Chapter 1

INTRODUCTION AND BASIC CONCEPTS

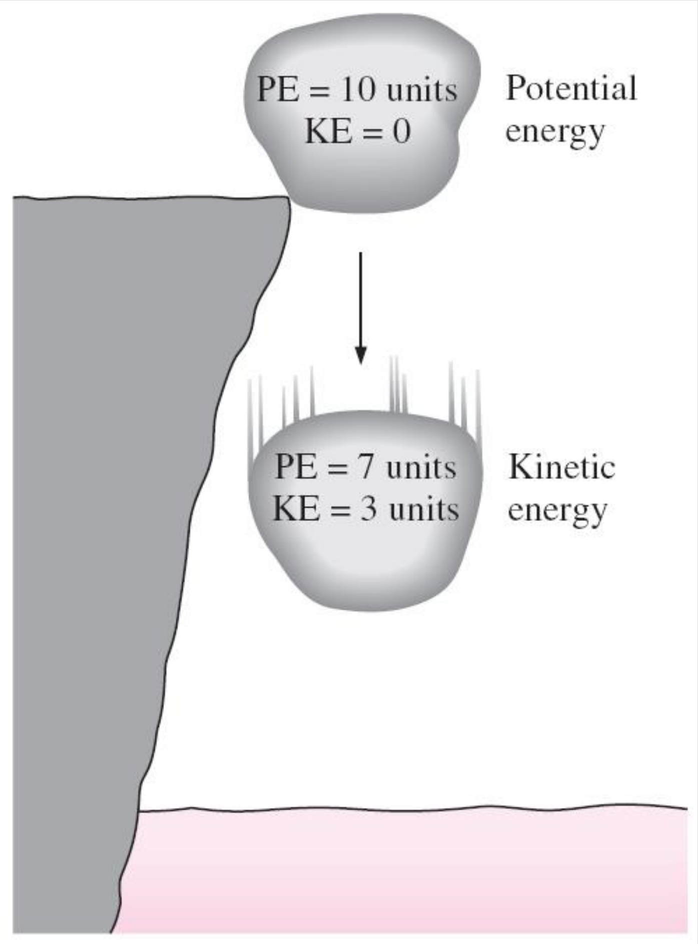
THERMODYNAMICS AND ENERGY

- **Thermodynamics:** The science of *energy.*
- **Energy:** The ability to cause changes – The capacity to do work.

CONSERVATION OF ENERGY

- **Conservation of energy principle**: Energy can change from one form to another but the total amount of energy remains constant.
- Energy cannot be created or destroyed.

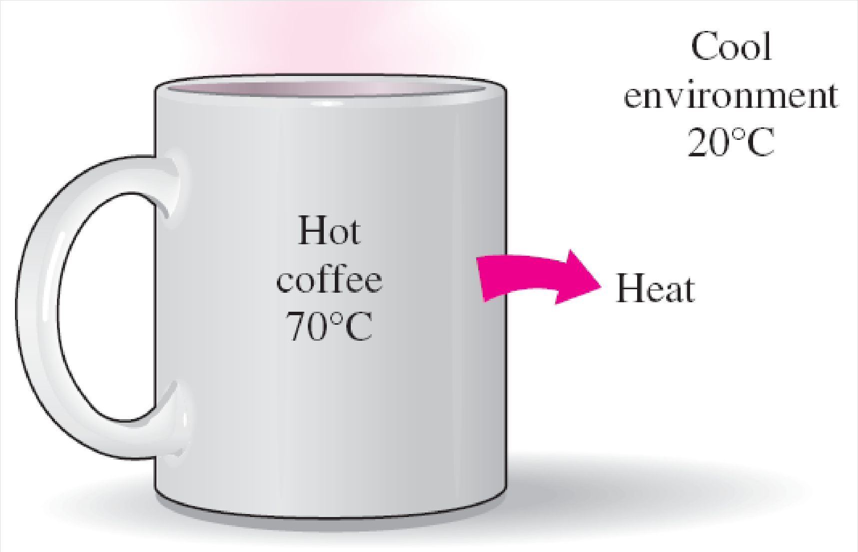
Conservation of energy principle for the human body.



Energy cannot be created or destroyed; it can only change forms (the first law).

LAWS OF THERMODYNAMICS

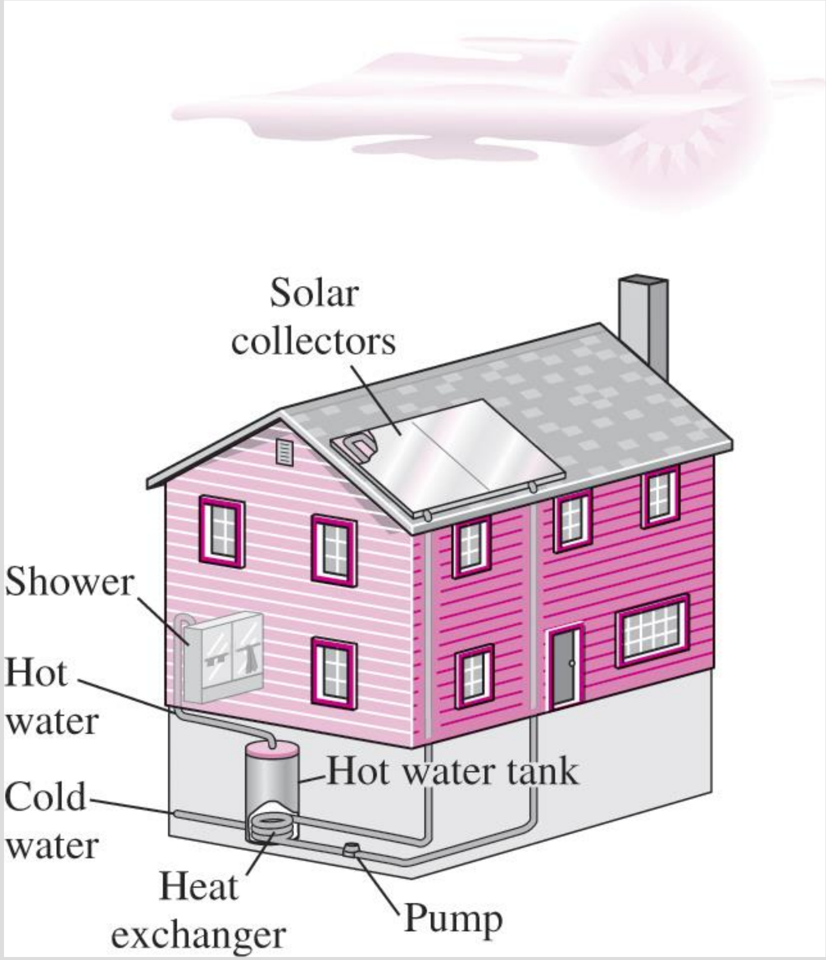
- **The first law of thermodynamics**: An expression of the conservation of energy principle.
- The first law asserts that *energy* is a thermodynamic property.
- **The second law of thermodynamics:** It asserts that energy has *quality* as well as *quantity*, and actual processes occur in the direction of decreasing quality of energy.



TYPES OF THERMODYNAMIC ANALYSIS

- **Classical thermodynamics**: A macroscopic approach to the study of thermodynamics that does not require a knowledge of the behavior of individual particles.
- It provides a direct and easy way to the solution of engineering problems
- **Statistical thermodynamics**: A microscopic approach, based on the average behavior of large groups of individual particles.
- Only classical thermodynamics will be studied in this course.

Application Areas of Thermodynamics



Application Areas of Thermodynamics

IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to the dimensions are called **units**.
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**.
- Other dimensions such as velocity *V*, energy *E*, and volume *V* are expressed in terms of the primary dimensions and are called **secondary dimensions**, or **derived dimensions**.

TABLE 1–1

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

METRIC vs. ENGLISH SYSTEM OF UNITS

- **Metric SI system**: A simple and logical system based on a decimal relationship between the various units.
- **English system**: It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily.

TABLE 1–2

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, μ
10^{-9}	nano, n
10^{-12}	pico, p

Dimensional homogeneity

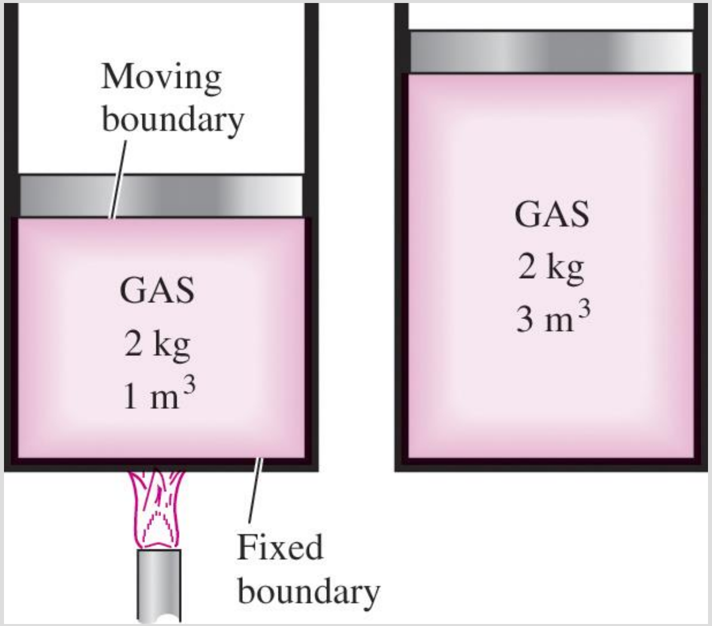
- All equations must be dimensionally **homogeneous**.
- To be dimensionally homogeneous, all the terms in an equation must have the same unit.
- A "term" is an expression in an equation that is separated from others by "-" or "+" or "="

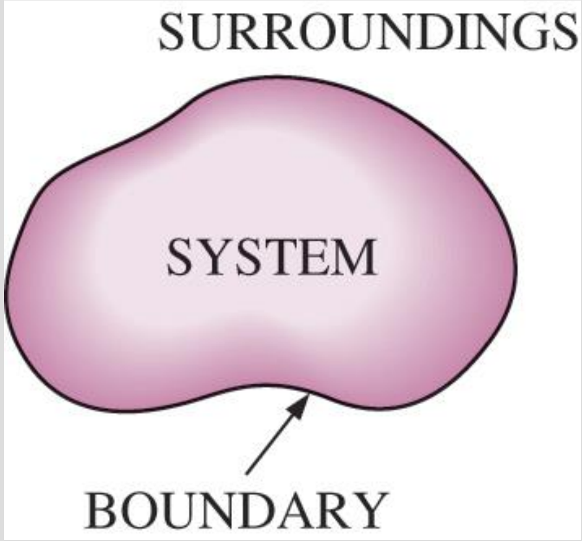
EXAMPLE

A tank is filled with oil whose density is 0.85 kg/L. The volume of the tank is 2 m^3. Another 1.5-m^3 tank is filled with water whose density is 1 g/cm^3. What is the total mass of oil and water in the two tanks?

SYSTEMS

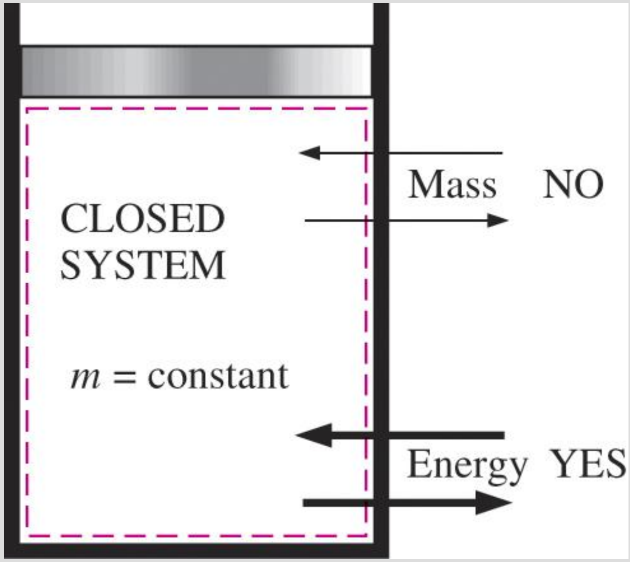
- **System**: A quantity of matter or a region in space chosen for study.
- **Surroundings**: The mass or region outside the system
- **Boundary**: The real or imaginary surface that separates the system from its surroundings.
- The boundary of a system can be *fixed* or *movable*.
- Systems may be considered to be *closed* or *open*.

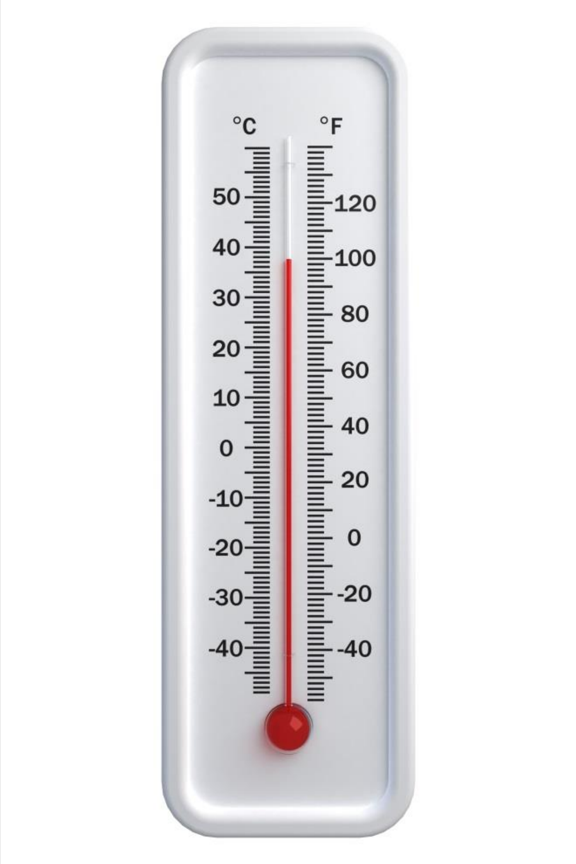




CLOSED SYSTEMS

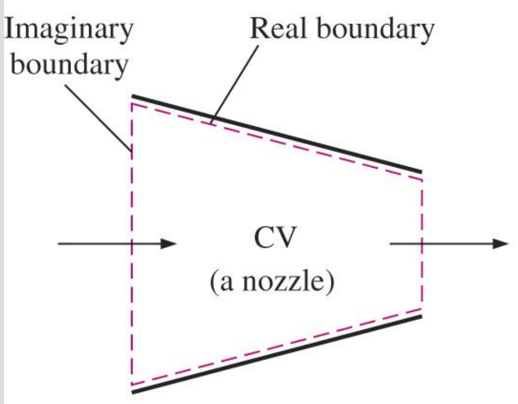
- **Closed system (Control mass):** A fixed amount of mass, and no mass can cross its boundary.



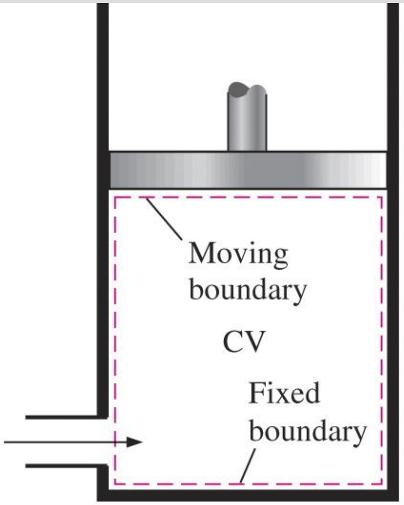


OPEN SYSTEMS

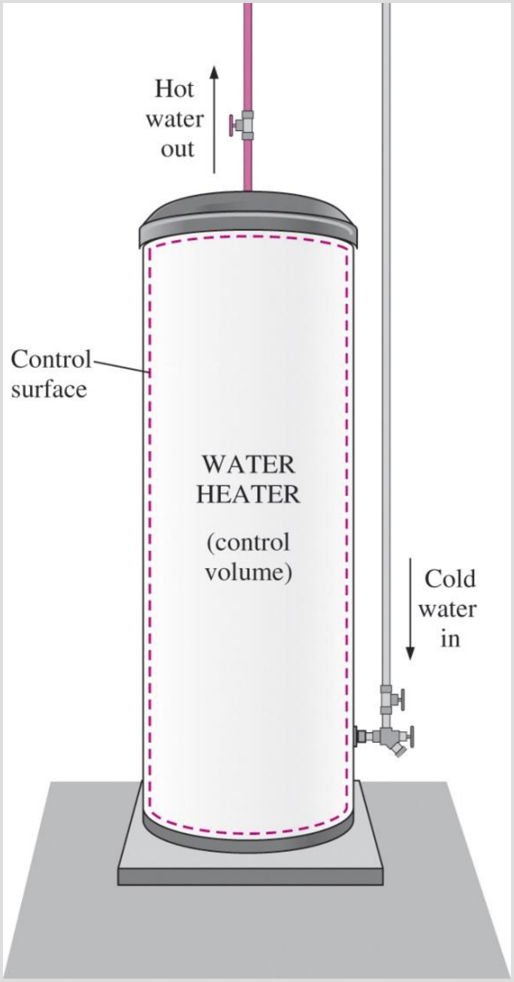
- **Open system (control volume)**: A properly selected region in space.
- It usually encloses a device that involves mass flow such as a compressor or turbine.
- Both mass and energy can cross the boundary of a control volume.
- **Control surface**: The boundaries of a control volume. It can be real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



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



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



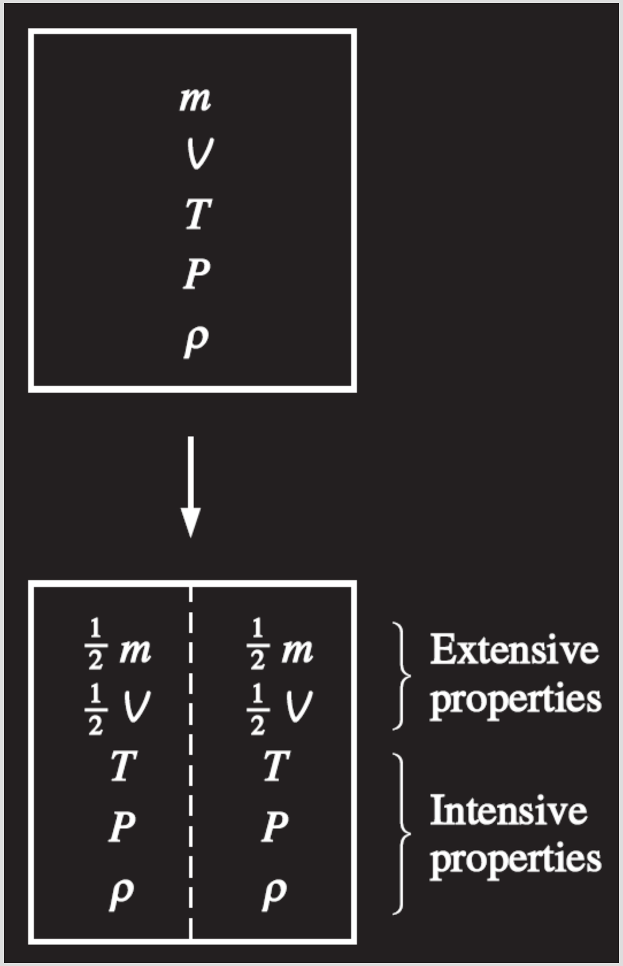
PROPERTIES OF A SYSTEM

- **Property:** Any characteristic of a system.
- Some familiar properties are pressure P, temperature T, volume V, and mass m.

OTHER EXAMPLES?

INTENSIVE AND EXTENSIVE PROPERTIES

- 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 of the system, such as mass and volume.



OTHER EXAMPLES?

SPECIFIC PROPERTIES

- **Specific properties:** Extensive properties per unit mass.
- Specific properties are denoted by lower case letters.
- **Examples**: specific volume (v), specific energy (e)
- Specific properties are intensive properties

DENSITY AND SPECIFIC VOLUME

Density

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

Specific volume

$$v = \frac{V}{m} = \frac{1}{\rho}$$

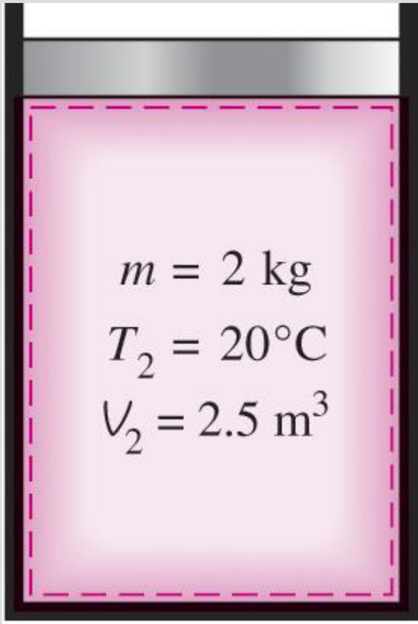
$$V = 12 \text{ m}^3$$
$$m = 3 \text{ kg}$$

$$\rho = 0.25 \text{ kg/m}^3$$
$$v = \frac{1}{\rho} = 4 \text{ m}^3\text{/kg}$$

THERMODYNAMICS STATE

- Consider a system **not** undergoing any change.
- At this point, all the properties can be measured or calculated throughout the entire system.
- This set of properties describes the thermodynamic state of the system.
- At a given state, all the properties of a system have fixed values.
- If the value of even one property changes, the state will change to a different one.

(*a*) State 1



(*b*) State 2

The State Postulate

- The number of properties required to determine 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.

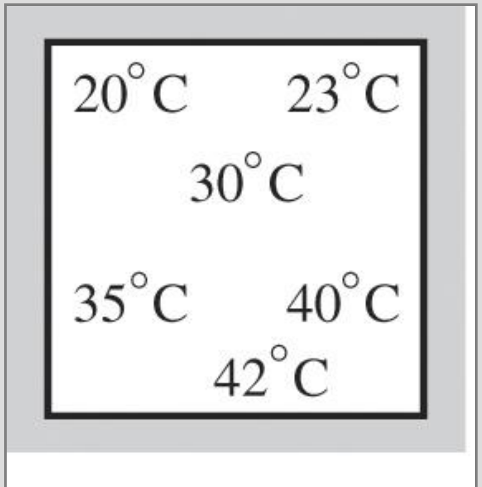
- **Simple compressible system:** If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.
- Two properties are **independent** if one can be fixed, while the other is changing.

THERMODYNAMIC EQUILIBRIUM

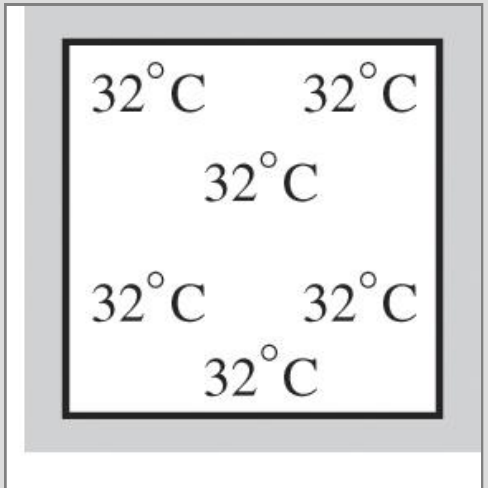
- When a system is in **equilibrium**, there are no unbalances that cause changes in the system.
- A system is in thermodynamic equilibrium if it has:
  - Thermal equilibrium
  - Mechanical equilibrium
  - Phase equilibrium
  - Chemical equilibrium

ELEMENTS OF THERMODYNAMIC 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 (no chemical reactions occur).



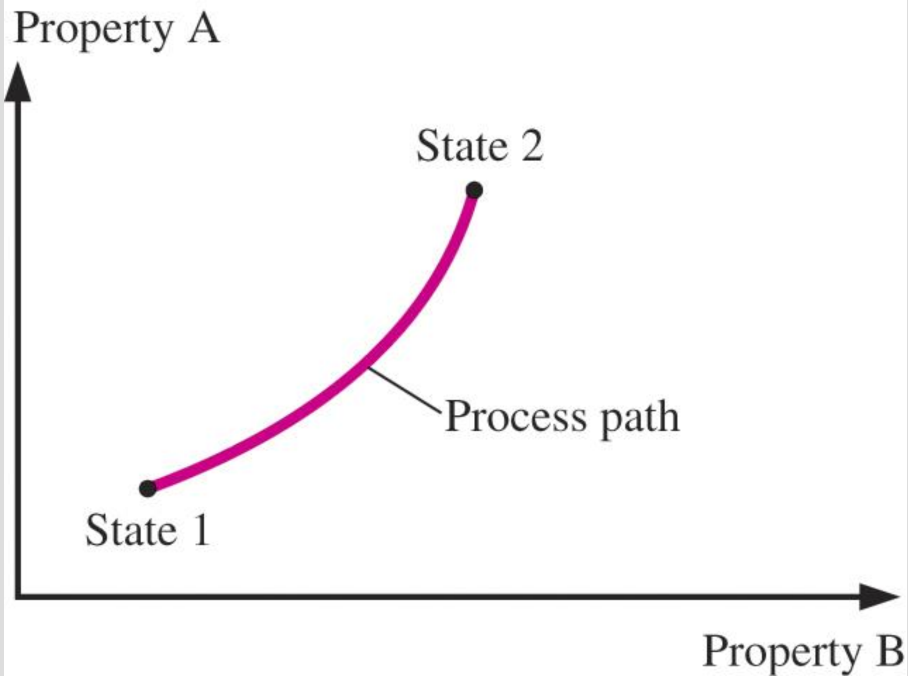
(*a*) Before



(*b*) After

PROCESS

- **Process**: Any change that takes a system from one equilibrium state to another.
- **Path**: The series of states through which a system passes during a process.
- To describe a process completely, one should specify the initial and final states **AND** the path it follows.



SPECIAL PROCESSES

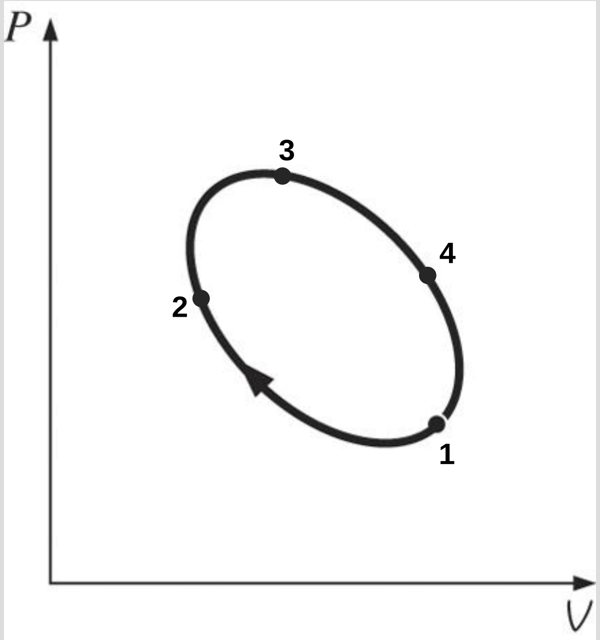
- The prefix *iso-* is often used to designate a process for which a particular property remains constant.

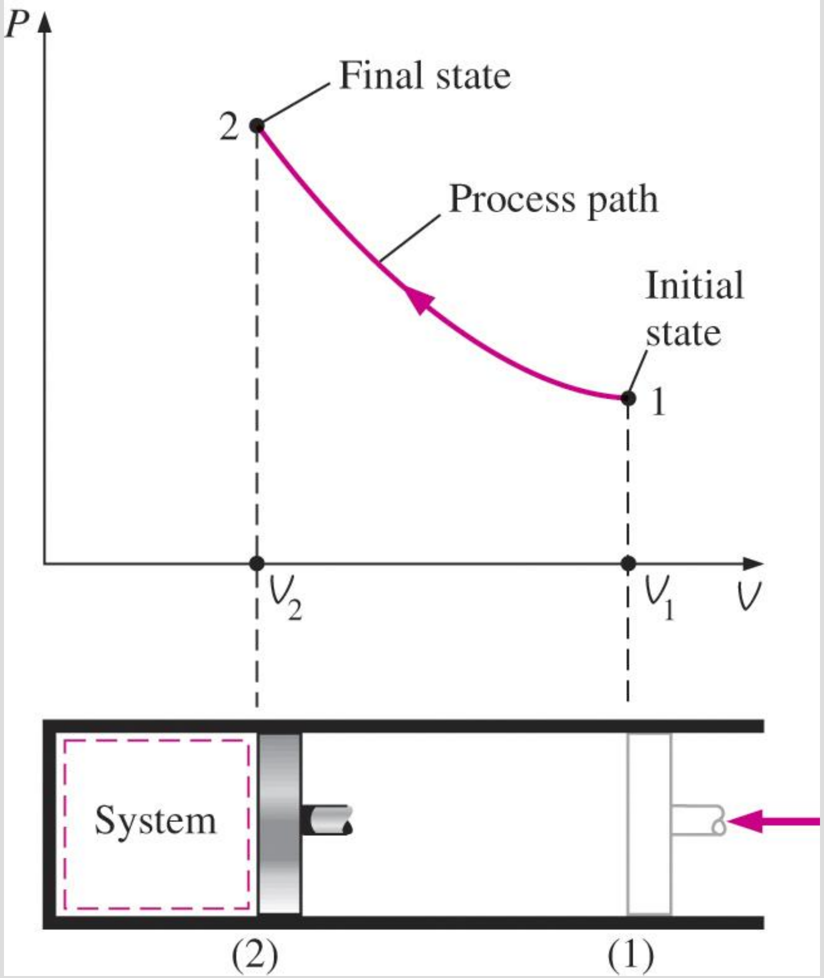
EXAMPLES

- **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.

PROCESS DIAGRAM AND CYCLE

- Process diagrams are very useful in visualizing the processes.
- **Cycle**: A process during which the initial and final states are identical.



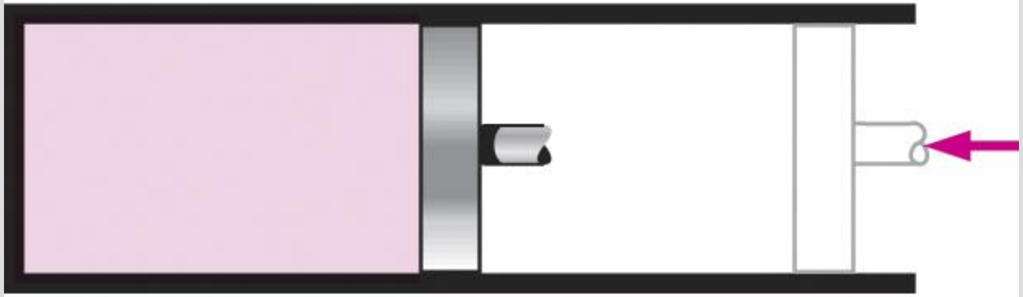


The *P-V* diagram of a compression process.

QUASI-EQUILIBRIUM PROCESS

- **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.

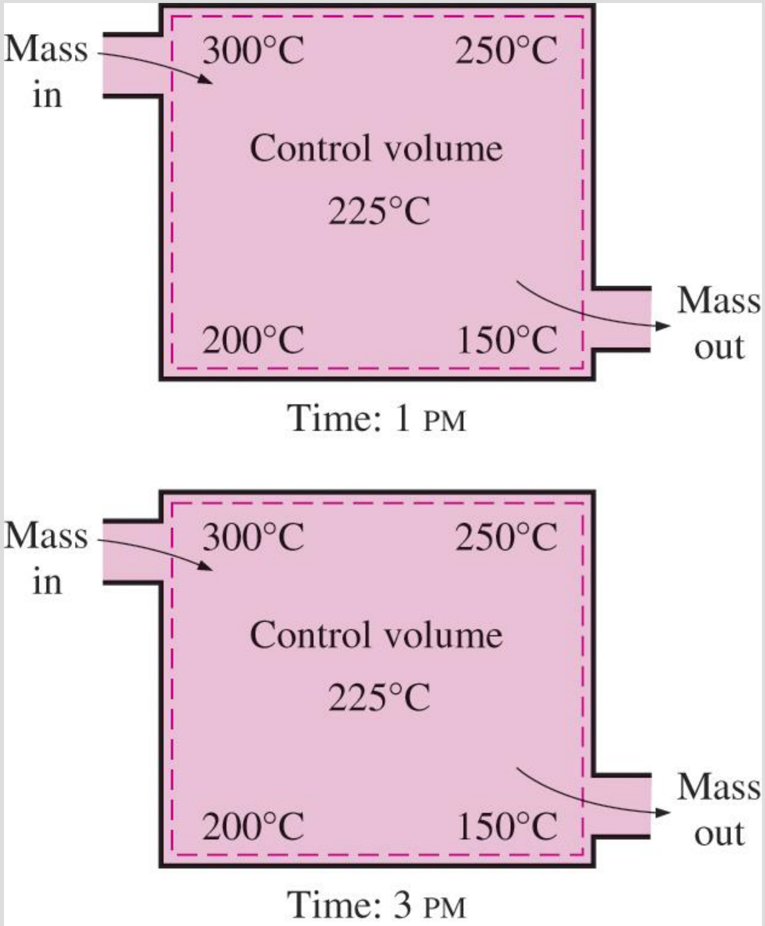
(*a*) Slow compression (quasi-equilibrium)



(*b*) Very fast compression (nonquasi-equilibrium)

The Steady-Flow Process

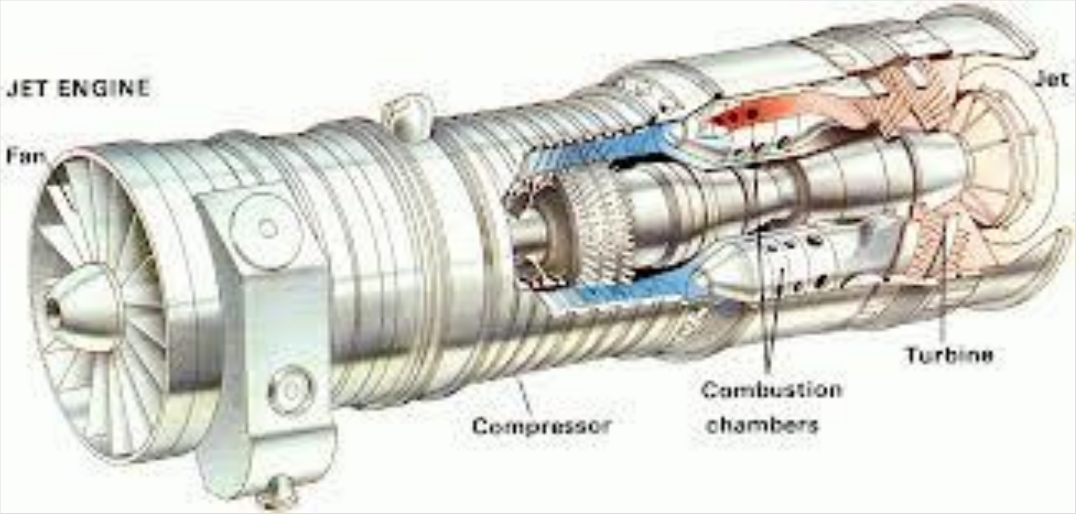
- The term *steady* implies *no change with time*.
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily.



Steady-Flow Devices

- A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as *steady-flow devices*.
- EXAMPLES: turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.

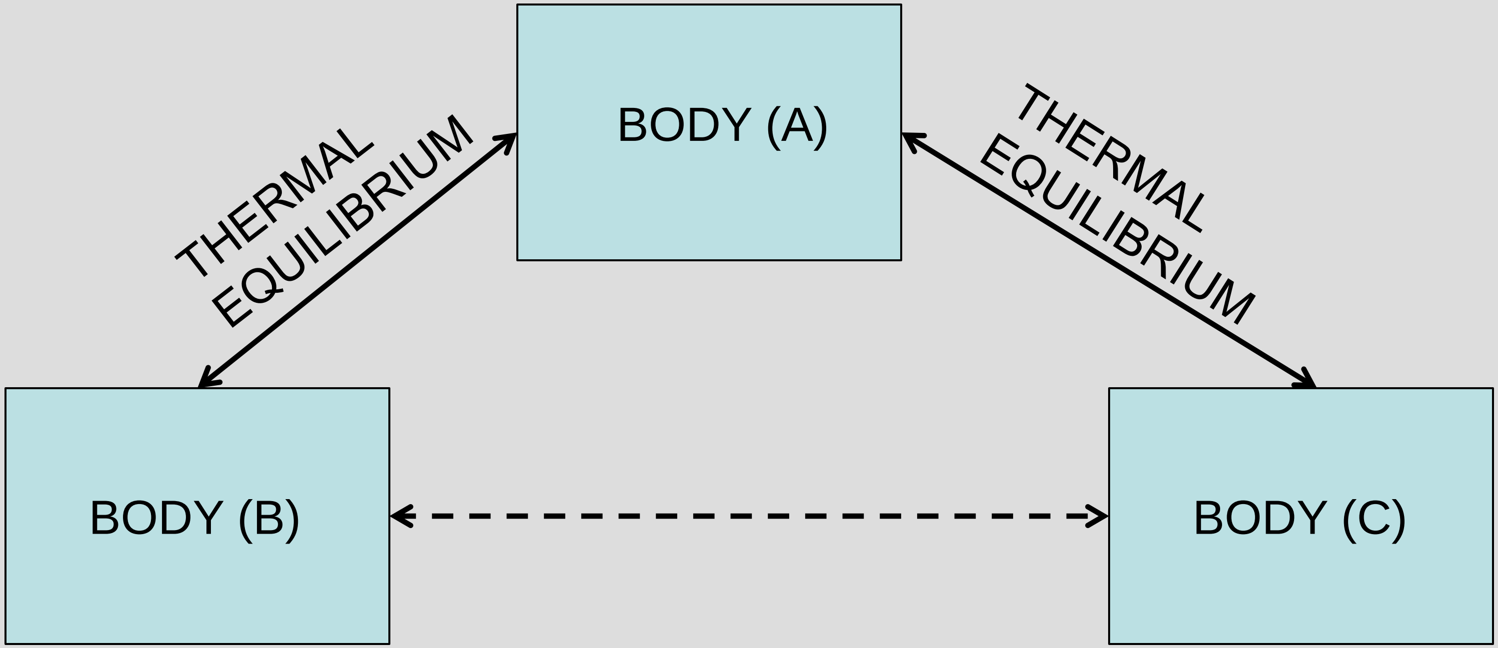
Condenser



Jet Engine

THE ZEROTH LAW OF THERMODYNAMICS

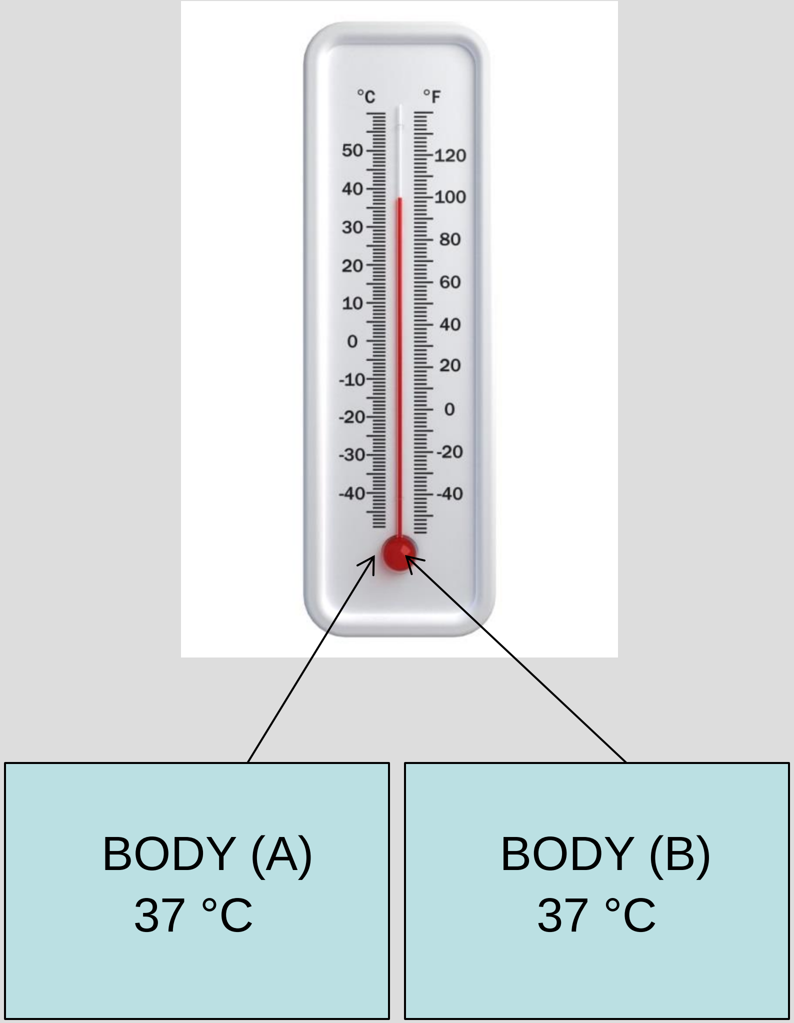
- **The zeroth law of thermodynamics**: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.



TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

- The zeroth law 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*.



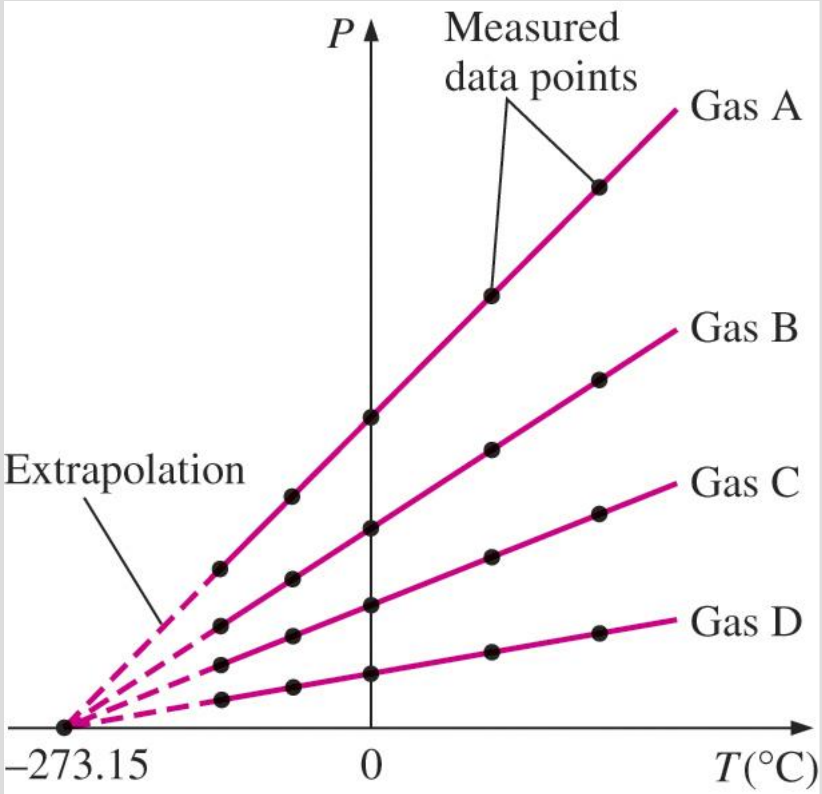
Temperature Scales

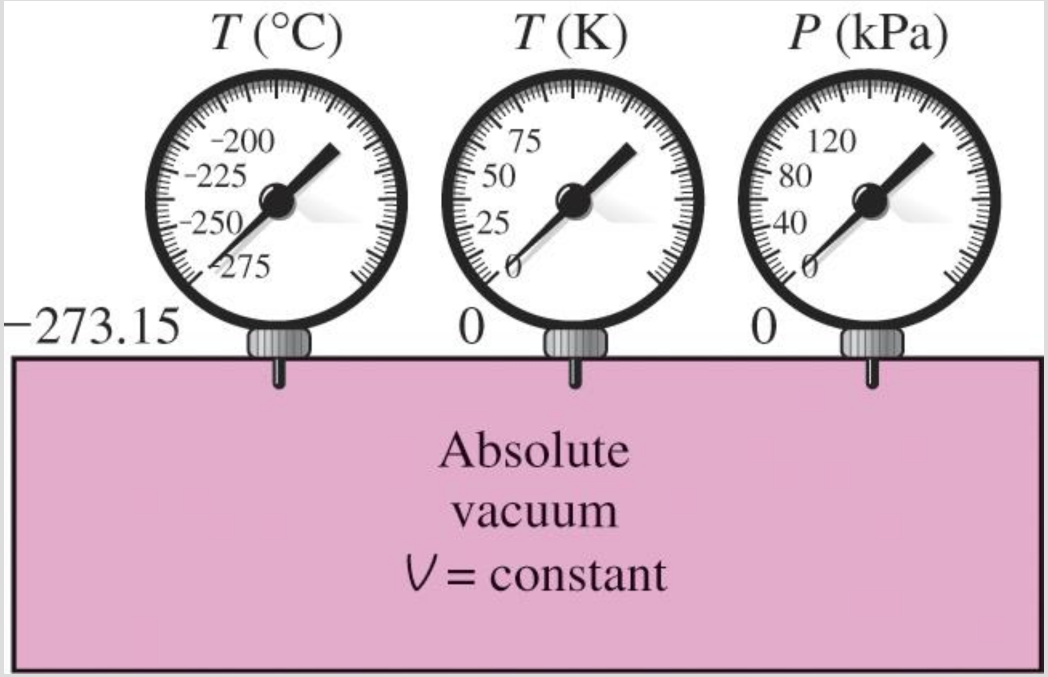
- Most temperature scales are based on some easily reproducible states such as the freezing and boiling points of water: the *ice point* and the *steam point.*
- **Ice point**: A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure (0°C or 32°F).
- **Steam point**: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

Thermodynamic Temperature Scale

- **Thermodynamic temperature scale**: A temperature scale that is independent of the properties of any substance.

- The constant-volume gas thermometer can be used as a thermodynamic temperature scale.





Thermodynamic Temperature Scale

- In a thermodynamic temperature scale, the value (0) is assigned to the lowest possible temperature in the universe
  - There are no negative values

- There are two well-known thermodynamics temperature scales
  - **Kelvin scale:** in SI unit system
  - **Rankine scale:** in English unit system

Temperature Scale Conversions

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

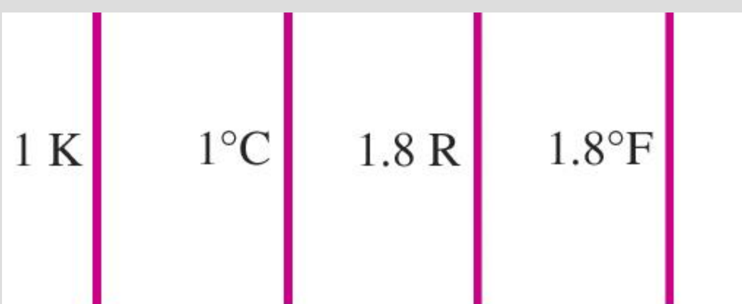
$$T(\text{R}) = T(^\circ\text{F}) + 459.67$$

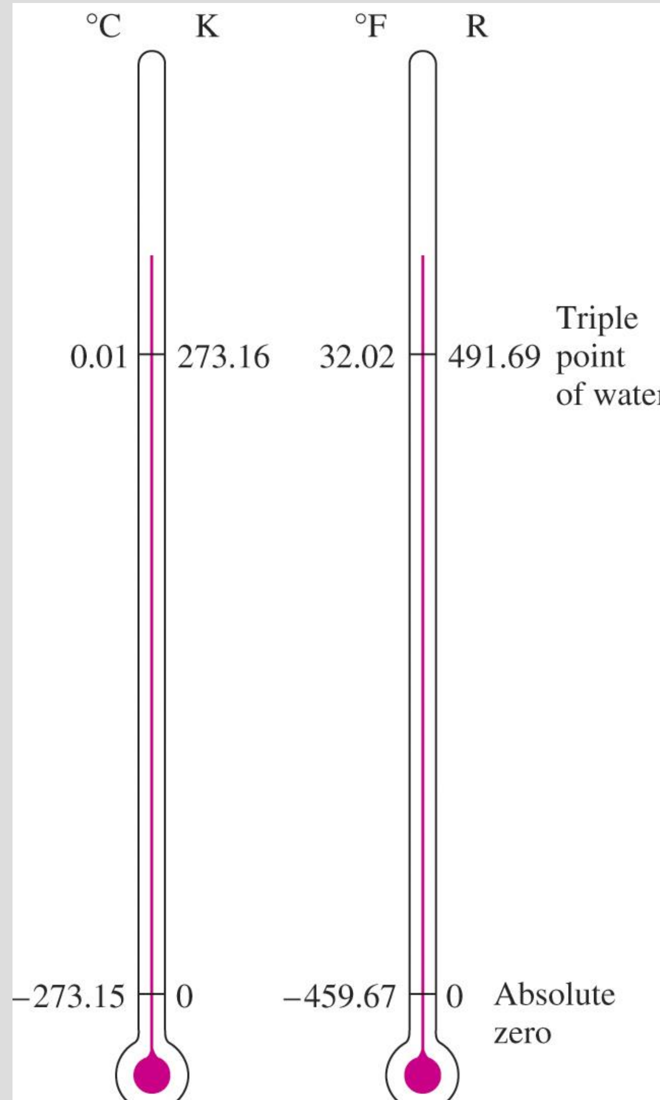
$$T(\text{R}) = 1.8T(\text{K})$$

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

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

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





Pressure

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

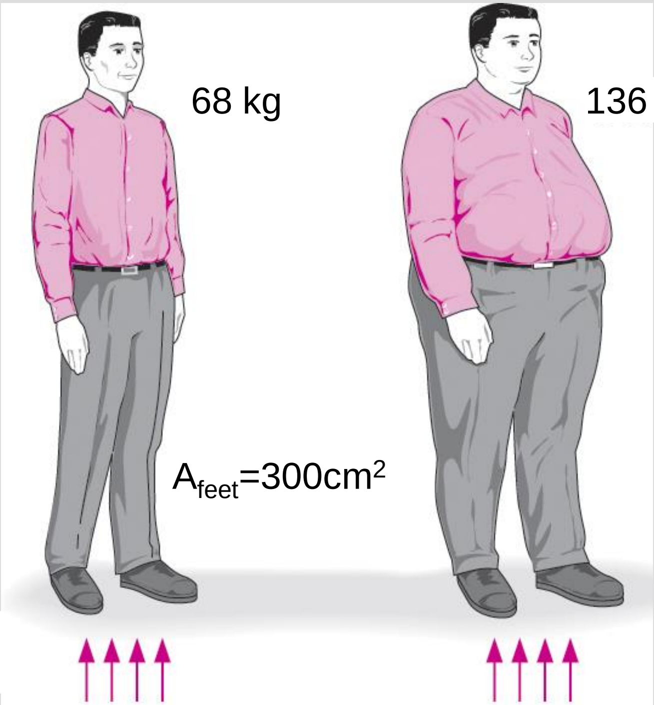
Common Units of pressure

- Pascal (Pa)
- Bar
- Atmosphere (atm)

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

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

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



P = 68x9.81 / 0.03

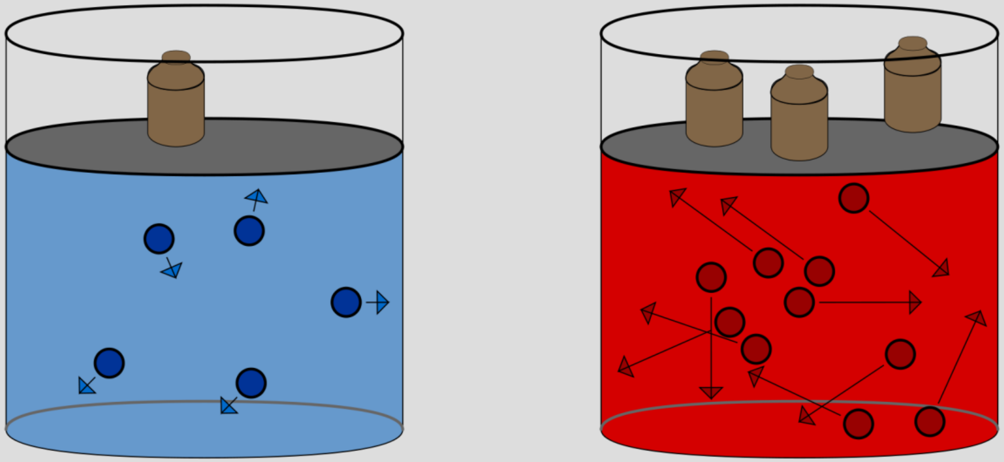
= 22.2 kPa

P = 136x9.81/0.03

= 44.5 kPa

Pressure

- Pressure is sensed in gases by the forces exerted on system boundaries due to molecular collisions
- When molecules have higher kinetic energy (i.e. higher temperature), molecular collisions with system boundaries become stronger → pressure is higher
  - There is a proportional relationship between temperature and pressure in gases



Temperature T   Temperature 3T

Absolute, Gage, and Vacuum Pressure

Absolute pressure

The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure)

Gage pressure

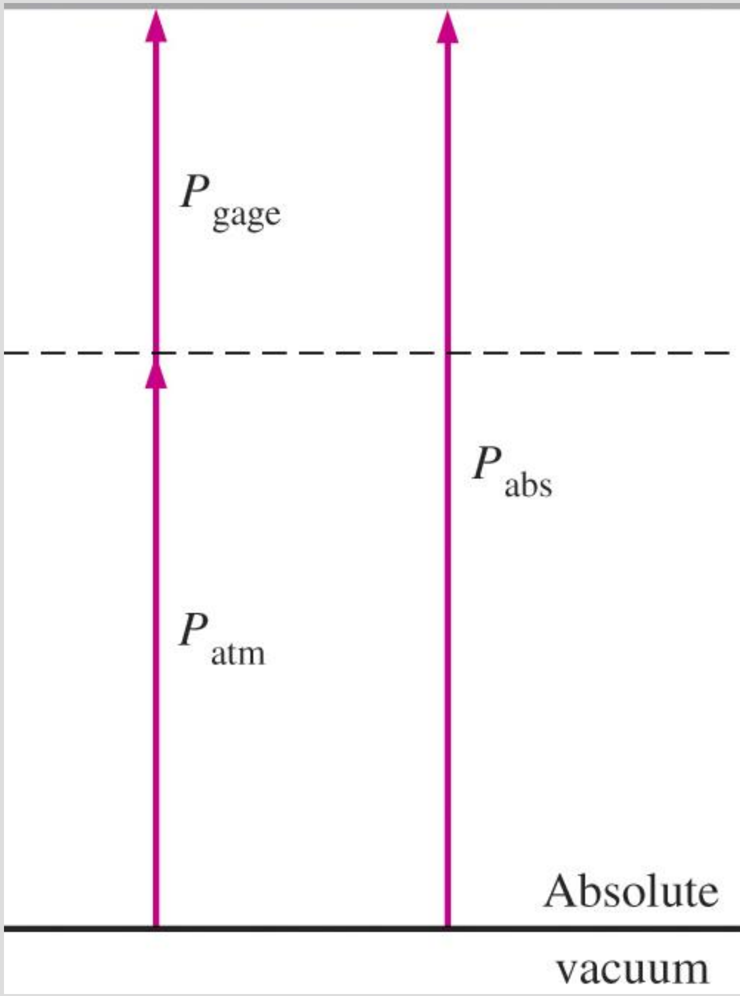
The difference between the absolute pressure and the local atmospheric pressure

Vacuum pressure

The difference between the local atmospheric pressure and absolute pressure (if absolute pressure is less than local atmospheric pressure).

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

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



Absolute, Gage, and Vacuum Pressure

Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure

Problems

1–34 The deep body temperature of a healthy person is 37°C. What is it in kelvins?

1–36 The temperature of a system rises by 45°C during a heating process. Express this rise in temperature in kelvins.

1–58 The vacuum pressure of a condenser is given to be 80 kPa. If the atmospheric pressure is 98 kPa, what is the gage pressure and absolute pressure in kPa, kN/m^2, lbf/in^2, psi, and mm Hg.