# Thermodynamics- Basic Concepts

MEE 1003 Thermodynamics

Fall 2019-20

Dr. Y. Mukkamala

# Outline

- Basic concepts – definitions
- SI units – review
- Properties of a system
- State, system (closed and open), equilibrium, process and cycle
- Energy, forms of energy
- Work and heat transfer
- Temperature, pressure (absolute and gage), temperature scales, zeroth law of Thermodynamics

# References

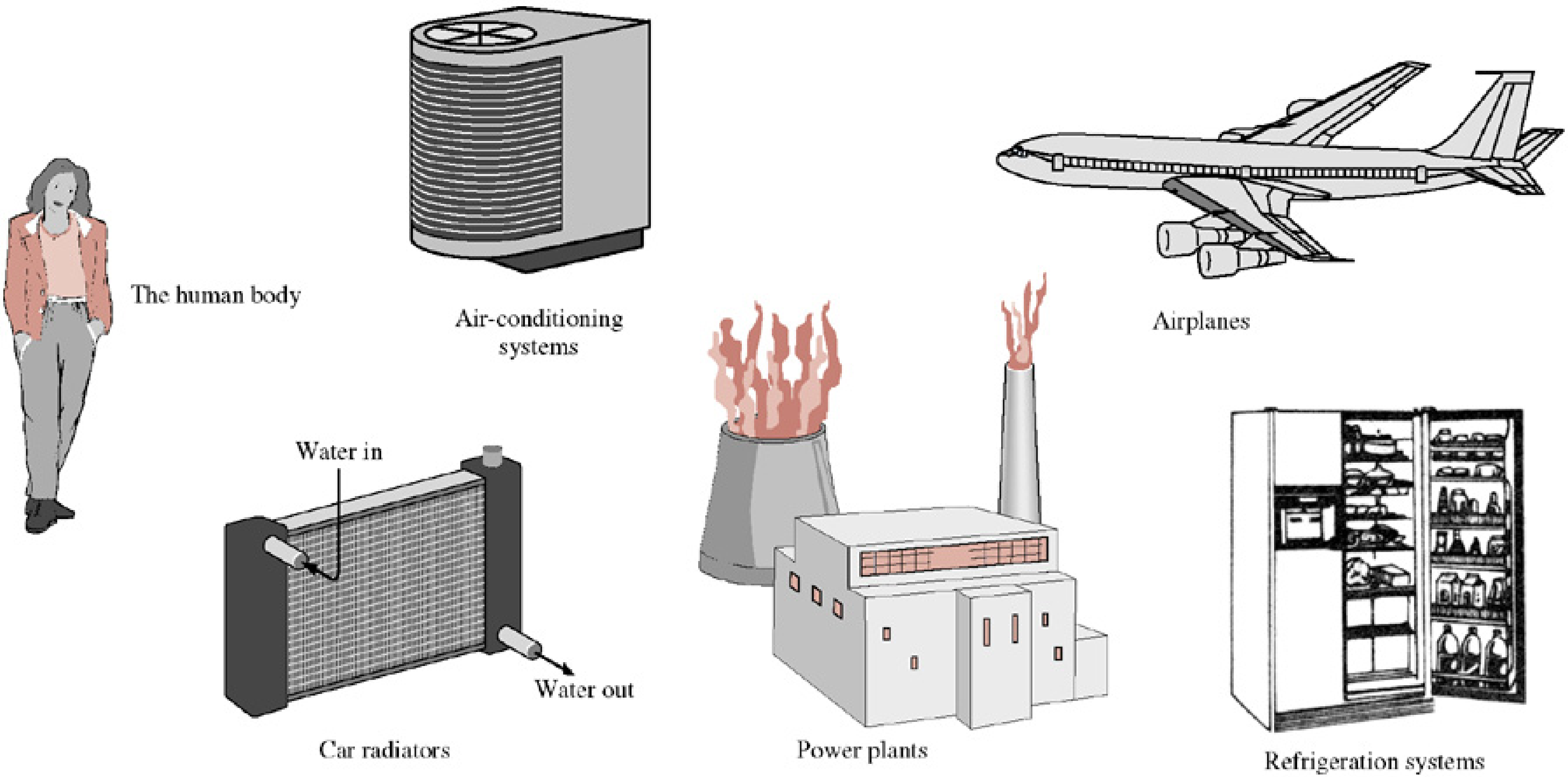

- Yunus Cengel, Michael A. Boles, “Thermodynamics and engineering approach”.
- Profesor H.K. Ma, National Taiwan University.

# Introduction to Thermodynamics

- https://www.youtube.com/watch?v=F_NmS-Wy2lE&t=12s

# Applications of Thermodynamics





# Basic Concepts - Definitions

- *Therme (heat in Greek) + dynamics (power) = Thermodynamics*
- *Thermodynamics:*
  - *Science of energy*
  - *Energy transformation*
  - *Power generation*
  - *Refrigeration*
  - *Properties and states of matter.*
- *Principle of conservation of energy:*

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

*-Energy is a thermodynamic property.*

# SI Units

- ***Dimension**: Any physical quantity*
- ***Units**: The arbitrary magnitudes assigned to the dimensions*
- ***Primary or fundamental dimension:***

  ***-mass m, length L, time t,***

  ***temperature T , etc***
- ***Second or derived dimension:***

  ***-velocity v, energy E, volume V, etc.***

- Mass: kg
- Length: m
- Temperature: C, K (absolute)
- Time: s

# Derived SI units

- Force F = ma; 1 N = 1 (kg) x 1 ($m/s^2$)
- Weight W = mg;
  - 1 kgf = 1 (kg) x 9.81 ($m/s^2$) = 9.81 N
- Work (form of energy) = F x s (distance);
- units – J (Joule); 1 J = 1 N x 1 m
- Energy E; units kJ

# Thermodynamic State

- Defined by its properties
- State postulate:
  - *State of a simple compressible system is completely defined by two independent and intensive properties.*
- A system is simply compressible if magnetic, electric, gravitational, motion, and surface tension forces are absent.

# System (Closed and open)

- System:

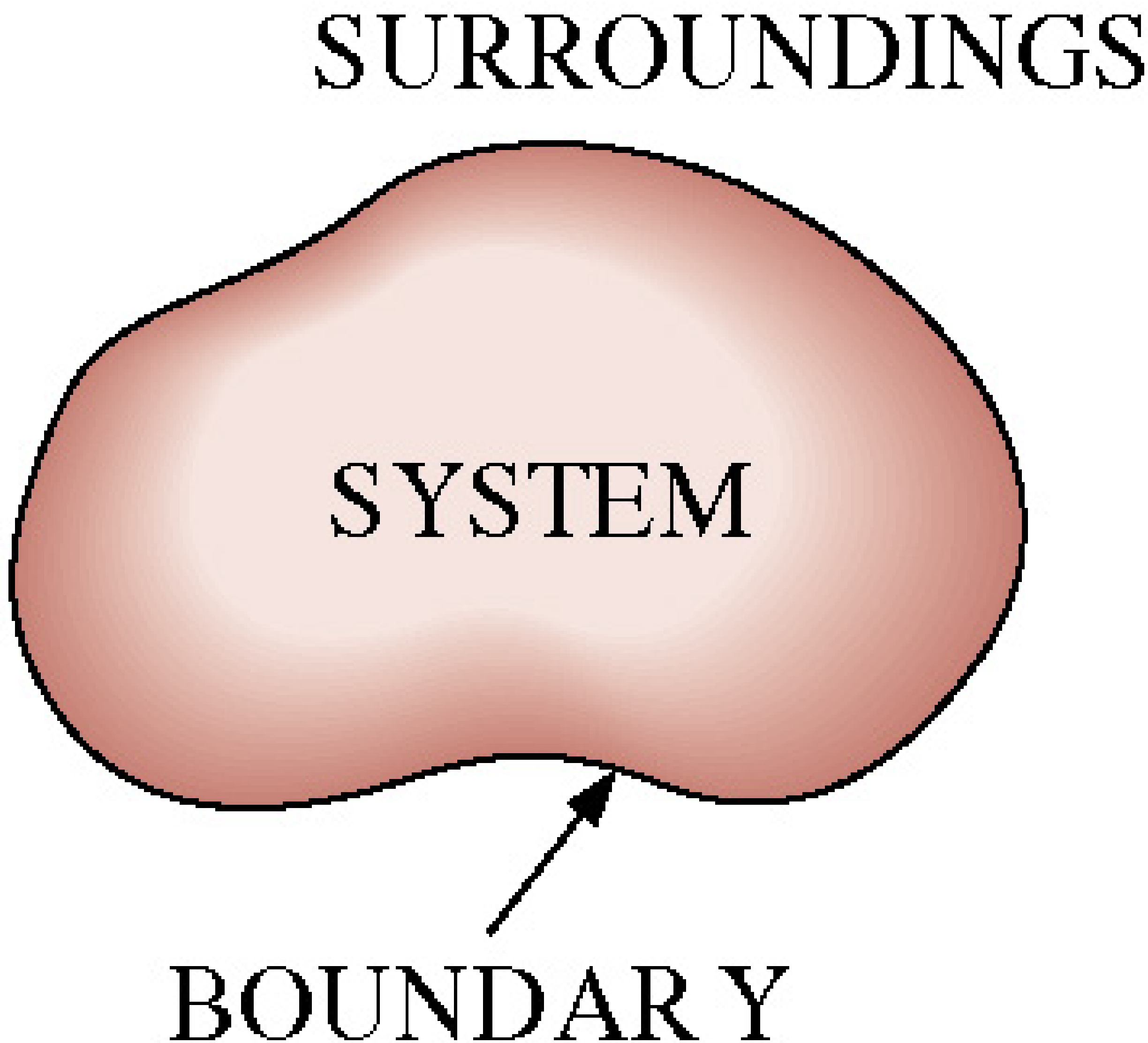
  A quantity of matter or a region in space chosen for study

- Surrounding:

  Everything external to the system

- Boundary:

  The real or imaginary surface that separates the system from its surroundings.


SURROUNDINGS
SYSTEM
BOUNDAR Y

# Closed and Open Systems

## Closed  system

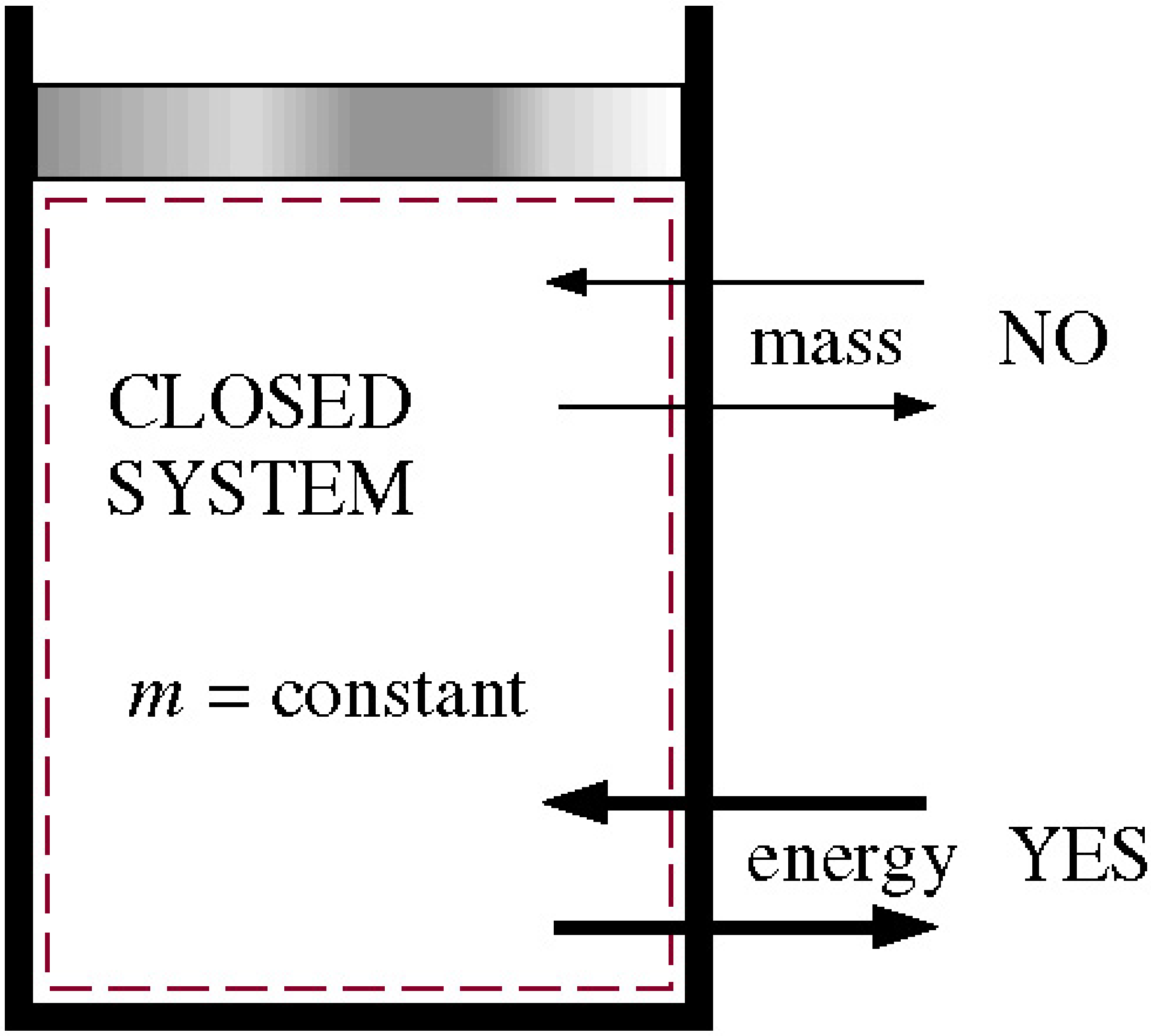
A specified amount of mass, no flow of matter

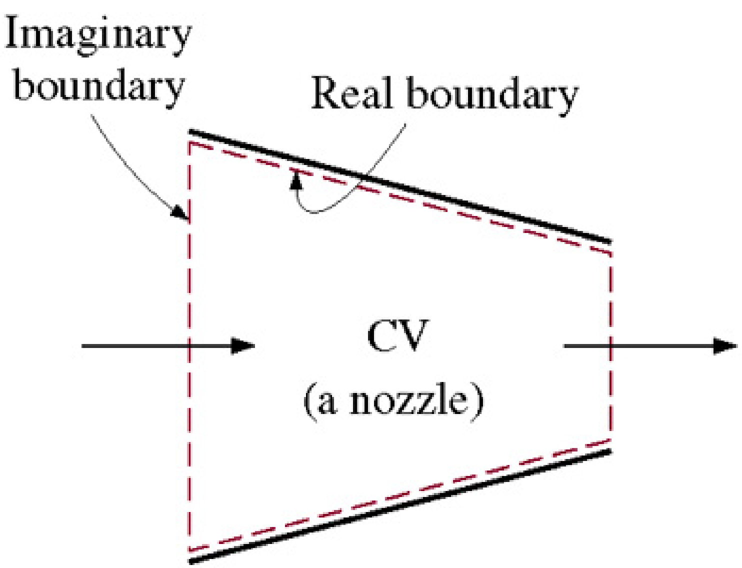
## Open system

A specified region in space, open to the flow of matter

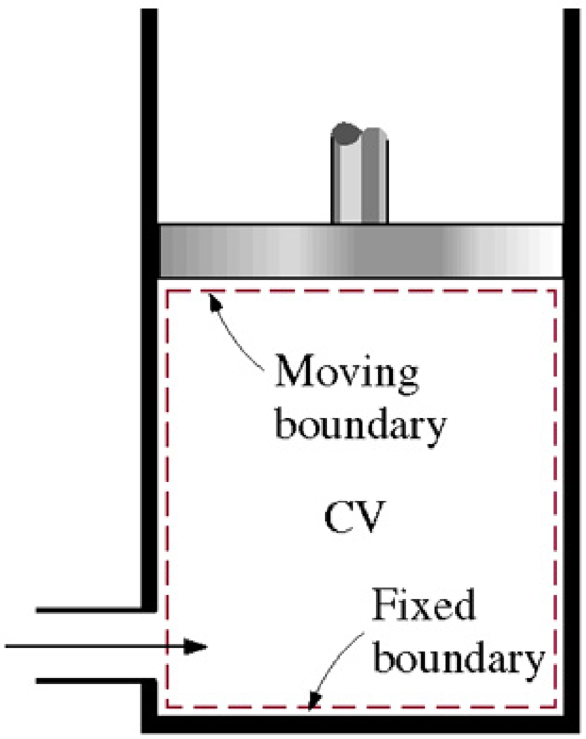
## Isolated system

One that is not influenced in anyway by surroundings)


mass NO
CLOSED SYSTEM
$m$ = constant
energy YES




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




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

# Properties of a system

- Any characteristic of a system
  - Ex: Pressure (p), Temperature (T), mass (m)
- Intensive
  - Independent of mass
  - Ex: Density ($kg/m^3$), Temperature, Pressure
- Extensive
  - Dependent on mass
  - Ex: Weight (mg), total mass (density x volume)

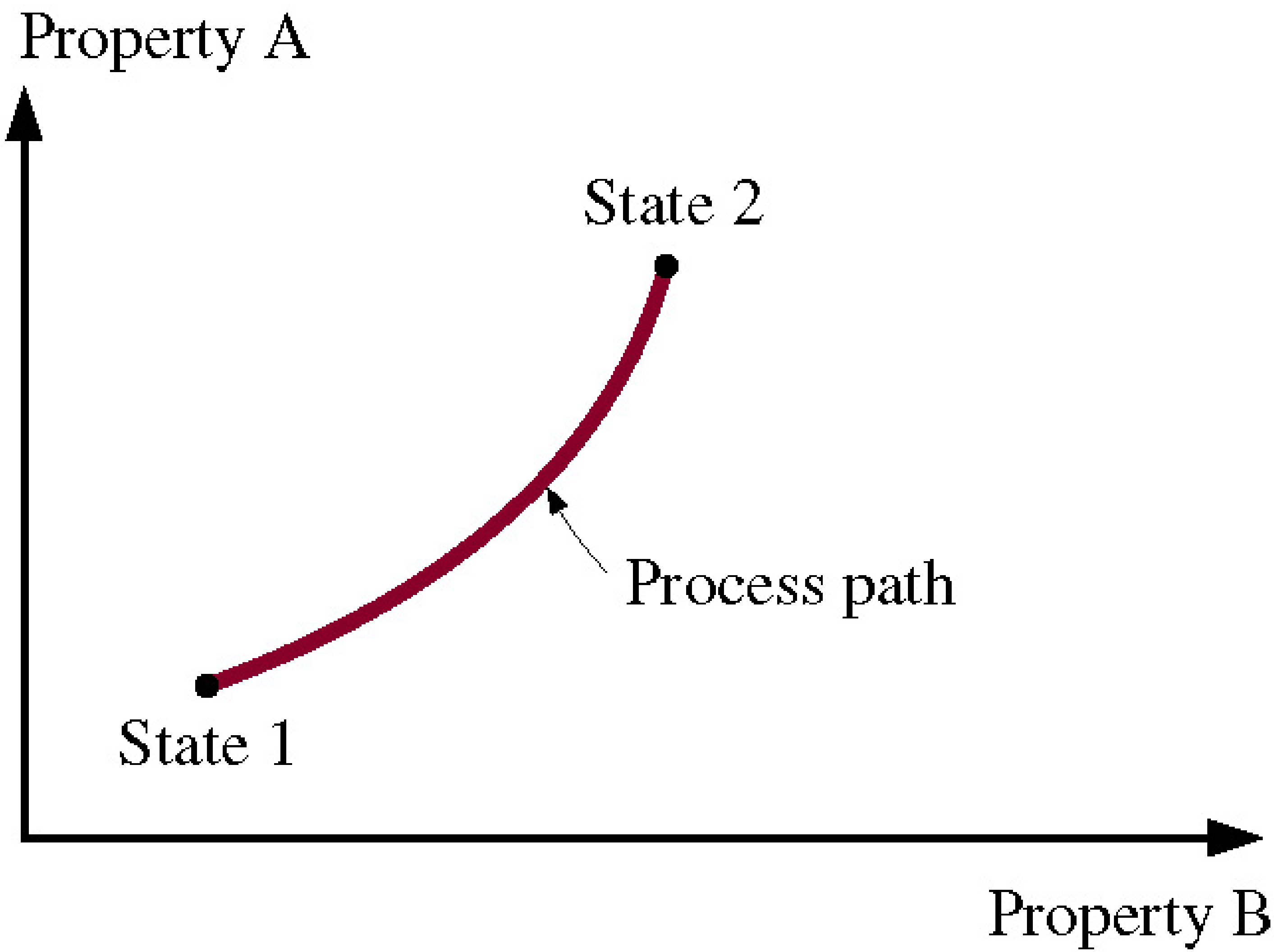
- Extensive properties per unit mass
  - Specific properties
  - Ex: Specific volume ($m^3/kg$)
- Continuum:
  - Continuous, homogeneous matter with disregard to atomic structure.
  - Ex: Air, water at room conditions

# Equilibrium

- A state of balance
  - No unbalanced potential (forces, temperature, voltage, etc.)
- A system in equilibrium is subjected to no change when isolated from surroundings.
- Thermal equilibrium
  - Temperature is the same throughout the system

# Processes

- Process
  - Any change in system from one equilibrium state to another
- Path
  - Series of states through which the system passes during a process
- Quasi-equilibrium (or quasi-static)
  - System changes infinitesimally slowly and always remains in equilibrium
  - Slow process allows internal variables to adjust to maintain constant equilibrium


Property A
State 2
Process path
State 1
Property B

# Types of Processes

- Steady flow process
  - Process which occurs with no change in time
- Uniform process
  - Process that doesn’t change with location.
- Isothermal process
  - Process that occurs at constant temperature
- Isobaric process
  - Process that happens at constant pressure
- Isochoric process
  - Process occurring at constant  volume

# Forms of Energy

- Thermal
- Mechanical
- Electrical
- Magnetic
- Chemical
- Nuclear
- The sum of them is *Total Energy*

- Total energy
  - Microscopic; Macroscopic
- Macroscopic
  - Ex: Potential and Kinetic energies (w.r.t an external reference frame)
- Microscopic
  - Ex: Internal energy (due to molecular activity independent of external reference frames)

- Energy equations:

Specific energy: $e = \dfrac{E}{m}$ (kJ/kg); E: total energy

$KE = m\dfrac{V^2}{2}$ (kJ); PE = mgz (kJ)

Total energy (excluding magnetic, electrical, surface tension, nuclear):

$$E = U + m\frac{V^2}{2} + mgz \text{ (kJ)}; \text{ Intensive (per unit mass) } e = u + \frac{V^2}{2} + gz \text{ (kJ/kg)}$$

Mass flow rate $\dot{m} = \rho VA$ (kg/s); Energy flow rate $\dot{E} = \dot{m}\,e\ (\dfrac{kg}{s} \text{ x } \dfrac{kJ}{kg} = kW)$

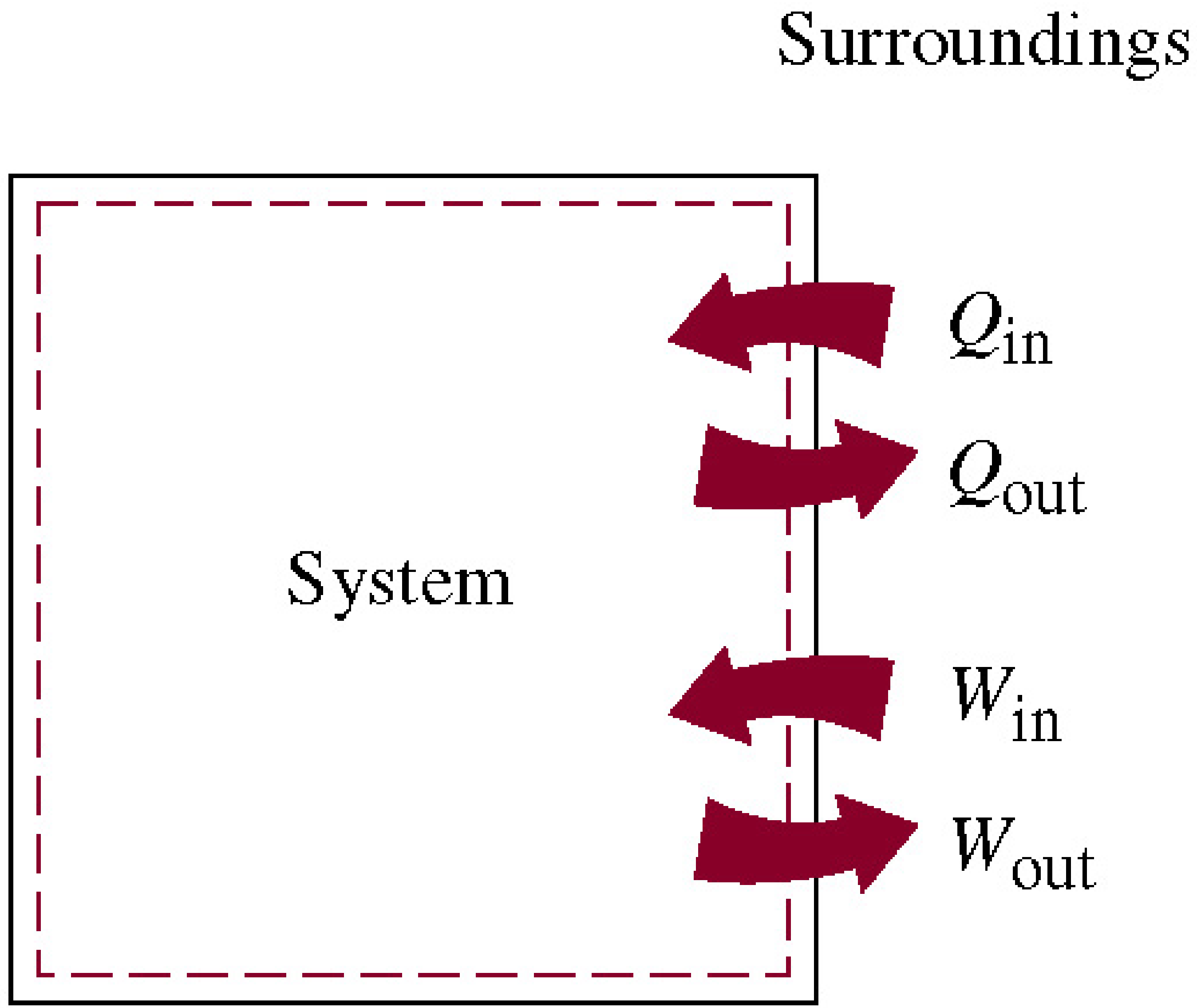
Mechanical energy = flow work + kinetic energy + potential energy

$$e_{mech} = pv + \frac{V^2}{2} + gz; \text{ v (specific volume)} = \frac{1}{\rho}$$

If $\rho$ = const (incompresible flow); $\Delta e = (p_2 - p_1)v + \dfrac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$ (kJ/kg)

# Work and Heat Transfer

- Energy transfer at a boundary:
  - Heat
  - Work
- Heat
  - Energy transfer between two systems by virtue of temperature difference.
  - Thermodynamics deals with quantity of energy transfer.
  - Heat flow or transfer is the rate of that energy transfer.


Surroundings
$Q_{in}$
$Q_{out}$
System
$W_{in}$
$W_{out}$

# Modes of heat transfer

- Conduction
  - Heat transfer in a solid, liquid or gas due to inter-molecular vibrations (lattice vibrations in solids)
- Convection
  - Heat transfer in liquids and gases due to the bulk motion of the fluid.
- Radiation
  - Heat transfer with or without medium due to photon and electromagnetic wave emissions.
- Adiabatic
  - No heat transfer between system and surroundings

- Modes of heat transfer

Conduction: $\dot{Q} = -kA_c \frac{dT}{dx}$ (Fourier's law); k - coefficient of thermal conductivity

Convection: $\dot{Q} = hA_{surface} \Delta T$ (Newton's law of cooling); h - convective heat transfer coefficien

Radiation: $\dot{Q} = \sigma\varepsilon A_{surface}(T_1^4 - T_2^4)$; $\sigma$ - Stefan Boltzmann constant; $\varepsilon$ - Emissivity

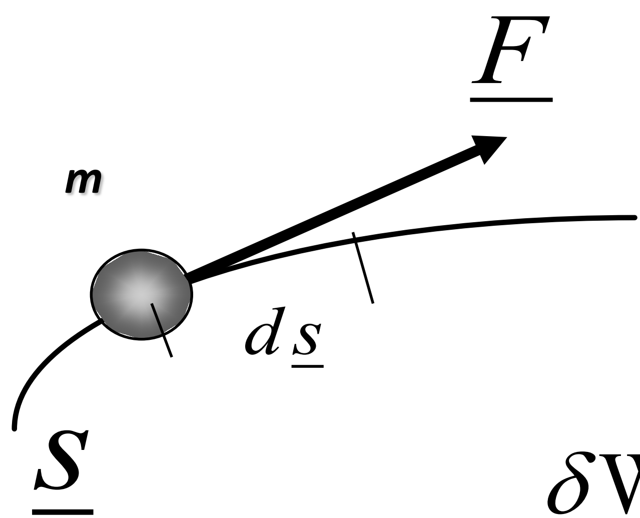
# Work

- Energy transfer when force acts through a certain distance.
  - Work done by a system is +ve
  - Work done on a system is negative
  - Like heat, work is path dependent
  - Both heat and work transfer are represented by inexact differentials
  - δQ, δW

$$\int_1^2 \delta W = \mathrm{W}_{12}$$

- Work Equation

$$\delta W = \underline{F} \cdot d\,\underline{s}$$




$$\delta \mathrm{W} \neq \mathrm{W}_1 - \mathrm{W}_2$$

# • Types of work

Mechanical work (Shaft, spring, acceleration)

Shaft work: $T = Fr$; $s = (2\pi r)\,N$ for N rpm

If $T = \text{const}$, $W_{shaft} = F \times s = \left(\frac{T}{r}\right) \times (2\pi rN) = (2\pi rNT)$

Spring Work: $F = kx$ (k is the spring constant in N/m).

$$\delta W_{spring} = Fdx$$

$$\int_1^2 \delta W_{spring} = \int_1^2 Fdx = \int_1^2 kx\,dx = \left.\frac{kx^2}{2}\right|_1^2 = \frac{1}{2}k(x_2^2 - x_1^2)$$

Acceleration work

$$F = ma = m\frac{dV}{dt}.\ W = \int_1^2 Fds = \int_1^2 m\frac{dV}{dt}Vdt \quad \left(\frac{ds}{dt} = V\right)$$

$$\Rightarrow W = \int_1^2 mV\,dV \ = \frac{1}{2}m(V_2^2 - V_1^2)$$

- Energy-Work correlation

Energy change of a system = Heat flow + work transfer + mass flow

$$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,in} - E_{mass,out})$$

Adiabatic system: $\Delta Q = 0$; Closed system: $\Delta E_{mass} = 0$; Static systems: $\Delta W = 0$

In rate form:

$$\Delta \dot{E} = \Delta \dot{Q} + \Delta \dot{W} + \Delta \dot{E}_{mass}$$

$$Q = \dot{Q}\,\Delta t;\ W = \dot{W}\,\Delta t;\ E = \dot{E}\,\Delta t$$

- Energy conversion efficiencies

$$\text{Energy efficiency} = \frac{\text{Actual output}}{\text{Required output}}$$

$$\eta_{\text{combustion}} = \frac{\text{Actual heat release during combustion}}{\text{Heating value (Calorific value)}}$$

$$\text{Electrical generator (power} \rightarrow \text{electricity)}$$

$$\eta_{\text{overall}} = \eta_{\text{comb}} \times \eta_{\text{thermal}} \times \eta_{\text{generator}} = \frac{\dot{W}_{\text{net}}}{\text{HHV} \times \dot{m}_{\text{net}}}$$

$$\eta_{\text{mech}} = \frac{E_{\text{mech,out}}}{E_{\text{mech, in}}}; \;\; \eta_{\text{turbine}} = \frac{\text{Power out}}{\text{Ideal power (isentropic)}};$$

$$\eta_{\text{compresor/pump}} = \frac{\text{Ideal power input (isentropic)}}{\text{Actual power input}}$$

# Temperature and Zeroth Law of Thermodynamics

- Temperature
  - The degree of hotness or coldness
  - Measured indirectly my detecting changes in physical properties (ex: volume variation of Hg in a glass thermometer)
  - "Feel" can be misleading.
    - A metal chair feels colder than a wooden chair at same temperature because of higher radiation loss.

- Zeroth law of Thermodynamics
  - *Two bodies in thermal equilibrium with a third body are also in equilibrium with each other.*
  - Thermal equilibrium occurs when heat transfer from hot to cold object stops.
  - At that state, all bodies have same temperature.

- Thermodynamic Temperature Scale:
  - C; F; K; R; Ideal gas temperature scale, K

- Constant-volume gas thermometer

  *At low pressure, the temperature of a gas is proportional to its pressure at constant volume*