Thermodynamics

What is it?

Why do we study it?

Thermodynamics

Science dealing with how Matter behaves in relation to heat and work exchanged with the surroundings.

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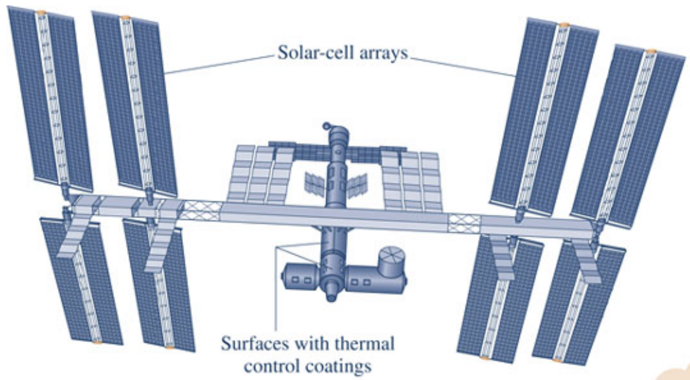
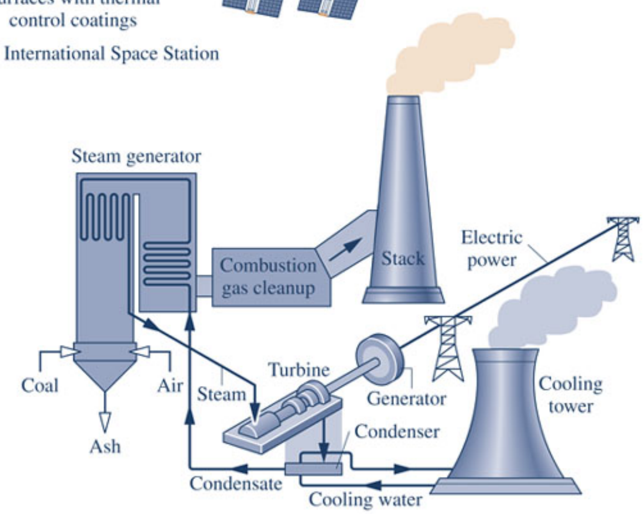
Phases of Matter - Solid (ES2001 Materials), Liquids (ES3001), Gases (ES3001), Plasma (Graduate School)

Applications of Thermodynamics: (See Table 1.1 of text - huge!)

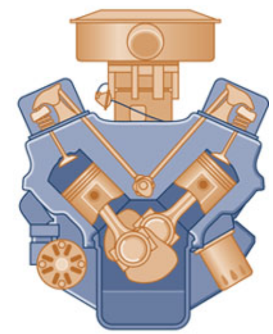


International Space Station

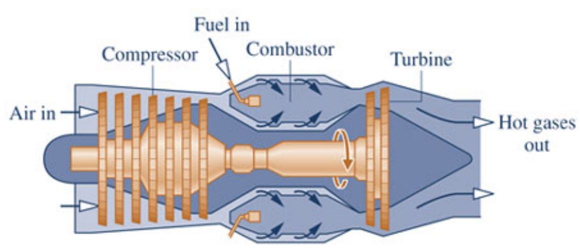
Refrigerator



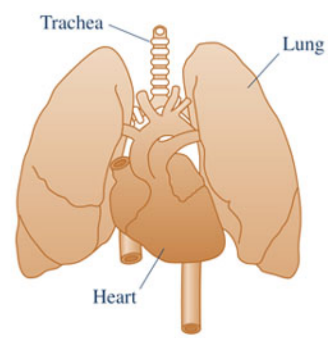
Electrical power plant



Vehicle engine



Turbojet engine



Biomedical applications

Thermodynamics

The Design and Analysis of many engineering systems requires thermodynamics (in addition to fluid mechanics, heat transfer, structural analysis, etc.).

Another short description of Thermodynamics is:

Link Location:

http://www.sciencelearn.org.nz/Science-Stories/Science-Made-Simple/Sci-Media/Video/Thermodynamics

Course Objectives:

Thermodynamics is both a branch of science and a specialty within engineering. In this course you will be introduced to properties of matter (Temperature, Pressure, Enthalpy, Specific Volume, Entropy, etc.) and governing laws which can be used to describe the behavior of matter and its interaction with the surrounding environment.

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You will learn how to identify systems and to use thermodynamic analysis to describe the behavior of the system in terms of properties and processes. Understanding how to apply these concepts is a powerful tool for the engineer, enabling the evaluation of material states (phases) under different conditions and the maximum efficiency achievable with various power cycles.

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After completing this course, you should be able to define and describe properties and processes used in thermodynamic analysis and the governing laws. In addition you should be able to apply control volume analysis and thermodynamic principles to solve problems involving power and refrigeration cycles.

Chapter 1

Getting Started

Introductory Concepts and Definitions

Learning Outcomes

- Demonstrate understanding of several fundamental concepts used throughout this book . . . Including closed system, control volume, boundary and surroundings, property, state, process, the distinction between extensive and intensive properties, and equilibrium.

Learning Outcomes, cont.

- Apply SI and English Engineering units, including units for specific volume, pressure, and temperature.

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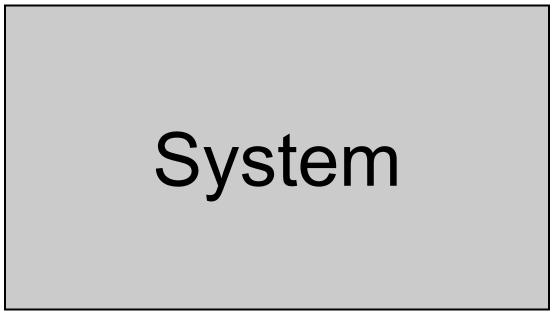
- ►Work with the Kelvin, Rankine, Celsius, and Fahrenheit temperature scales.

Learning Outcomes, cont.

- ►Apply SI and English Engineering units, including units for specific volume, pressure, and temperature.
- ►Work with the Kelvin, Rankine, Celsius, and Fahrenheit temperature scales.
- ►Apply the problem-solving methodology used in this book.

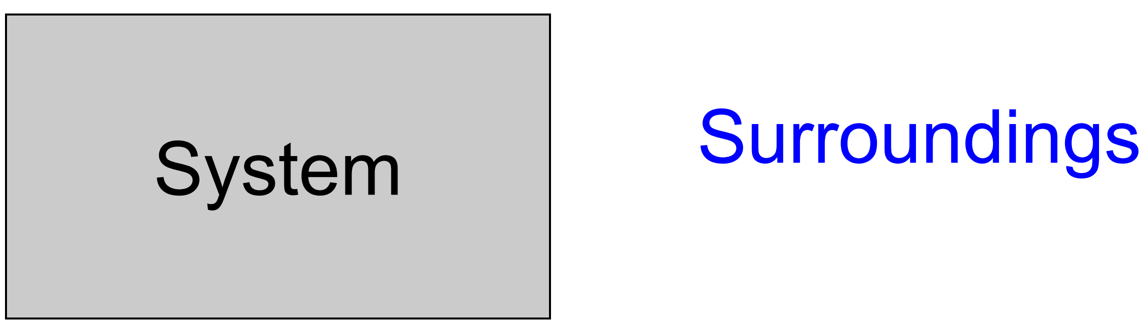
Defining Systems

- System: whatever we want to study.



Defining Systems

- System: whatever we want to study.
- Surroundings: everything external to the system.



Defining Systems

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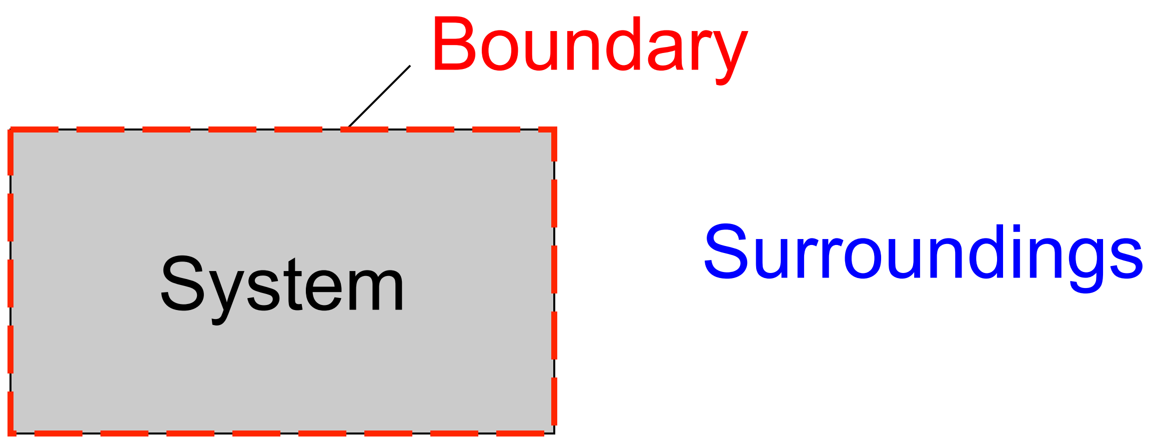
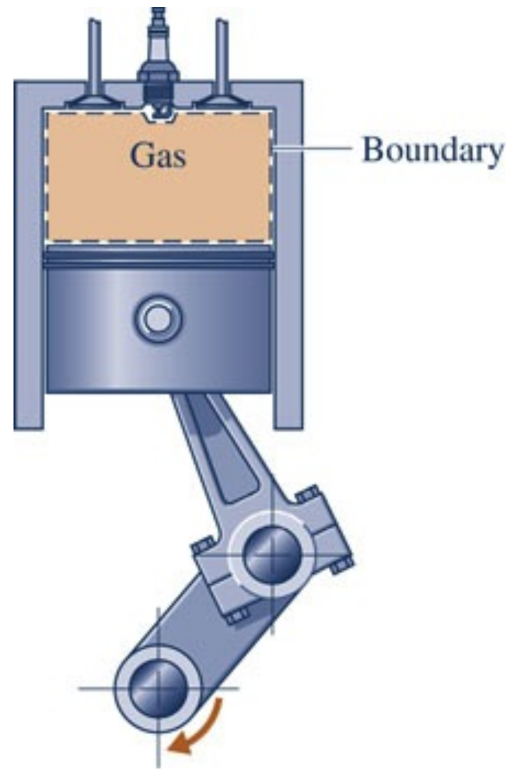
- Surroundings: everything external to the system.
- Boundary: distinguishes system from its surroundings.



Closed System

► A system that always contains the same matter.



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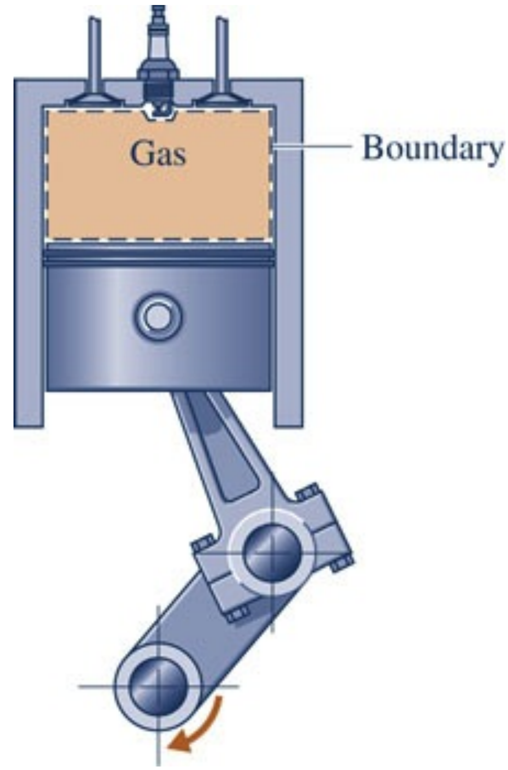
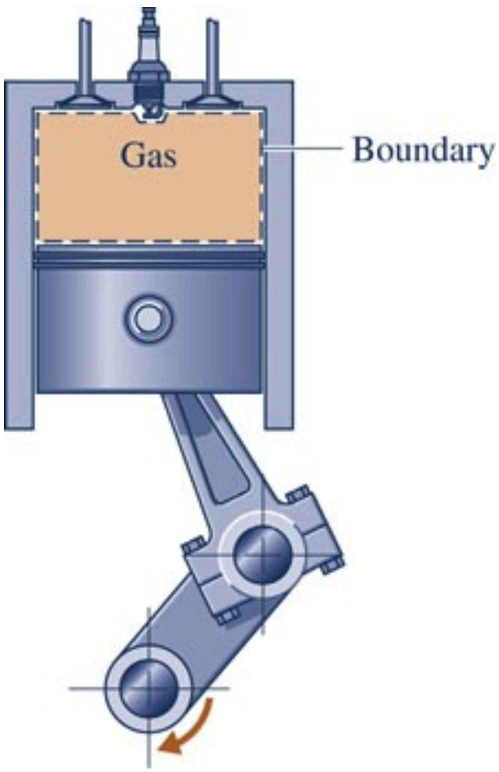
- ►No transfer of mass across its boundary can occur.



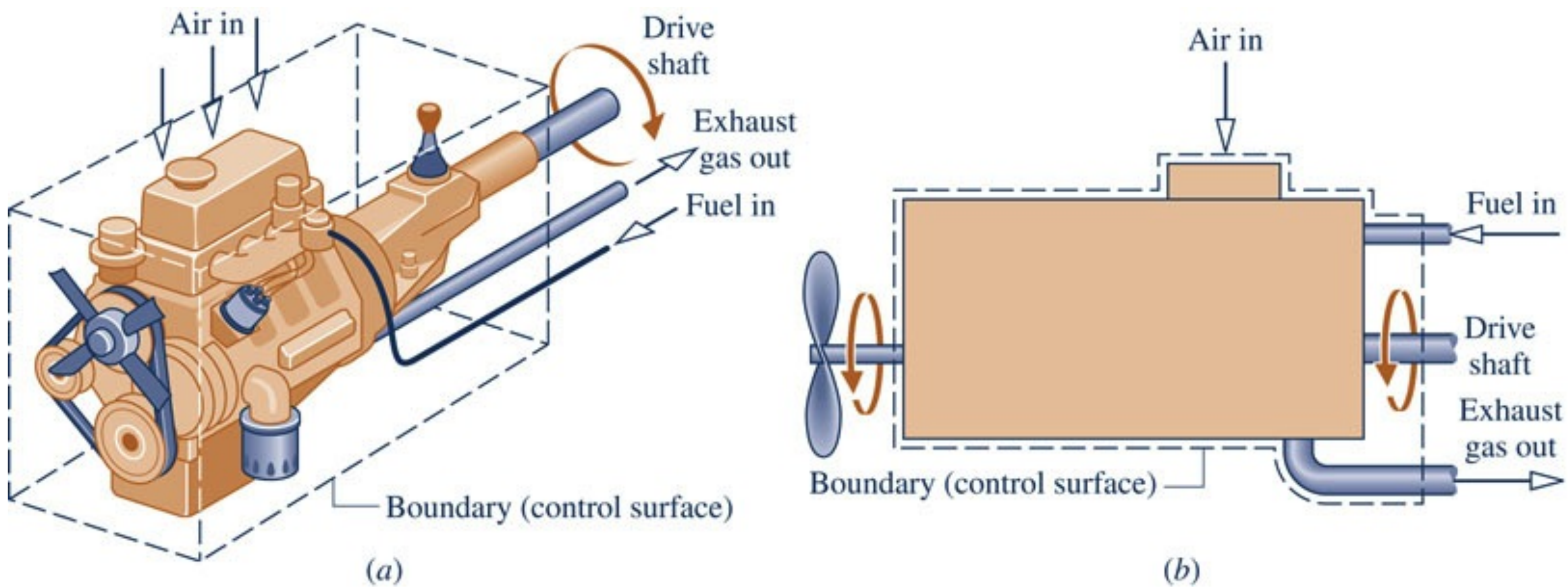
Closed System

- ►A system that always contains the same matter.
- ►No transfer of mass across its boundary can occur.
- ►Isolated system: special type of closed system that does not interact in any way with its surroundings.



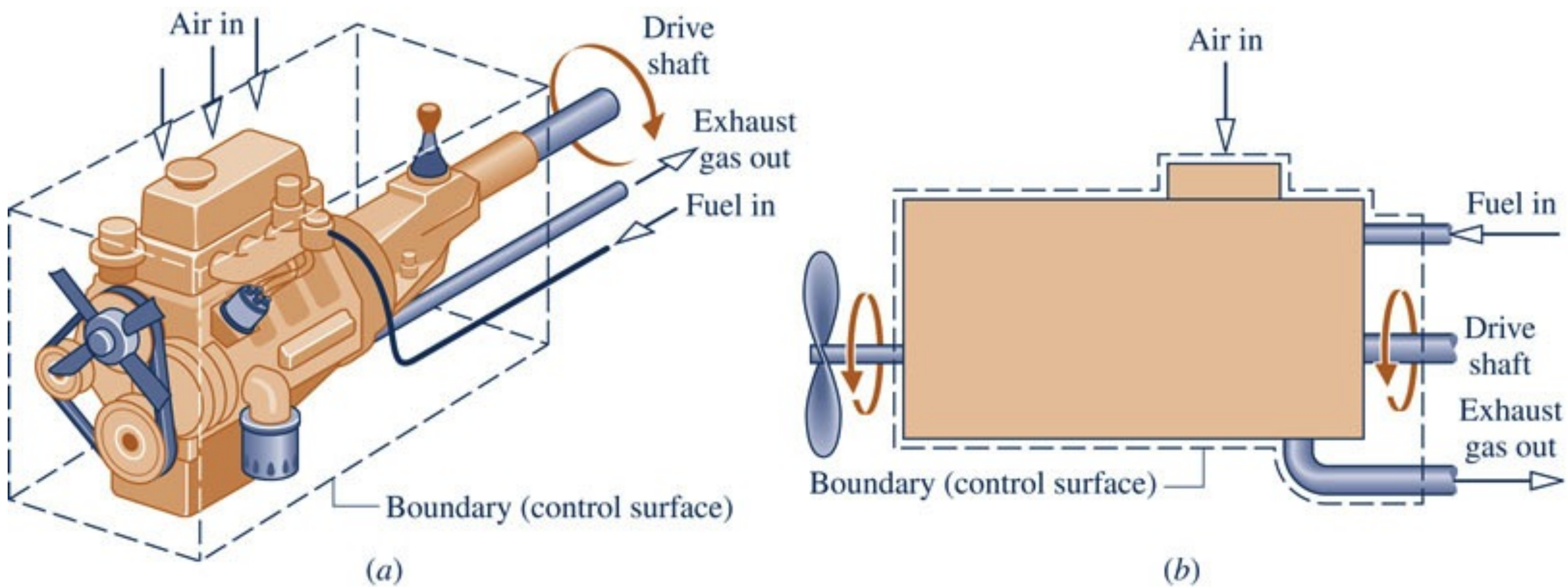
Control Volume

► A given region of space through which mass flows.



Control Volume

- ►A given region of space through which mass flows.
- ►Mass may cross the boundary of a control volume.



Macroscopic and Microscopic Views

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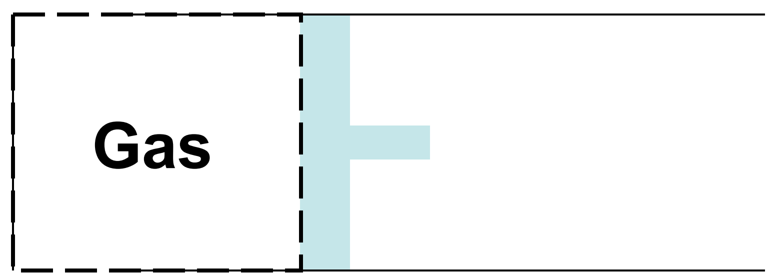
►Engineering thermodynamics predominately uses the macroscopic approach.

Property

► A macroscopic characteristic of a system to which a numerical value can be assigned at a given time without knowledge of the previous behavior of the system.

► For the system shown, examples include:



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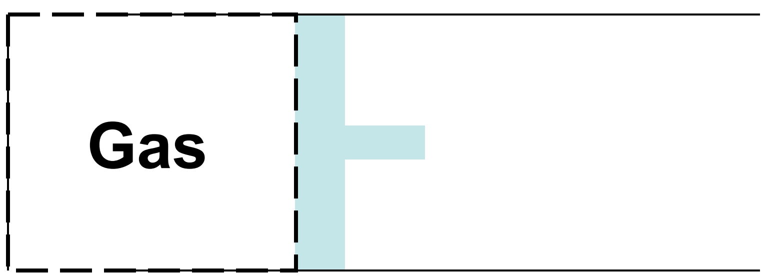

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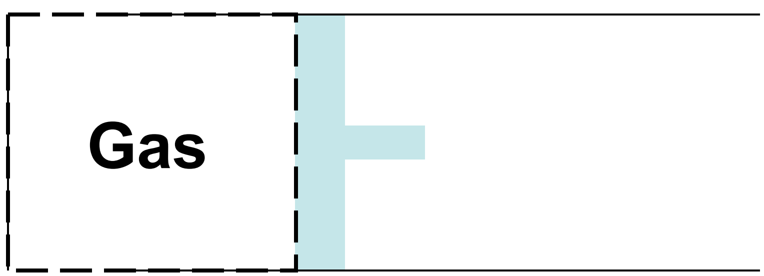

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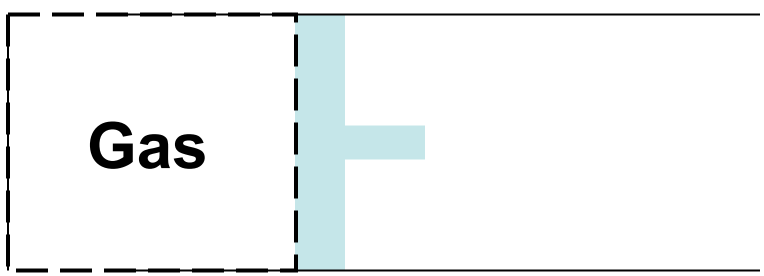

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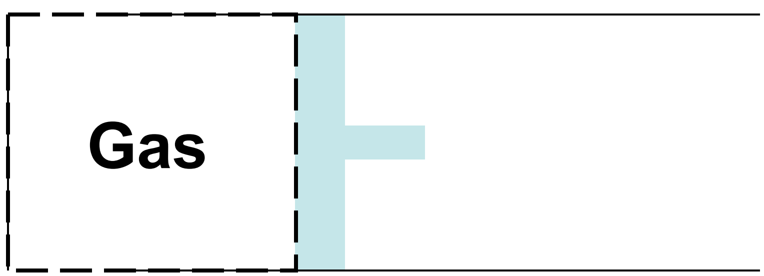
- **Pressure**



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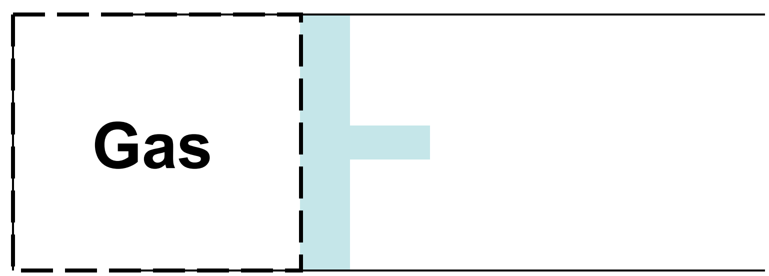
  - ►**Temperature**



State

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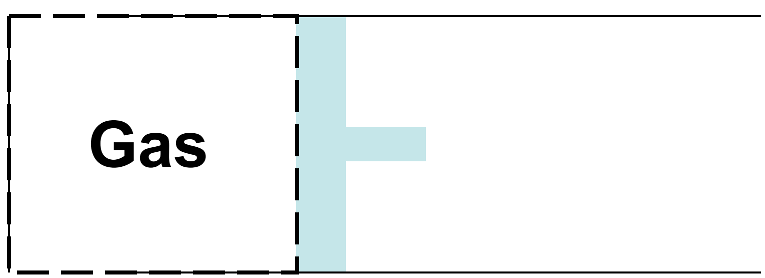
State: $\boldsymbol{p, V, T, \ldots}$



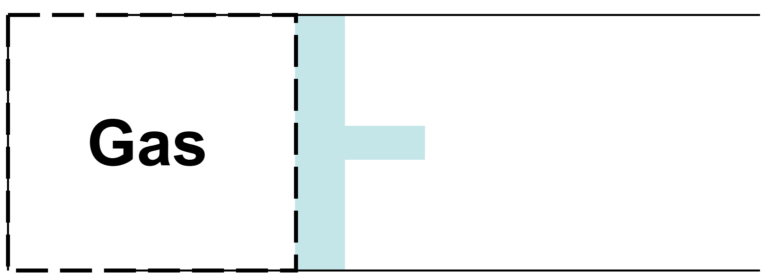
State

► The condition of a system as described by its properties.

► Example: The state of the system shown is described by p, V, T,….

► The state often can be specified by providing the values of a subset of its properties. All other properties can be determined in terms of these few.

State: p, V, T, …



Process

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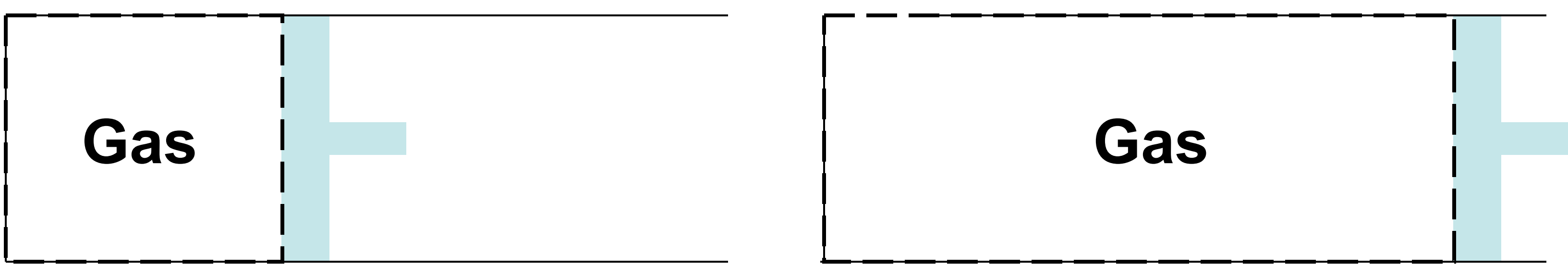
► When any of the properties of a system changes, the state changes, and the system is said to have undergone a process.

► Example: Since $V_2 > V_1$, at least one property value changed, and the gas has undergone a process from State 1 to State 2.

State 1: $p_1, V_1, T_1, \ldots$ **State 2:** $p_2, V_2, T_2, \ldots$



Extensive Property

►Depends on the size or extent of a system.

►Examples: mass, volume, energy.

►Its value for an overall system is the sum of its values for the parts into which the system is divided.

(a) (b)

Intensive Property

- ►Independent of the size or extent of a system.
- ►Examples: pressure, temperature.
- ►Its value is not additive as for extensive properties.
- ►May vary from place to place within the system at any moment – function of both position and time.

Equilibrium

►When a system is isolated, it does not interact with its surroundings; however, its state can change as a consequence of spontaneous events occurring internally as its intensive properties such as temperature and pressure tend toward uniform values. When all such changes cease, the system is at an **equilibrium state**.

►Equilibrium states and processes from one equilibrium state to another equilibrium state play important roles in thermodynamic analysis.

<u>Units</u>

- ►A unit is any specified amount of a quantity by comparison with which any other quantity of the same kind is measured (e.g., meter, kilometers, feet, and miles are all *units of length*).
- ►Two systems of units:
  - ►SI (Système International d’Unités)
  - ►English Engineering units.

Units

Units for Mass, Length, Time, and Force

	SI		English	
Quantity	Unit	Symbol	Unit	Symbol
mass	kilogram	kg	pound mass	lb
length	meter	m	foot	ft
time	second	s	second	s
force	newton (= 1 kg · m/s²)	N	pound force (= 32.1740 lb · ft/s²)	lbf

In these unit systems, mass, length, and time are base units and force has a unit derived from them using,

$$F = ma \qquad \text{(Eq. 1.1)}$$

SI: $1\ \text{N} = (1\ \text{kg})(1\ \text{m/s}^2) = 1\ \text{kg}\cdot\text{m/s}^2$ **(Eq. 1.2)**

English:

$1\ \text{lbf} = (1\ \text{lb})(32.1740\ \text{ft/s}^2) = 32.1740\ \text{lb}\cdot\text{ft/s}^2$ **(Eq. 1.5)**

Density (ρ) and Specific Volume (v)

► From a macroscopic perspective, description of matter is simplified by considering it to be distributed continuously throughout a region.

► When substances are treated as continua, it is possible to speak of their intensive thermodynamic properties "at a point."

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►From a macroscopic perspective, description of matter is simplified by considering it to be distributed continuously throughout a region.

►When substances are treated as continua, it is possible to speak of their intensive thermodynamic properties "at a point."

►At any instant the density (ρ) at a point is defined as

$$\rho = \lim_{V \to V'} \left(\frac{m}{V} \right)$$

(Eq. 1.6)

where V' is the smallest volume for which a definite value of the ratio exists.

Density (ρ) and Specific Volume (v)

► Density is mass per unit volume.

► Density is an intensive property that may vary from point to point.

► SI units are (kg/m^3).

► English units are (lb/ft^3).

Density (ρ) and Specific Volume (v)

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►English units are (ft^3/lb).

Specific volume is usually preferred for thermodynamic analysis when working with gases that typically have small density values.

Pressure (p)

►Consider a small area **A** passing through a point in a fluid at rest.

►The fluid on one side of the area exerts a compressive force that is normal to the area, F_{normal}. An equal but oppositely directed force is exerted on the area by the fluid on the other side.

►The pressure (p) at the specified point is defined as the limit

$$p = \lim_{A \to A'} \left(\frac{F_{normal}}{A} \right) \qquad \textbf{(Eq. 1.10)}$$

where A' is the area at the "point" in the same limiting sense as used in the definition of density.

Pressure Units

- SI unit of pressure is the **pascal**:

  1 pascal = 1 N/m^2

- Multiples of the pascal are frequently used:
  - 1 kPa = 10^3 N/m^2
  - 1 bar = 10^5 N/m^2
  - 1 MPa = 10^6 N/m^2
- English units for pressure are:
  - pounds force per square foot, **lbf/ft^2**
  - pounds force per square inch, **$lbf/in.^2$**

Absolute Pressure

► **Absolute pressure**: Pressure with respect to the zero pressure of a complete vacuum.

► **Absolute pressure** *must* be used in thermodynamic relations.

► **Pressure-measuring devices** often indicate the *difference* between the absolute pressure of a system and the absolute pressure of the atmosphere outside the measuring device.

Gage and Vacuum Pressure

► When system pressure is greater than atmospheric pressure, the term gage pressure is used.

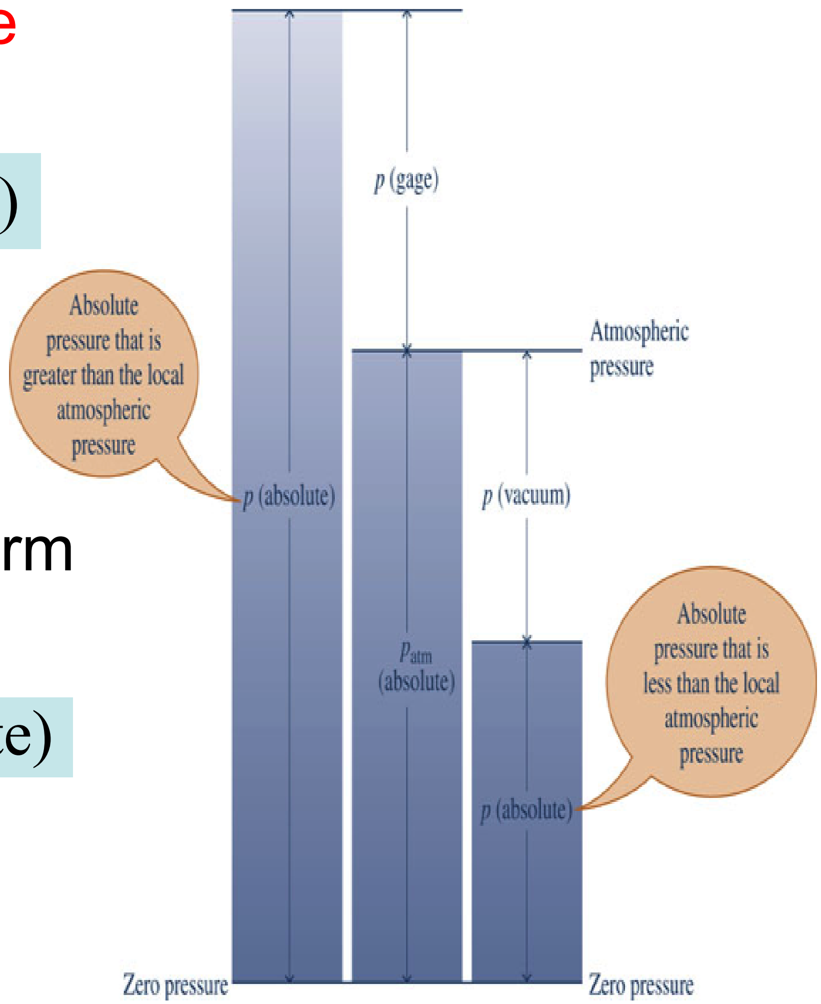
$$p(\text{gage}) = p(\text{absolute}) - p_{\text{atm}}(\text{absolute})$$

(Eq. 1.14)

► When atmospheric pressure is greater than system pressure, the term vacuum pressure is used.

$$p(\text{vacuum}) = p_{\text{atm}}(\text{absolute}) - p(\text{absolute})$$

(Eq. 1.15)



Temperature (T)

► If two blocks (one warmer than the other) are brought into contact and isolated from their surroundings, they would interact thermally with changes in observable properties.

► When all changes in observable properties cease, the two blocks are in thermal equilibrium.

► Temperature is a physical property that determines whether the two objects are in thermal equilibrium.

Thermometers

► Any object with at least one measurable property that changes as its temperature changes can be used as a **thermometer**.

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► Such a property is called a **thermometric property**.

► The substance that exhibits changes in the thermometric property is known as a **thermometric substance**.

Thermometers

- **Example**: Liquid-in-glass thermometer
  - Consists of glass capillary tube connected to a bulb filled with liquid and sealed at the other end. Space above liquid is occupied by vapor of liquid or an inert gas.
  - As temperature increases, liquid expands in volume and rises in the capillary. The length (L) of the liquid in the capillary depends on the temperature.
  - The liquid is the thermometric substance.
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- Other types of thermometers:
  - Thermocouples
  - Thermistors
  - Radiation thermometers and optical pyrometers

Temperature Scales

►**Kelvin scale**: An absolute thermodynamic temperature scale whose unit of temperature is the kelvin (K); an SI base unit for temperature.

►**Rankine scale**: An absolute thermodynamic temperature scale with absolute zero that coincides with the absolute zero of the Kelvin scale; an English base unit for temperature.

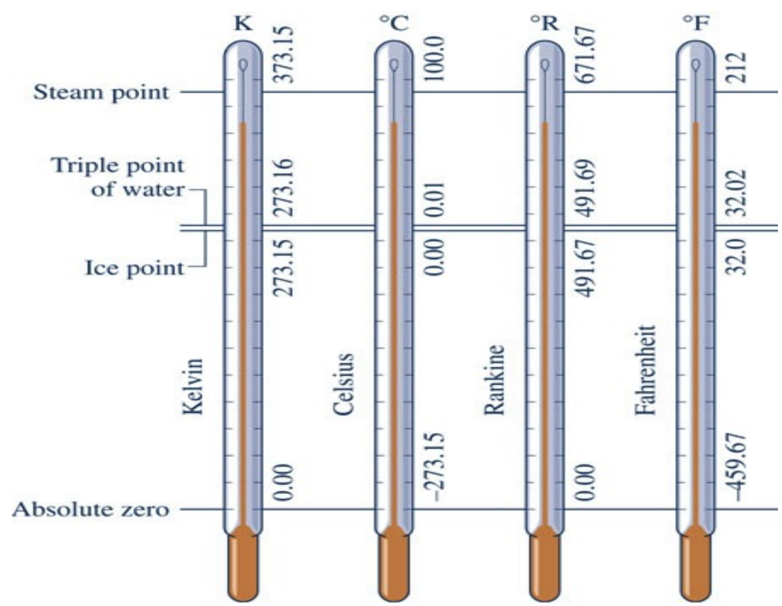
$$T(^{o}\text{R}) = 1.8T(\text{K})$$ **(Eq. 1.16)**

►Celsius scale (^{o}C):

$$T(^{o}\text{C}) = T(\text{K}) - 273.15$$ **(Eq. 1.17)**

►Fahrenheit scale (^{o}F):

$$T(^{o}\text{F}) = T(^{o}\text{R}) - 459.67$$ **(Eq. 1.18)**



Problem-Solving Methodology

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►**Find**: State what is to be determined.

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►**Engineering Model**: List all simplifying assumptions and idealizations made.

►**Analysis**: Reduce appropriate governing equations and relationships to forms that will produce the desired results.