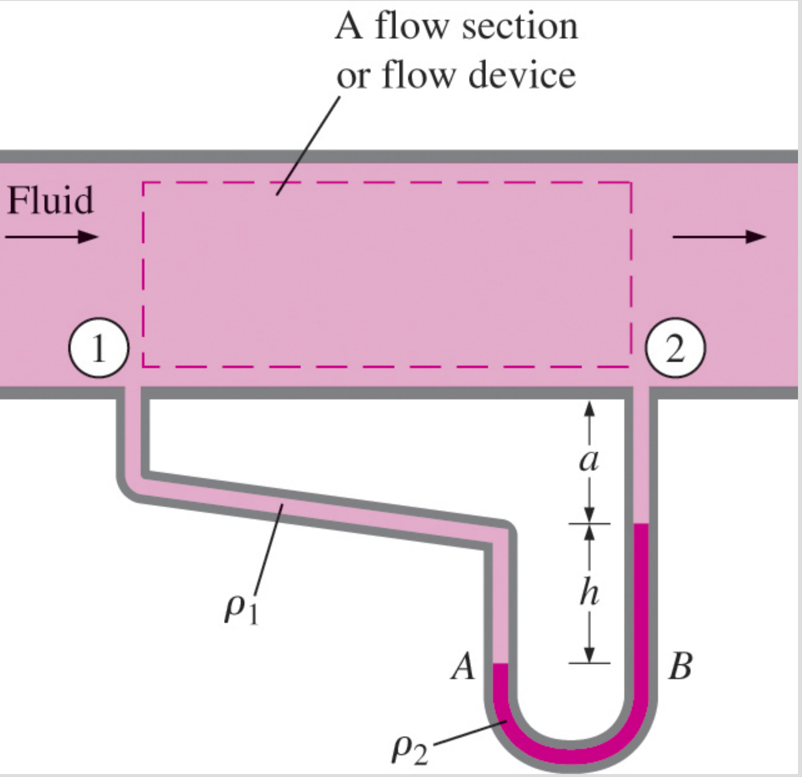
$$P_{atm} + \rho_1 g h_1 + \rho_2 g h_2 + \rho_3 g h_3 = P_1$$

The Basic Manometer



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

The Differential Manometer



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

$$P_1 - P_2 = (\rho_2 - \rho_1)gh$$

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

Pressure Measurement Devices

1. **Bourdon tube:**

   Consists of a hollow metal tube bent like a Hook a dial indicator needle.

2. **Pressure transducers:**

   Use various techniques to convert the pressure effect to an electrical effect such as a change in voltage, resistance, or capacitance. Pressure transducers are smaller and faster, and they can be more sensitive, reliable, and precise than their mechanical counterparts.

3. **Strain-gauge pressure transducers:**

   Work by having a diaphragm deflect between two chambers open to the pressure inputs.

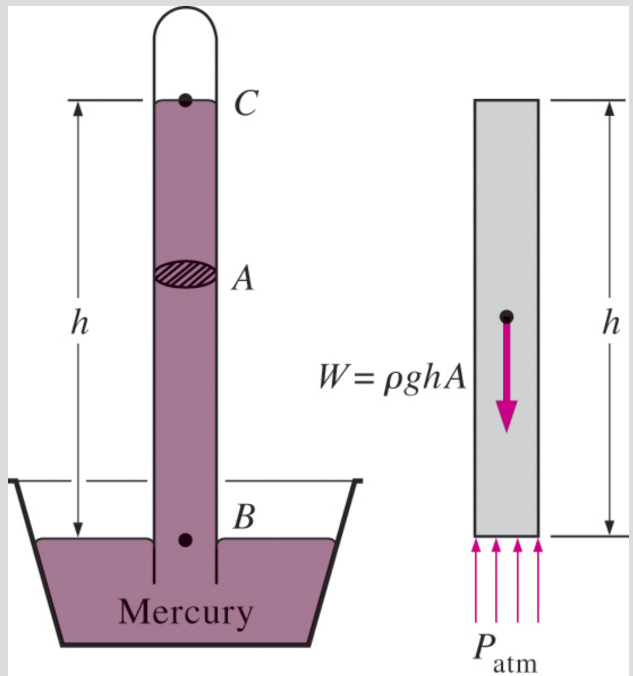
4. **Piezoelectric transducers:**

   Also called solid-state pressure transducers, work on the principle that an electric potential is generated in a crystalline substance when it is subjected to mechanical pressure.

THE BAROMETER AND ATMOSPHERIC PRESSURE

- Atmospheric pressure is measured by a device called a **barometer**; thus, the atmospheric pressure is often referred to as the ***barometric pressure***.
- A frequently used pressure unit is the *standard atmosphere*, which is defined as the pressure produced by a column of mercury 760 mm in height at 0°C (ρ_{Hg} = 13,595 kg/m^3) under standard gravitational acceleration (g = 9.807 m/s^2).

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



The basic barometer.

THE END