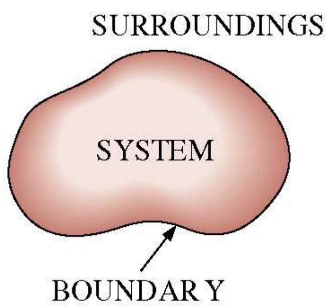
CHAPTER TWO

BASIC CONCEPTS OF THERMODYNAMICS

Closed and Open Systems (Section 2.1)

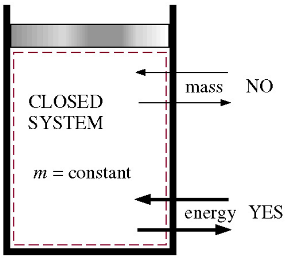


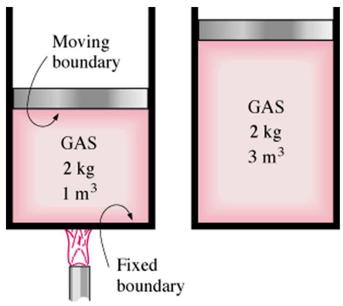
<u>Thermodynamic System (System)</u>
A quantity of matter or a region in space chosen for study

<u>Surroundings</u>
The mass or region outside the system

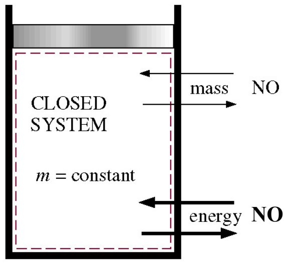
<u>Boundary</u>
- The real or imaginary surface that separates the system from its surroundings
- It is a contact surface shared by both the system and the surroundings
- It has zero thickness

<u>Closed System</u>
- Consists of a fixed amount of mass, and no mass can cross the boundary, i.e. no mass can enter or leave the closed system
- Energy can cross the boundary
- The volume of a closed system does not have to be fixed

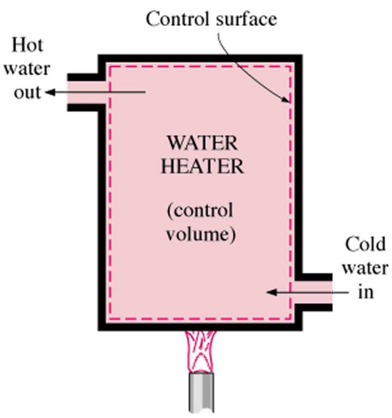


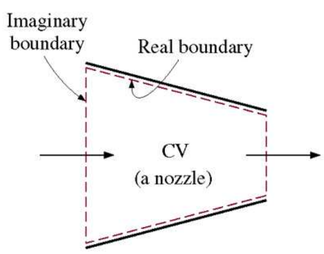


<u>Isolated System</u>
- Special case of a closed system
- Energy is not allowed to cross the boundary

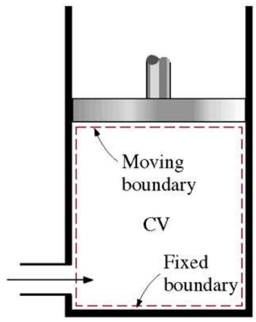


<u>Open System (Control Volume)</u>
- A properly selected region in space
- Both mass and energy can cross the boundary
- Boundaries of a control volume are called a control surface
- Control surface can be real or imaginary
- A control volume can be fixed in size and shape or it may involve a moving boundary





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



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

Properties of a System (Section 2.2)

- Any characteristic of a system
- Pressure, temperature, volume, and mass are all properties

Intensive Properties

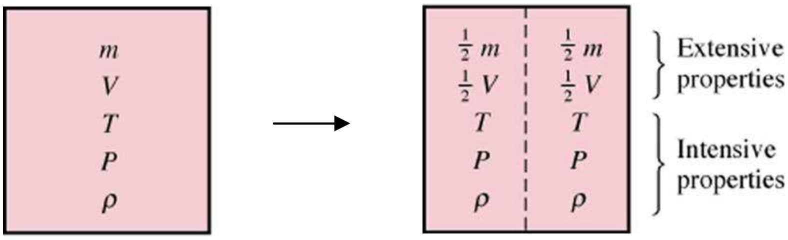
Properties that do not depend on the size of the system, such as temperature, pressure, and density

Extensive Properties

Properties whose values depend on the size of the system

How To Differentiate Between Intensive and Extensive Properties?

- Divide the system into two equal parts with a partition
- If each part has the same property value as the original system, the property is **intensive**
- If each part has only half the property value of the original system, the property is **extensive**



Specific Properties

- Extensive properties per unit mass
  Examples: $v = V / m$, $e = E / m$
- There are no specific properties for intensive properties

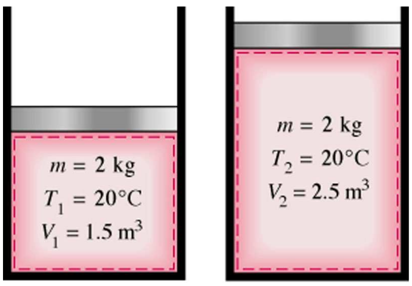
Density and Specific Volume

- Density is defined as mass per unit volume: $\rho = m / V$ (kg/m^3)
- Specific volume is defined as volume per unit mass: $v = V / m$ (m^3/kg)
- Density is the reciprocal of specific volume: $\rho = 1/v$

State and Equilibrium (Section 2.3)

State

- The condition of a system at which a set of properties can completely describe it
- At a given state, all the properties of a system have fixed values
- If the value of one property changes, the state will change



(*a*) State 1　(*b*) State 2

Equilibrium

- In an equilibrium state, there are no unbalanced potentials (or driving forces) within the system

Thermodynamic Equilibrium

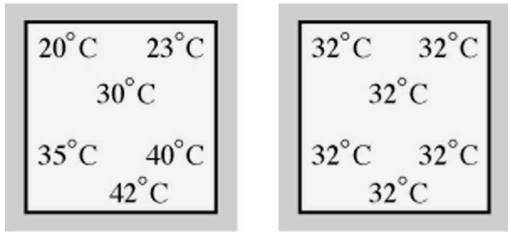
A system is said to be in thermodynamic equilibrium if it maintains thermal, mechanical, phase, and chemical equilibrium.

Thermal Equilibrium
The temperature throughout the entire system is uniform

Mechanical Equilibrium
The pressure throughout the entire system is uniform

Phase Equilibrium
The mass of each phase is in equilibrium

Chemical Equilibrium
Chemical composition does not change with time, i.e. no chemical reactions take place



(a) Before (b) After

A simple compressible system

- A system in which electrical, magnetic, and gravitational effects are absent

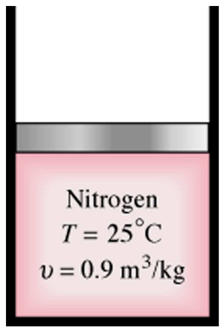
Independent properties

Two properties are independent if one property can be varied while the other one is held constant

Example

- Temperature and specific volume are always independent properties
  - ⇨ the specific volume of a cylinder can be held constant while the temperature is being raised

OR ⇨ the temperature inside a cylinder can be held constant while the volume is being increased



The State Postulate

- Not all properties need to be specified to fix a state
- Once a sufficient number of properties are specified, the values of the rest of the properties are automatically known

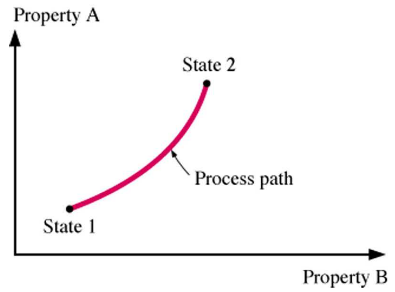
The state postulate
The state of a simple compressible system is completely specified by two independent, intensive properties (in addition to mass)

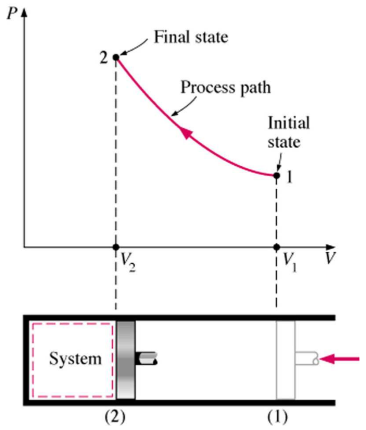
Processes and Cycles (Section 2.4)

<u>Process</u>
Any change that a system undergoes from one equilibrium state to another

<u>Path</u>
The series of states through which a system passes during a process

<u>How to describe a process completely?</u>
One should specify the initial and final states AND the path the process follows





In most of the processes we study, one thermodynamic property is held constant

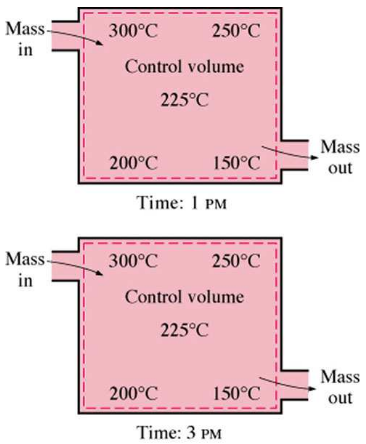
Isobaric process: Pressure held constant
Isothermal process: Temperature held constant
Isochoric process: Specific volume held constant
Isentropic process: Entropy held constant

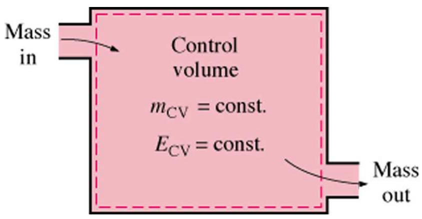
<u>Cycle</u>

- The system returns to its initial state at the end of the process
- The initial and final states are identical

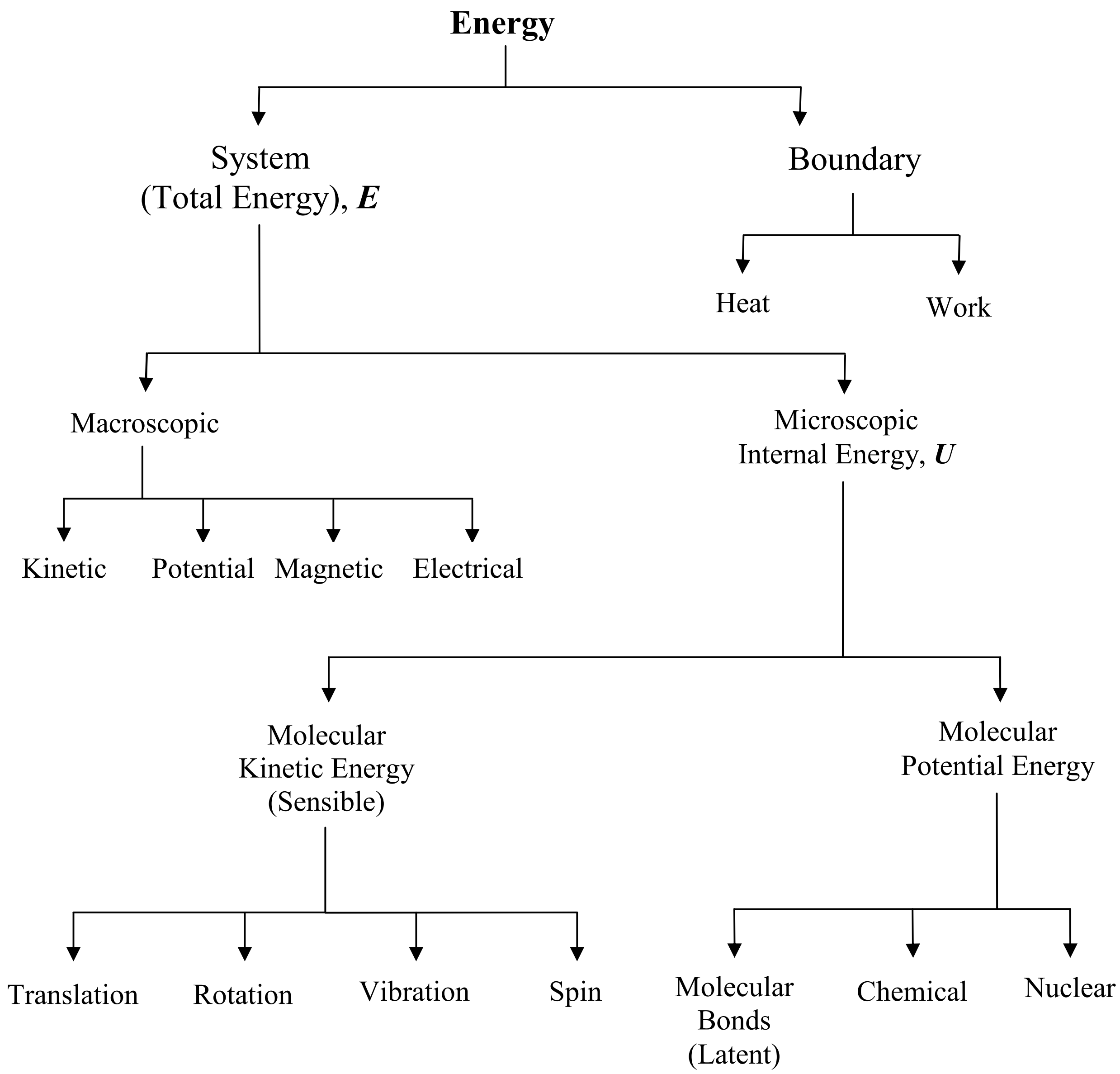
<u>Steady-Flow Process</u>

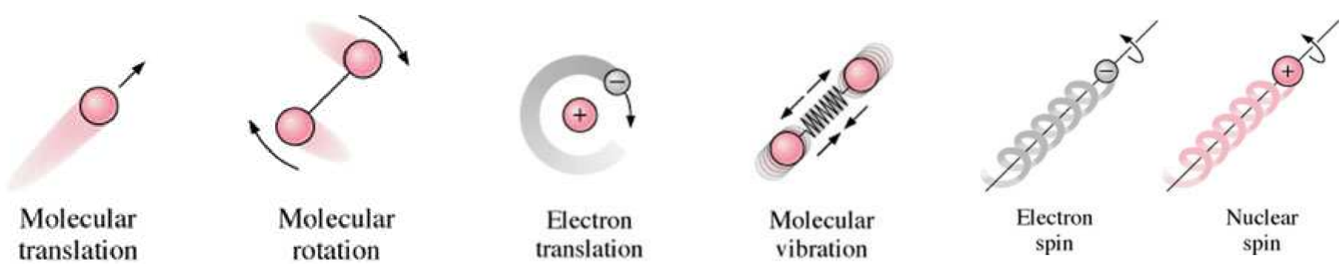
- A process during which a fluid flows through a control volume steadily, i.e. does not change with time
- Fluid properties can change from point to point within the control volume, but at any fixed point they remain the same during the entire process
- The volume V, mass m, and total energy content E of the control volume remain constant





Forms of Energy (Section 2.5)





Total Energy (E)

The sum of all forms of energy a system possesses.

Forms of Energy

Macroscopic Energy

The forms of energy that a system possesses as a whole with respect to an outside reference (*Examples*: kinetic and potential energy)

Microscopic Energy

The forms of energy related to the molecular structure of a system and the degree of the molecular activity. They are independent of outside reference frames

Internal Energy

- The sum of all the microscopic forms of energy
- Denoted by U

Macroscopic Kinetic Energy

- The energy that a system possesses as a result of its motion relative to a reference frame
- It is a macroscopic form of energy

$$\text{KE} = \frac{m\mathcal{V}^2}{2} \qquad \text{AND} \qquad \text{ke} = \frac{\mathcal{V}^2}{2}$$

Macroscopic Potential Energy

- The energy that a system possesses as a result of its elevation in a gravitational field
- It is a macroscopic form of energy

$$\text{PE} = mgz \quad \text{AND} \quad \text{pe} = gz$$

Total Energy (Special Case)

- When magnetic, electric, and surface tension effects are absent, the total energy of a system consists only of kinetic, potential, and internal energies

$$E = U + \text{KE} + \text{PE} \ = U + \frac{m\text{V}^2}{2} + mgz$$

- Furthermore, when changes in kinetic and potential energy are negligible, the change in total energy ΔE becomes identical to the change in its internal energy ΔU

Temperature and the Zeroth Law of Thermodynamics (Section 2.7)

Temperature
A measurement of the overall microscopic kinetic energy of a body or a system
⇨ fast-moving molecules have high kinetic energy ⇨ they have high temperature

Zeroth law of thermodynamics

- If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other
- If the third body is a thermometer and it is in thermal equilibrium with two different bodies, then the two bodies must also be in equilibrium and at the same temperature

Temperature Scales
Usually based on the freezing and boiling points of water at 1 atmospheric pressure

Celsius Scale
Freezing (Ice) point is at 0 and the boiling (steam) point is at 100

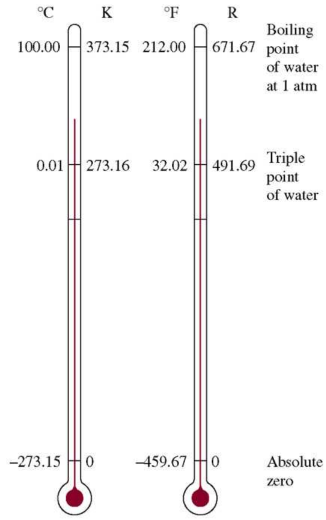
Fahrenheit Scale
Freezing (Ice) point is at 32 and the boiling (steam) point is at 212

Kelvin Scale

- It is the thermodynamic temperature scale (independent of properties) in the international system of units (SI)
- The lowest temperature is 0, and it is absolute
  ⇨ no substance can have a temperature less than 0 K

Rankine Scale

- It is the thermodynamic temperature scale in the English system
- The lowest temperature is also 0 and it is also absolute



Relationship between various SI and English units of temperature

$T(\text{K}) = T(^\circ\text{C}) + 273.15$	$\Delta T(\text{K}) = \Delta T(^\circ\text{C})$
$T(\text{R}) = T(^\circ\text{F}) + 459.67$	$\Delta T(\text{R}) = \Delta T(^\circ\text{F})$
$T(^\circ\text{F}) = 1.8\ T(^\circ\text{C}) + 32$	$\Delta T(^\circ\text{F}) = 1.8\ \Delta T(^\circ\text{C})$
$T(\text{R}) = 1.8\ T(\text{K})$	$\Delta T(\text{R}) = 1.8\ \Delta T\ (\text{K})$

Pressure (Section 2.8)

Pressure

- The force exerted by a fluid per unit area
- Pressure is related only to fluids (gases and liquids)
- The official SI unit of pressure is Pascal (Pa): 1 Pa = 1 N/m^2

Other Units of Pressure

1 bar = 10^5 Pa = 0.1 MPa = 100 kPa
1 atm = 101325 Pa = 101.325 kPa = 1.01325 bar

Absolute Pressure

- The actual pressure at a given position
- It is measured relative to the absolute vacuum

Gage Pressure

The difference between the absolute pressure and the local atmospheric pressure

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

Vacuum Pressure

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

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