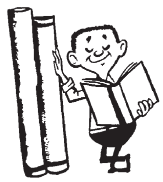
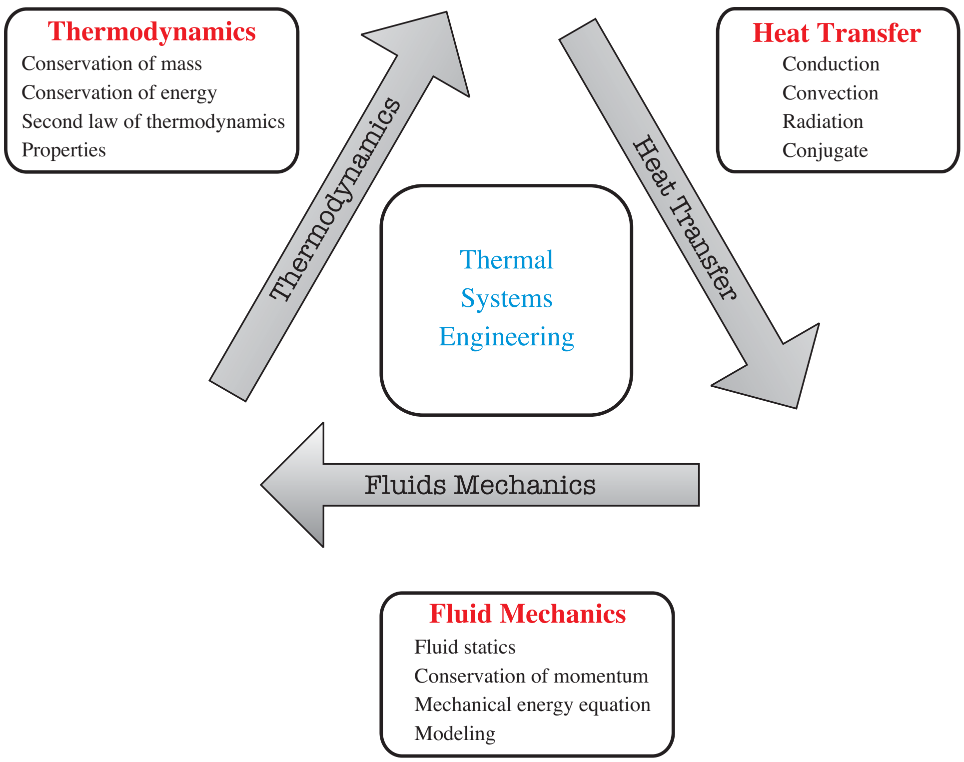
Basic Concepts of Thermodynamics



Reading	**Problems**
2-1 $\longrightarrow$ 2-10	2-44, 2-59, 2-78, 2-98

Thermal Sciences



Thermodynamics: the study of energy, energy transformations and its relation to matter. The analysis of thermal systems is achieved through the application of the governing conservation equations, namely *Conservation of Mass*, *Conservation of Energy* (1st law of thermodynamics), the 2nd law of thermodynamics and the property relations.

Heat Transfer: the study of energy in transit including the relationship between energy, matter, space and time. The three principal modes of heat transfer examined are conduction, convection and radiation, where all three modes are affected by the thermophysical properties, geometrical constraints and the temperatures associated with the heat sources and sinks used to drive heat transfer.

Fluid Mechanics: the study of fluids at rest or in motion. While this course will not deal extensively with fluid mechanics we will be influenced by the governing equations for fluid flow, namely *Conservation of Momentum* and *Conservation of Mass*.

Thermodynamics

Microscopic: tracking the movement of matter and energy on a particle by particle basis

Macroscopic: use the conservation equations (energy and mass) to track movement of matter and energy on an average over a fixed domain (referred to as classical thermodynamics)

Energy

- the total energy of the system per unit mass is denoted as e and is given as

$$e = \frac{E}{m} \quad \left(\frac{kJ}{kg}\right)$$

- if we neglect the contributions of magnetic, electric, nuclear energy, we can write the total energy as

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

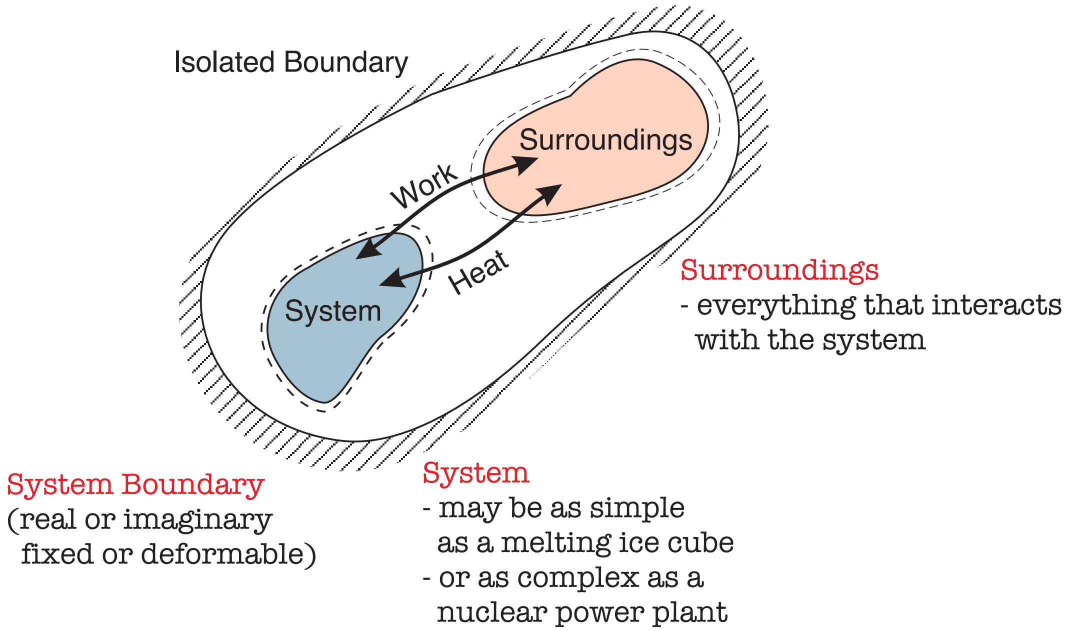
Dimensions and Units

SI: International System

- SI is the preferred because it is logical (base 10) and needs no correction factors
- unit convention:

Parameter	Units	Symbol
length, L	meters	m
mass, m	kilograms	kg
time, t	seconds	s
temperature, T	kelvin	K
velocity, $\mathcal{V}$	meter per second, $\equiv L/t$	m/s
acceleration, a	meter per second squared $\equiv L/t^2$	m/s^2
force, F	newton, $\equiv m \cdot L/t^2$	N
energy, E	joule $\equiv m \cdot L^2/t^2$	J

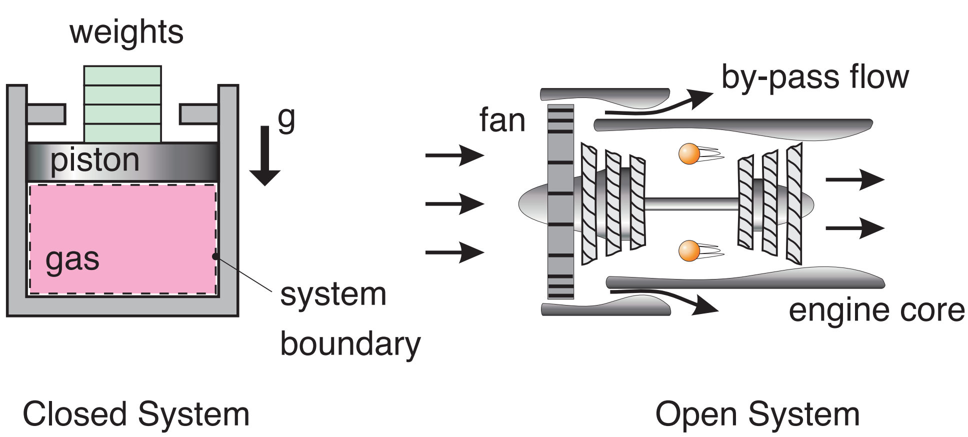
Thermodynamic Systems



SYSTEM:

Closed System: composed of a control (or fixed) mass where heat and work can cross the boundary but no mass crosses the boundary.

Open System: composed of a control volume (or region in space) where heat, work, and mass can cross the boundary or the control surface



WORK & HEAT TRANSFER:

- work and heat transfer are <u>NOT</u> properties $\longrightarrow$ they are the forms that energy takes to cross the system boundary

Thermodynamic Properties of Systems

Basic Definitions

Thermodynamic Property: Any observable or measurable characteristic of a system. Any mathematical combination of the measurable characteristics of a system

Intensive Properties: Properties which are independent of the size (or mass) of the system

- they are **not** additive $\Rightarrow X_{A+B} \neq X_A + X_B$
- examples include: pressure, temperature, and density

Extensive Properties: Properties which are dependent of the size (or mass) of the system

- they are additive $\Rightarrow X_{A+B} = X_A + X_B$
- examples include: volume, energy, entropy and surface area

Specific Properties: Extensive properties expressed per unit mass to make them intensive properties

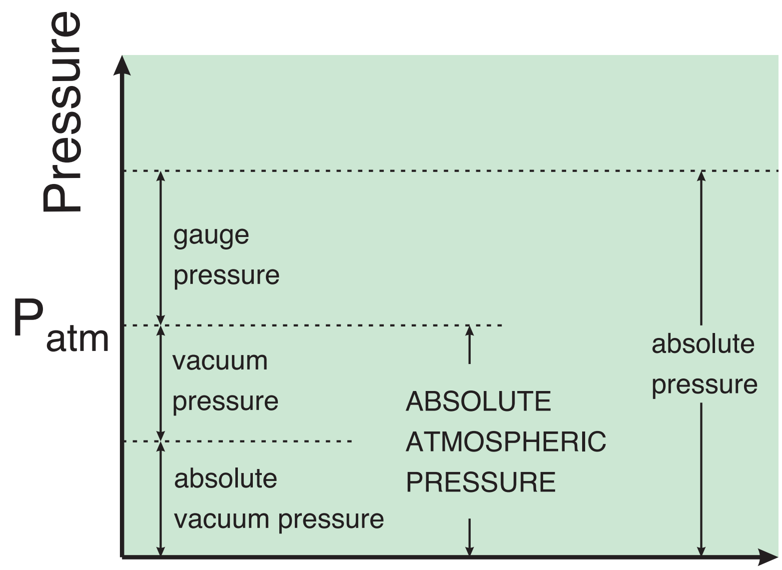
- specific property (intensive) $\longrightarrow \dfrac{\text{extensive property}}{\text{mass}}$

Measurable Properties

- P, V, T, and m are important because they are measurable quantities. Many other thermodynamic quantities can only be calculated and used in calculations when they are related to P, V, T, and m
  - Pressure (P) and Temperature (T) are easily measured intensive properties.
    Note: They are not always independent of one another.
  - Volume (V) and mass (m) are easily measured extensive properties

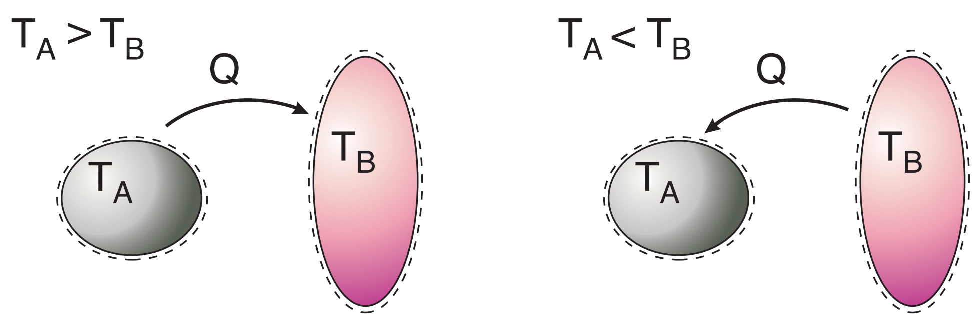
Pressure

- $Pressure = \dfrac{Force}{Area}$; $\quad \rightarrow \quad \dfrac{N}{m^2} \equiv Pa$
  - in fluids, this is pressure (normal component of force per unit area)
  - in solids, this is stress



<u>Temperature</u>

- temperature is a pointer for the direction of energy transfer as heat

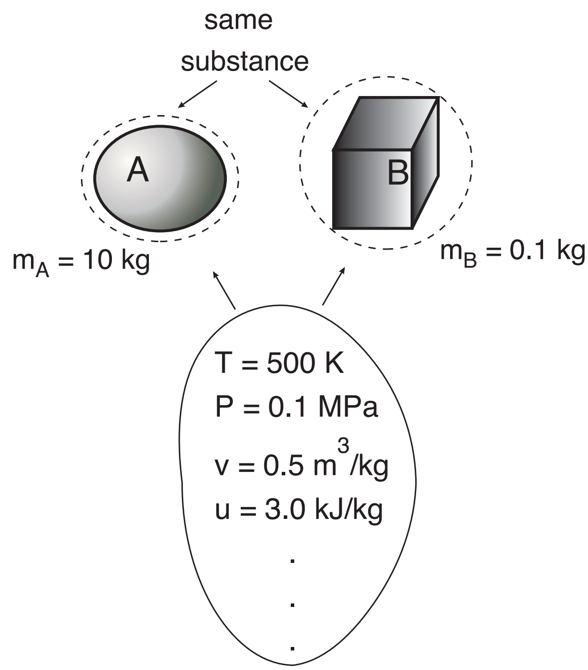


0^{th} ***Law of Thermodynamics:*** if system C is in thermal equilibrium with system A, and also with system B, then $\boldsymbol{T_A = T_B = T_C}$

State and Equilibrium

State Postulate

- how long does the list of intensive properties have to be in order to describe the intensive state of the system?



- System A and B have the same intensive state, but totally different extensive states.

State Postulate (for a simple compressible system): The state of a simple compressible system is completely specified by 2 independent and intensive properties.

- note: a simple compressible system experiences negligible electrical, magnetic, gravitational, motion, and surface tension effects, and only PdV work is done
- in a single phase system, T, v, and P are independent and intensive (in a multiphase system however, T and P are not independent)
- if the system is not simple, for each additional effect, one extra property has to be known to fix the state. (i.e. if gravitational effects are important, the elevation must be specified and two independent and intensive properties)
- it is important to be able to:
  - find two appropriate properties to fix the state
  - find other properties when the state is fixed (we will discuss this later)

Thermodynamic Processes

- the *process* is any change from one equilibrium state to another. (If the end state = initial state, then the process is a cycle)

- the *process path* is a series intermediate states through which a system passes during the process (we very seldom care what the process path is)
- *processes* are categorized based on how the properties behave:
  - isobaric ($P = constant$)
  - isothermal ($T = constant$)
  - isochoric or isometric ($V = constant$)
  - isentropic ($s = constant$)
  - isenthalpic ($h = constant$)
  - adiabatic (no heat transfer)

Stored Energy

- how is energy stored in matter?

$$Stored\ Energy = E = KE + PE + U$$

- Kinetic Energy: Energy due to motion of the matter with respect to an external reference frame ($KE = m\mathcal{V}^2/2$)
- Potential Energy: Energy due to the position of the matter in a force field (gravitational, magnetic, electric). It also includes energy stored due to elastic forces and surface tension ($PE = mgz$)
- Internal Energy = microscopic forms of energy, U)
  - forms of the energy in the matter due to its internal structure (independent of external reference frames)

Transit Energy

Heat

- transit form of energy that occurs when there is ΔT (a temperature gradient)
- notation - $Q\ (kJ),\ q\ (kJ/kg),\ \dot{Q}\ (kW),\ \dot{q}\ (kW/kg)$

Work

- transit form of energy that occur due to all other driving forces
- notation - $W\ (kJ),\ w\ (kJ/kg), \dot{W}\ (kW), \dot{w}\ (kW/kg)$