University of Anbar

Engineering Thermodynamics
CHE 215

Lecture # 02

Objectives of Lecture Note

- **Explain the closed and open system, surrounding and boundary .**
- **Explain the basic concepts of thermodynamics such as system, state, state postulate, equilibrium, process, and cycle.**
- **Review concepts of temperature, temperature scales, pressure, and absolute and gage pressure.**

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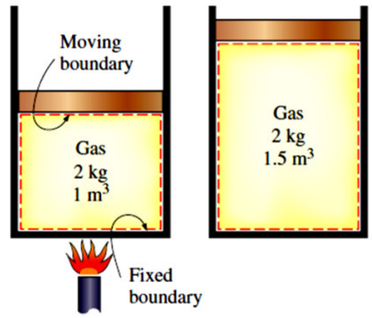
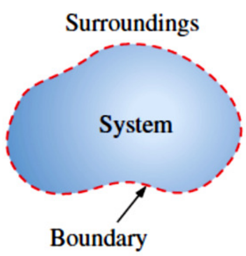
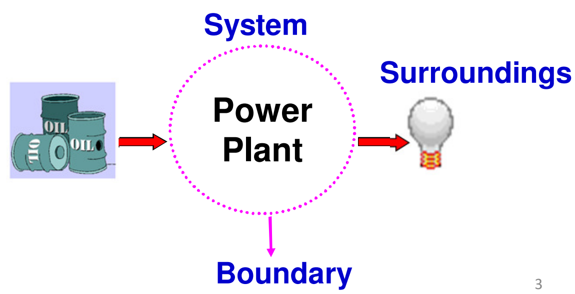
Systems and Control Volumes

- **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***.
- Mathematically, the boundary has zero thickness.

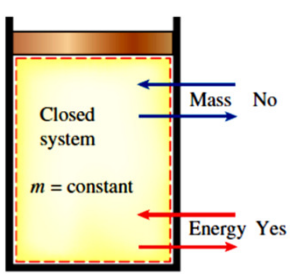


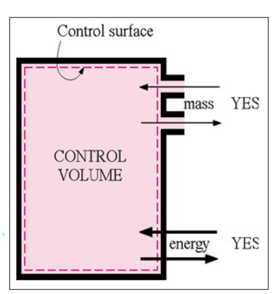


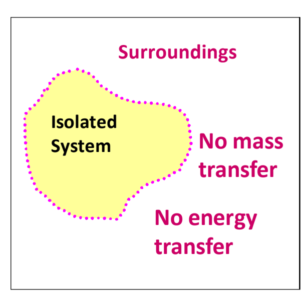


Types of Systems

- Closed system (control mass)
- Open system (control volume)
- Isolated system



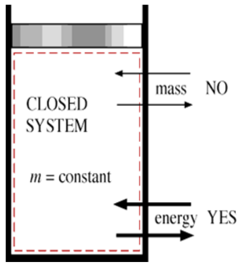




Closed system (control mass)

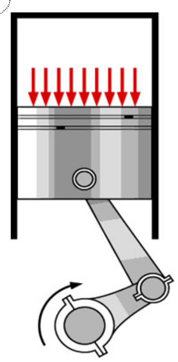
☺ Mass in closed system is always fixed

☺ System boundary may be fixed or moving



Examples

Piston-cylinder unit



Closed Cooking pot

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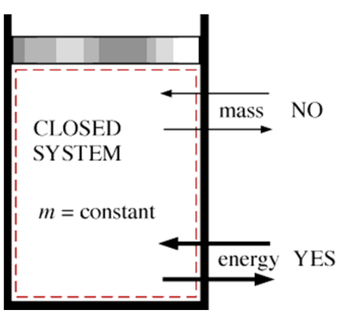
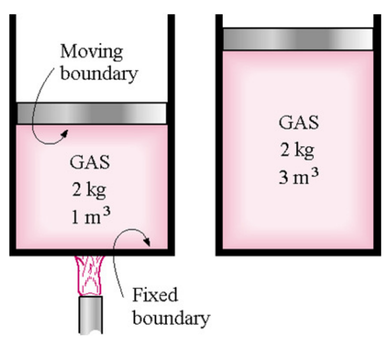
Closed System/Control Mass

- A system of fixed mass is called a ***closed** system*, or ***control mass***
- The *closed system boundary* does not have to be fixed
- No mass can cross the *closed system* boundary
- Energy in the form of ***heat*** and ***work*** can cross the ***closed system boundary***
- If even energy is not allowed to cross we have an isolated system



Energy, not mass, crosses closed-system boundaries



Closed system with moving boundary

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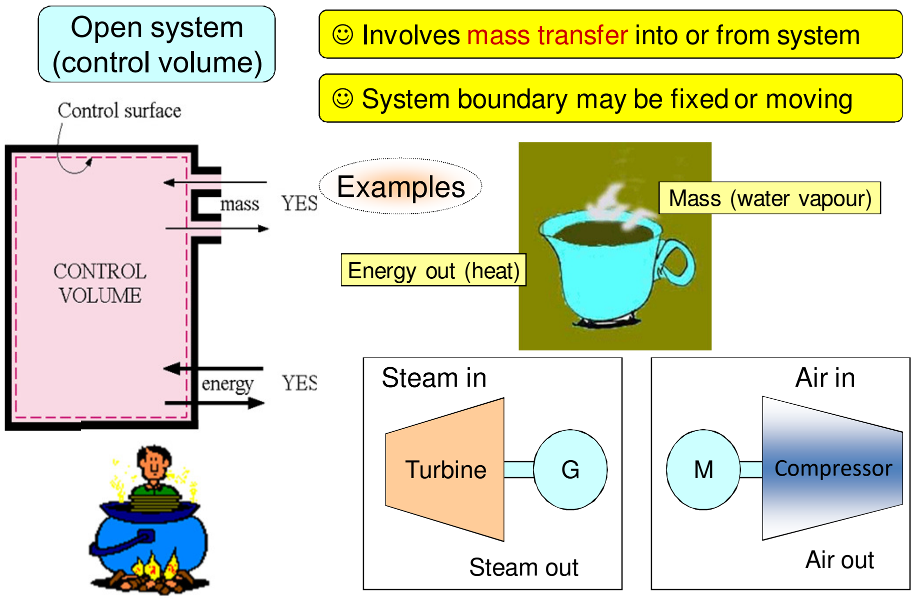

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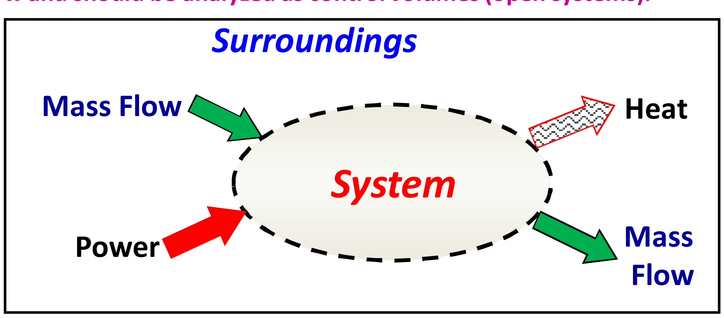
Open System / Control Volume

- A system that involves mass transfer across its boundaries is called an open system, or control volume
- The boundaries of a control volume is called control boundaries and is fixed in shape and position
- Energy in the form of heat and work as well as mass can cross the control boundaries
- A water heater, a car radiator, a turbine, and a compressor all involve mass flow and should be analyzed as control volumes (open systems).



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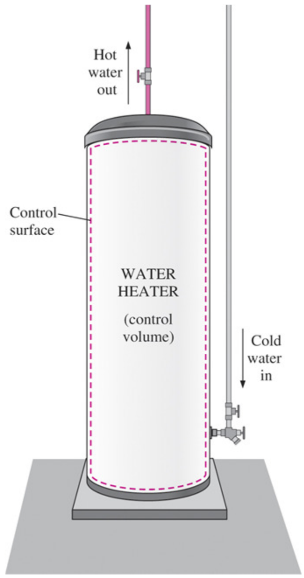
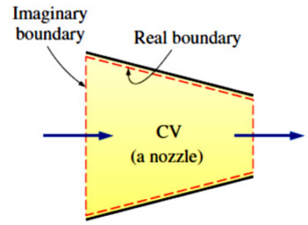
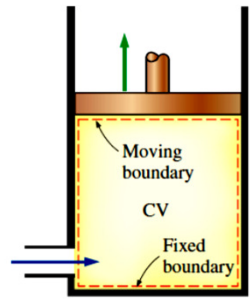


An open system (a control volume) with one inlet and one exit.



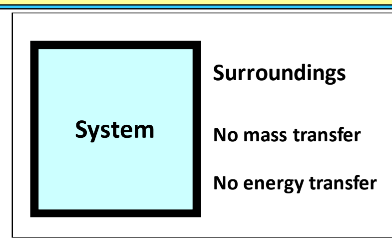
(*a*) A control volume (CV) with real and imaginary boundaries



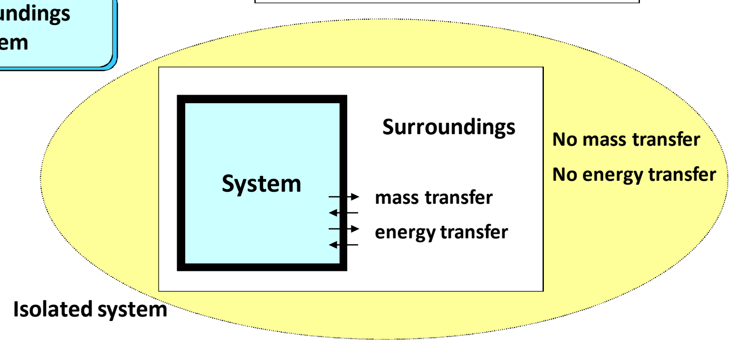
(*b*) A control volume (CV) with fixed and moving boundaries as well as real and imaginary boundaries

Isolated system

☺ **No mass & energy transfer into/from system**

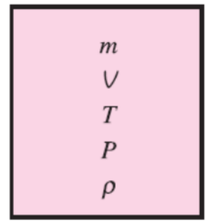


System + surroundings => isolated system



Properties of a System

- **Property:** **Any characteristic of a system.**



Some familiar properties are:

- **pressure P,**
- **temperature T,**
- **volume V, and**
- **mass m.**

The list can be extended to include less familiar ones such as:

- **viscosity,**
- **thermal conductivity,**
- **modulus of elasticity,**
- **thermal expansion coefficient,**
- **electric resistivity, and**
- **even velocity and elevation.**

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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—or extent—of the system, such as total mass, total volume V, and total momentum.**
- **Specific properties:** **Extensive properties per unit mass, such as specific total energy** $(e = E/m, v = V/m)$

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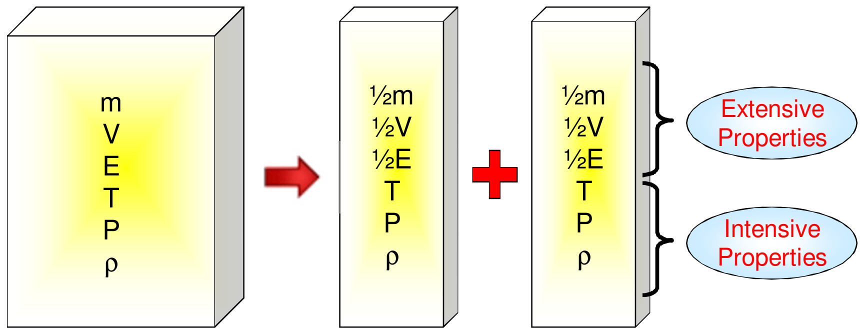
Intensive or Extensive Properties



An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with a partition, each part will have the same value of intensive properties as the original system, but half the value of extensive properties.

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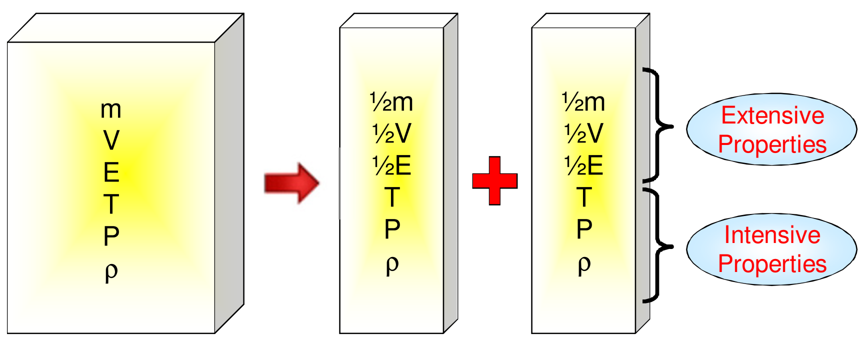
Intensive or Extensive Properties



General rule

Extensive properties => uppercase letters (except *m*)

Intensive properties => lowercase letters (except *T* & *P*)

Specific property

Extensive properties that are made intensive by dividing with mass

Example

Specific volume

$v=V/m$

Density

Density is defined as *mass per unit volume*

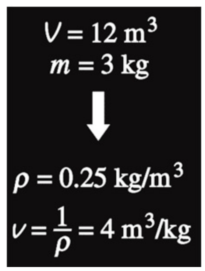
$$\rho = \frac{m}{V} \qquad (\text{kg/m}^3)$$

m **= mass, and** ***V*****= volume.**

- **Different fluids can vary greatly in density**
- **Liquids densities do not vary much with pressure and temperature**
- **Density of water at $4\,°C$: $1000\ kg/m^3$**
- **Density of Air at $4\,°C$: $1.20\ kg/m^3$**

Specific volume is defined as *volume per unit mass*

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



Density is mass per unit volume; specific volume is volume per unit mass.

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Density

- **The density of a substance, in general, depends on temperature and pressure.**
- **The density of most gases is proportional to pressure and inversely proportional to temperature.**
- **Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible.**
- **For example at $20°C$ the density of water changes from 998 kg/m^3 at 1 atm to $1003\ kg/m^3$ at 100 atm, a change of just 0.5 percent.**
- **For example, at 1 atm, the density of water changes from $998\ kg/m^3$ at $20\ °C$ to $975\ kg/m^3$ at $75\ °C$, a change of 2.3 percent, which can still be neglected in many engineering analyses.**
- **Hence, the density of liquids and solids depends more strongly on temperature than it does on pressure.**

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Specific Gravity (Relative Density)

- Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called ***specific gravity***, or ***relative density***.

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

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

TABLE 2–1

Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

- Density of water at 4 °C : $1000\frac{kg}{m^3}$
- **Gases have low specific gravities**
- **A liquid such as Mercury has a high specific gravity, 13.2**
- **The ratio is unitless.**

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Specific Weight

Specific weight: **The weight of a unit volume of a substance and is expressed as;**

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

g = **local acceleration of gravity, 9.807 m/s^2**

- **Specific weight characterizes the weight of the fluid system**
- **Specific weight of water at 4 °C : 9.80 kN/m^3**
- **Specific weight of air at 4 °C : 11.9 N/m^3**

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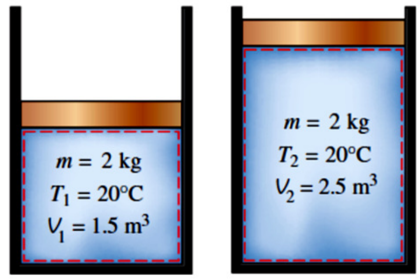
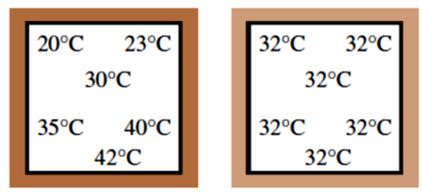
State and Equilibrium

- Thermodynamics deals with ***equilibrium*** states.
- **Equilibrium:** A state of balance.
- In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.
- **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*) State 1 (*b*) State 2

A system at two different states.



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

A closed system reaching thermal equilibrium.

The State Postulate

- **Simple compressible system:** If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.
- 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 (or fixed) by two independent, intensive properties.***

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

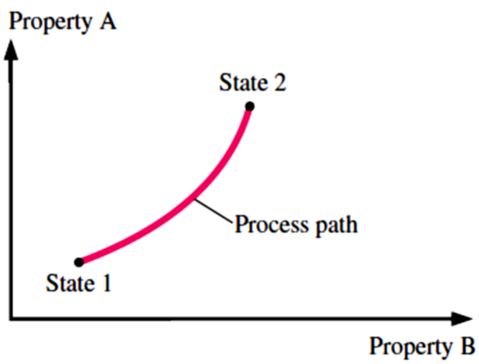
Processes and Cycles

Process: Any change that a system undergoes from one equilibrium state to another.

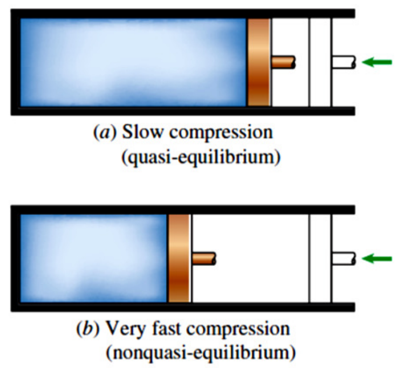
Path: The series of states through which a system passes during a process.

To describe a process completely, one should specify the **initial** and **final** states, as well as the **path** it follows, and the **interactions** with the **surroundings**.

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.

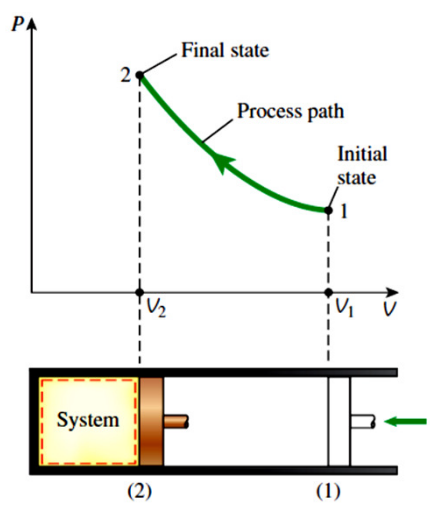


A process between states 1 and 2 and the process path



Quasi-equilibrium and nonquasi-equilibrium compression processes

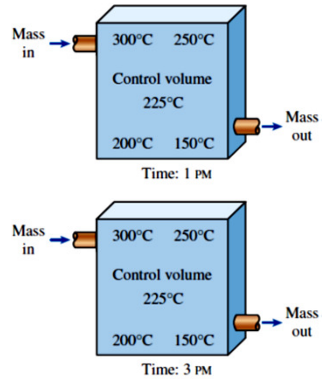
- Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.
- Some common properties that are used as coordinates are temperature T, pressure P, and volume V (or specific volume v).
- The prefix *iso-* is often used to designate a process for which a particular property remains constant.
- **Isothermal process:** A process during which the temperature remains constant $(T = constant)$.
- **Isobaric (or isopiestic) process:** A process during which the pressure remains constant $(P = constant)$.
- **Isochoric (or isometric) process:** A process during which the specific volume remains constant $(v = constant)$.
- **Cycle:** A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical.



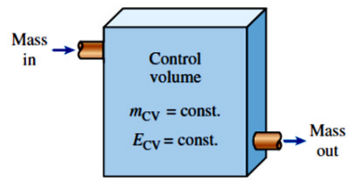
The *P-V* diagram of a compression process

The Steady-Flow Process

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



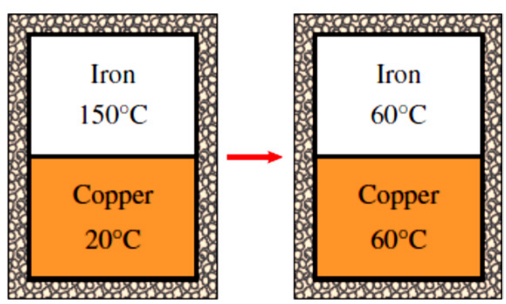
During a steady-flow process, fluid properties within the control volume may change with position but not with time.



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).
- Celsius scale: in SI unit system
- Fahrenheit scale: in English unit system
- Thermodynamic temperature scale: A temperature scale that is independent of the properties of any substance.

✓ Kelvin scale (SI)

✓ Rankine scale (E)

- A temperature scale nearly identical to the Kelvin scale is the ideal-gas temperature scale. The temperatures on this scale are measured using a constant-volume gas thermometer.

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

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

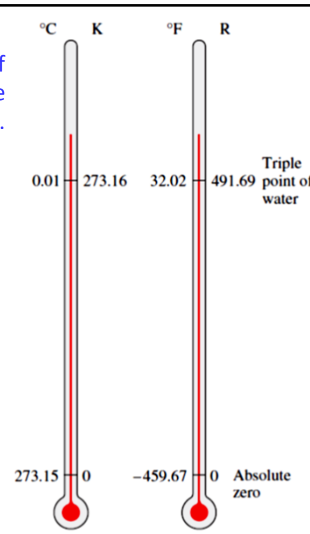
$$T(\text{R}) = 1.8T(\text{K})$$

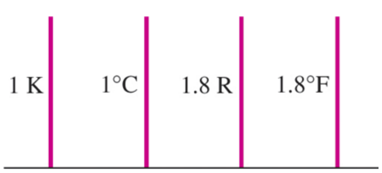
$$T(°\text{F}) = 1.8T(°\text{C}) + 32$$

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

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

Comparison of temperature scales.





Comparison of magnitudes of various temperature units.

- The reference temperature in the original Kelvin scale was the ***ice point***, 273.15 K, which is the temperature at which water freezes (or ice melts).
- The reference point was changed to a much more precisely reproducible point, the ***triple point*** of water (the state at which all three phases of water coexist in equilibrium), which is assigned the value 273.16 K.

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Problem-Solving Technique

- Step 1: Problem Statement
- Step 2: Schematic
- Step 3: Assumptions and Approximations
- Step 4: Physical Laws
- Step 5: Properties
- Step 6: Calculations
- Step 7: Reasoning, Verification, and Discussion

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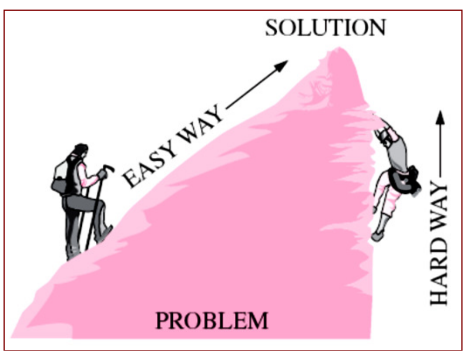

A step-by-step approach can greatly simplify problem solving.

Given: Air temperature in Denver

To be found: Density of air

Missing information: Atmospheric pressure

Assumption #1: Take $P = 1$ atm (Inappropriate. Ignores effect of altitude. Will cause more than 15% error.)

Assumption #2: Take $P = 0.83$ atm (Appropriate. Ignores only minor effects such as weather.)

The assumptions made while solving an engineering problem must be reasonable and justifiable.

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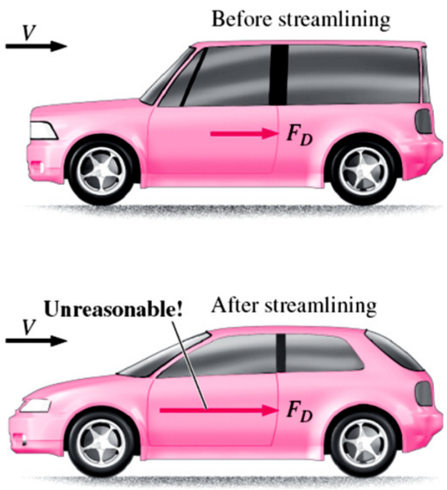

The results obtained from an engineering analysis must be checked for reasonableness.

Neatness and organization are highly valued by employers.

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