

Basic Concepts of Thermodynamics

Thermodynamics can be defined as the science of energy and it is concerned with the energy storage and energy conversion processes. It deals with the relations between heat, work and the properties of systems.

The name “*thermodynamics*” stems from the Greek words *therme* (heat) and *dynamis* (power).

Thermodynamic can be studied from two points of view:

1. Classical Thermodynamics (macroscopic point of view (macroscopic approach))

It concerns with the gross or average effects of many molecules which does not require knowledge of the behavior of individual particles. It provides a direct and easy way to the solution of engineering problems.

2. Statistical Thermodynamics (microscopic point of view (microscopic approach))

It deals with average values for all particles under consideration so it is rather involved and it requires statistical methods.

Application Fields of Thermodynamics

It is difficult to imagine an area that does not relate to thermodynamics in some manner. Some application areas of thermodynamics is listed below:

- House Appliances
- Human body
- Heating and air-conditioning systems
- Automotive engines, rockets, jet engines
- Power plants
- etc

Dimension and Units

The physical quantity is characterized by dimensions and the arbitrary magnitudes assigned to the dimensions are called units.

The International System (SI) is considered Primary or fundamental dimensions are; mass (m), length (L), time (t), and temperature (T).

TABLE 1–1

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

Other physical quantities are called secondary or derived dimensions such as:

Velocity $Vel = L/t = m/s$

Acceleration $a = Vel/t = m/s^2$

Force $F = m a = kg \cdot m/s^2 = \text{Newton (N)}$

Pressure $P = \text{Force/Area} = F/A = F/(L \cdot L) = N/m^2$ or Pascal (Pa)

Work $W = \text{Force} \cdot \text{distance} = F L = N \cdot m = \text{Joule} = J$

Volume $V = L \cdot L \cdot L = L^3$

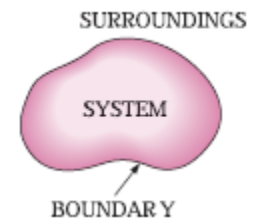
Density $= \text{mass/volume} = m/V = kg/m^3$

Power $= \text{Work/time} = J/s = \text{Watt (w)}$

Basic Thermodynamic Terminology

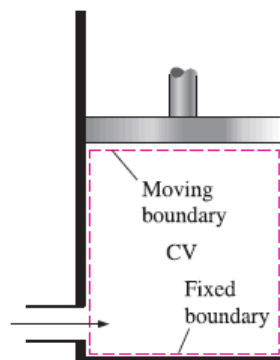
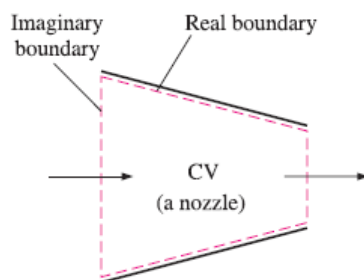
Thermodynamic System

- A thermodynamic system is simply any object, quantity of matter, or a region of space that has been selected for study. Everything that is not part of the system is referred to as the **surroundings**



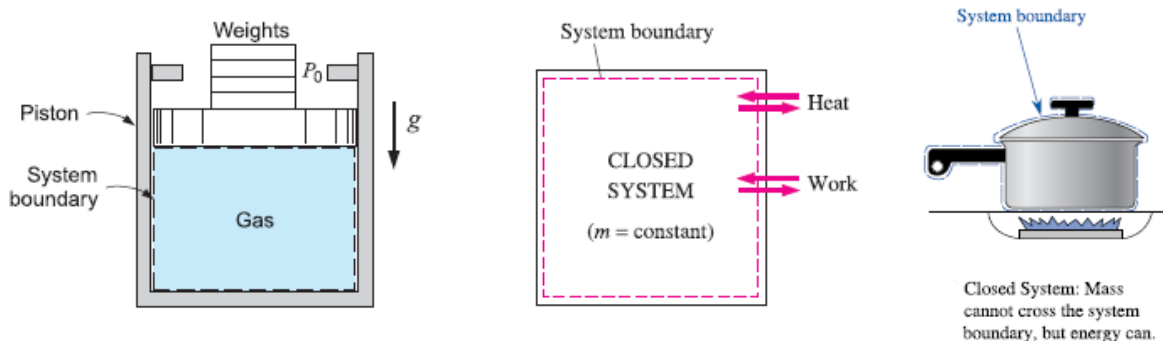
In practice, the matter contained within the boundaries of the system can be liquid, vapor, gas, and is known as working fluid.

- Boundary or control surface (CS) separates the system from its surroundings which
 - may be real or imaginary, at rest or in motion
 - may change its shape and size
 - neither contains matter nor occupies volume
 - has zero thickness and a property value at a point on the boundary is shared by both the system and the surroundings.



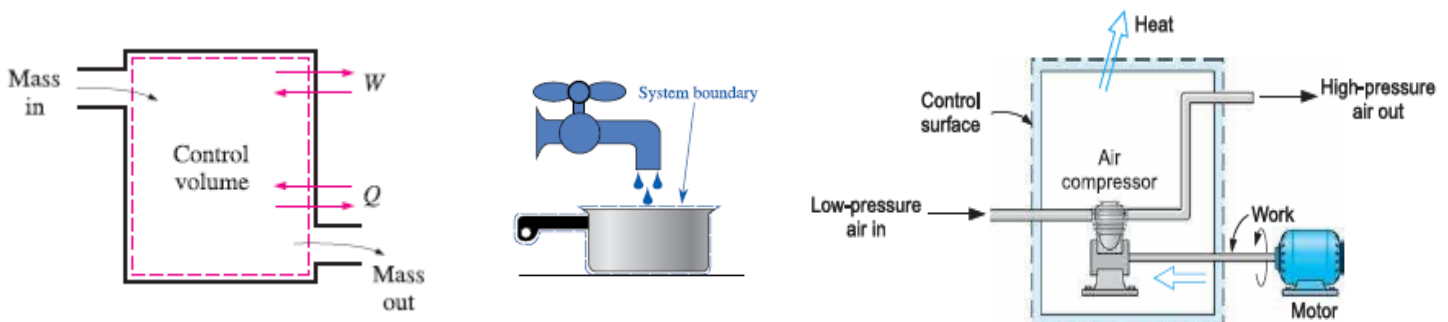
- Control Mass (CM) or Closed System (CS)

In Control Mass (CM) or Closed system, the CS is closed to mass flow, so that no mass can exit or enter the control volume. Energy (heat & work) may cross the system boundary, but the system contains the same amount of matter at all times.



- Control Volume (CV) or Open System

When there is flow of mass through control surface, the system is called a Control Volume (CV) or Open system. Both mass and energy (heat & work) can cross the boundary of a control volume, which is called a control surface.

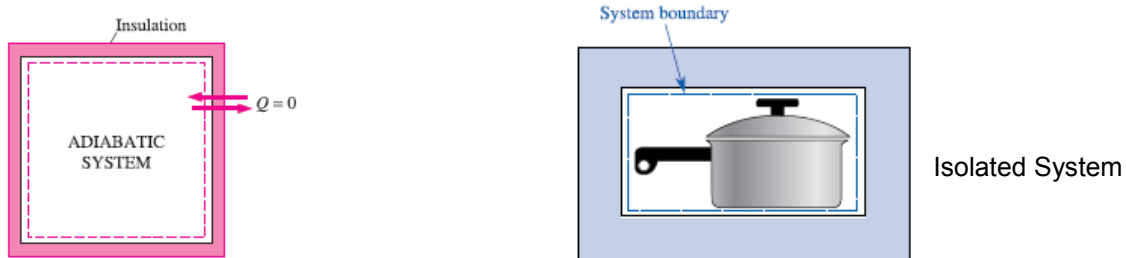


- Adiabatic System

An Adiabatic system is one in which the boundary is insulated and impermeable to heat transfer from or to the system.

- Isolated System

An Isolated system is a special case of closed system that does not interact in any way with its surroundings as no mass, heat, and work can cross the system boundary.



Forms of Energy

Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear, and their sum constitutes the **total energy** E of a system. The total energy of a system on a *unit mass* basis is called specific energy e (kJ/kg).

$$e = E/m \quad (\text{kJ/kg})$$

Thermodynamics deals only with the *change* of the total energy, which is what matters in engineering problems.

- The **internal energy** (U) represents the sum of all the microscopic forms of energy of a system.

The specific internal energy $u = U/m$

The macroscopic energy of a system is related to motion and the influence of some external effects such as gravity, magnetism, electricity, and surface tension.

- The **kinetic energy** (KE) of a system as a result of its motion relative to some reference.

$$KE = \frac{m Vel^2}{2} \quad (\text{kJ})$$

$$\text{Specific kinetic energy } ke = \frac{KE}{m} = \frac{Vel^2}{2} \quad (\text{kJ/kg})$$

where Vel denotes the velocity of the system relative to some fixed reference frame (m/s).

- The **potential energy** (PE) is the energy that a system possesses as a result of its elevation in a gravitational field and is expressed as:

$$PE = m g z \quad (\text{kJ})$$

The specific potential energy is:

$$pe = \frac{PE}{m} = g z \quad (\text{kJ/kg})$$

where g is the gravitational acceleration (m/s^2) and z is the elevation of the center of gravity of a system relative to some arbitrarily selected reference level (m).

- The magnetic, electric, and surface tension effects are significant in some specialized cases only and are usually ignored.
- the total energy E of a system consists of the kinetic, potential, and internal energies and is expressed as:

$$E = U + KE + PE = U + \frac{mVel^2}{2} + mgz \quad (\text{kJ})$$

Per unit mass:

$$e = \frac{E}{m} = u + ke + pe = u + \frac{Vel^2}{2} + gz \quad (\text{kJ/kg})$$

Properties of a thermodynamics system

The **property** is defined as any characteristic of a system such as pressure P , temperature T , volume V , and mass m .

Some properties are dependent as they rely on some independent one. For example, the density as defined as mass per unit volume:

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

The specific volume is a reciprocal of density as it defined of volume per unit mass:

$$v = \frac{V}{m} = \frac{1}{\rho} \quad (\text{m}^3/\text{kg})$$

Properties are classified into *intensive* or *extensive* properties.

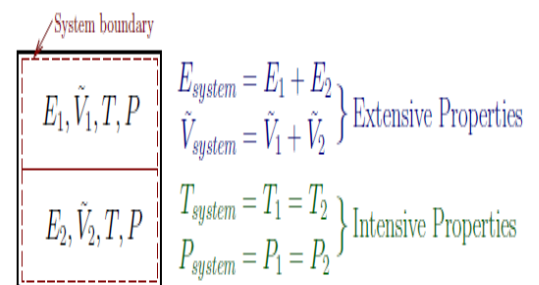
- Intensive properties are independent of the mass or the size of a system such as temperature, pressure, and density.
- Extensive properties depend on the size or extent of the system such as mass, volume and total energy. The value of the extensive properties of whole system is the sum of the values for its parts
- Extensive properties per unit mass are called intensive

or **specific properties**

e. g

- Specific volume
 $v = \text{total volume/mass} \quad v = V/m \quad (\text{m}^3/\text{kg})$
- Specific total energy
 $e = \text{Total Energy/mass} = E/m \quad (\text{kJ/kg})$
- Specific internal energy

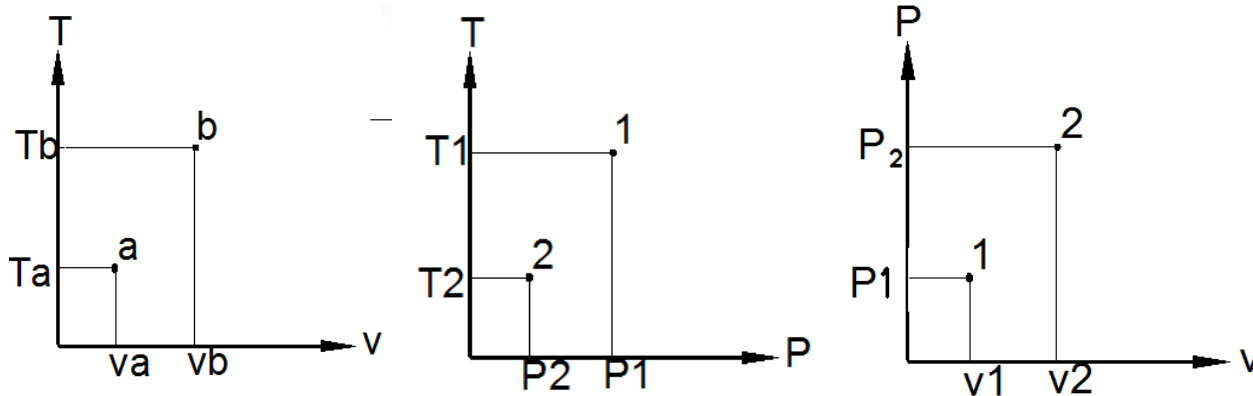
Property	Extensive	Intensive
Mass	m	ρ
Volume	\tilde{V}	v
KE	$\frac{1}{2}mV^2$	$\frac{1}{2}V^2$
PE	mgZ	gZ
Total Energy	E	e
Internal Energy	U	u
Enthalpy	H	h
Entropy	S	s



u =Total internal energy/mass, $u=U/m$ (kJ/kg)

State and Equilibrium

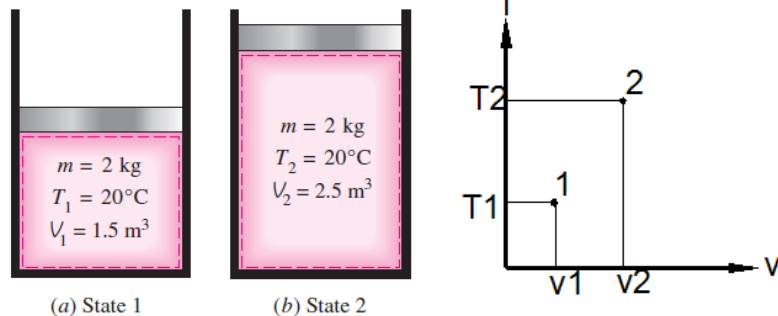
At any instant, the state of the system is defined by its properties. Only two independent properties are necessary to define completely the state of (compressible) working fluid or the system.



e.g

$$v_1 = V_1/m = 1.5/2 = 0.75 \text{ m}^3/\text{kg}$$

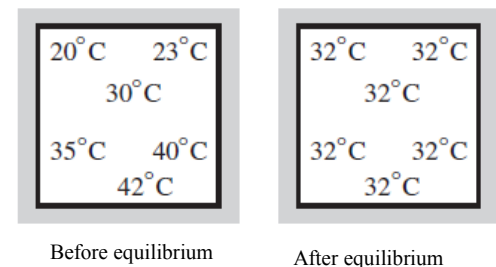
$$v_2 = V_2/m = 2.5/2 = 1.25 \text{ m}^3/\text{kg}$$



The system is said to be in thermodynamics equilibrium state when it does not have tendency to change its state and a system experiences no changes when it is isolated from its surroundings.

A system is not in thermodynamic equilibrium unless it satisfies the following types of equilibrium:

1. **Thermal equilibrium:** no temperature differences between parts of the system.
2. **Mechanical equilibrium:** no change in pressure (no unbalanced forces) at any point of the system with time. The variation of pressure as a result of gravity in most Thermodynamic systems is relatively small and usually disregarded.



3. **Chemical equilibrium:** the chemical composition does not change with time, that is, no chemical reactions occur.

4. **Phase equilibrium:** If a system involves two phases, when the mass of each phase reaches equilibrium level and stays there.

Processes and Cycles

The process occurs when a system undergoes change from one equilibrium state to another, and the series of states through which a system passes during a process is called the **path** of the process.

The complete description of process requires:

- Initial state
- Final state
- Path
- Interactions with the surroundings

The **quasistatic**, or **quasi-equilibrium process** is defined as a process proceeds sufficiently slowly so that the system remains infinitesimally close to an equilibrium state at all times.

A quasi-equilibrium process is an idealized process, but actual processes closely approximate it, and they can be modeled as quasi-equilibrium with negligible error.

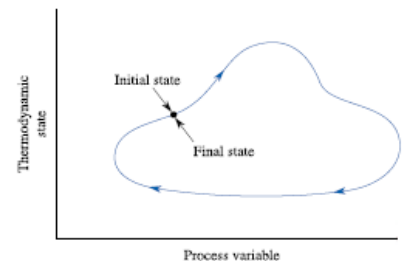
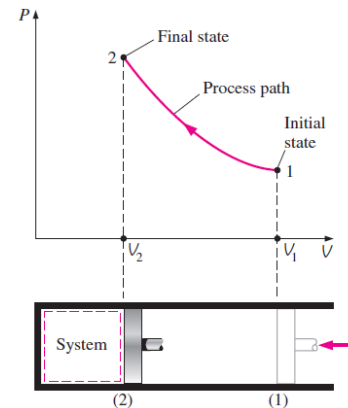
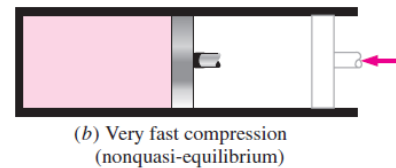
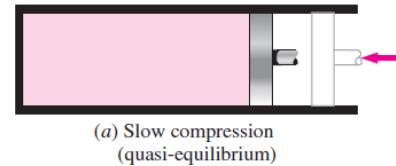
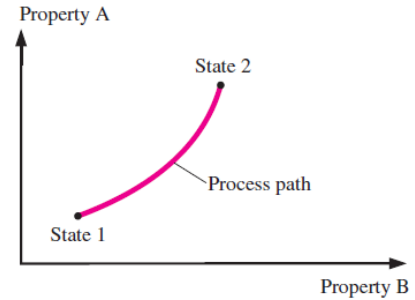
Engineers are interested in quasi-equilibrium processes for two reasons:

- they are easy to analyze
- work-producing devices deliver the most work when they operate on quasi-equilibrium processes.

Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the quasi-equilibrium processes.

For nonquasi-equilibrium processes, we cannot speak of a process path for a system as a whole. A nonquasi-equilibrium process is denoted by a dashed line between the initial and final states instead of a solid line.

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.



Pressure

Pressure is defined as *a normal force (F) exerted by a fluid per unit area (A)*

$$P = \frac{F}{A} \quad (\text{N/m}^2)$$

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

$$1 \text{ kPa} = 10^3 \text{ Pa}$$

$$1 \text{ MPa} = 10^6 \text{ Pa}$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ KPa}$$

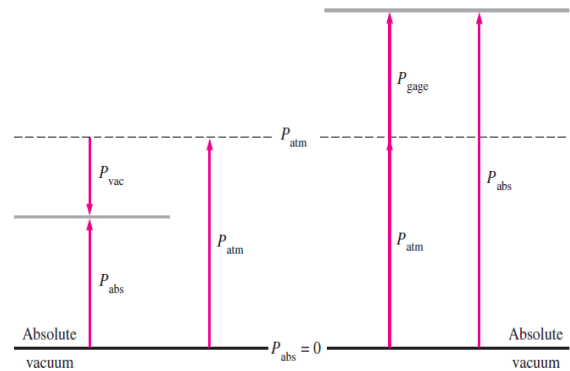
$$1 \text{ atm} = 101,325 \text{ Pa} = 101.325 \text{ KPa} = 0.101325 \text{ MPa} = 1.01325 \text{ bar}$$

In most thermodynamic investigations we are concerned with absolute pressure (P_{abs}).

Most pressure gauges, however, read the difference between the absolute pressure and the atmospheric pressure (P_{atm}) and this is referred to as *gauge pressure* (P_g) as:

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

If P_g has a negative sign as $P_{\text{abs}} < P_{\text{atm}}$, then the pressure is called vacuum pressure (P_{vac}).

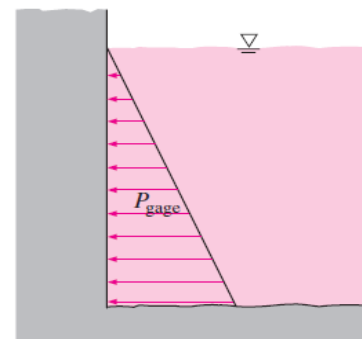
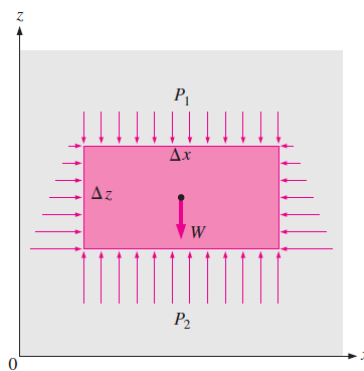


Pressure at any point in a fluid is the same in all directions but it differs from point to point they do not located at the same level, so the pressure varies with the depth inside the fluid container.

$$\Delta P = P_2 - P_1 = \rho g \Delta z = \gamma \Delta z$$

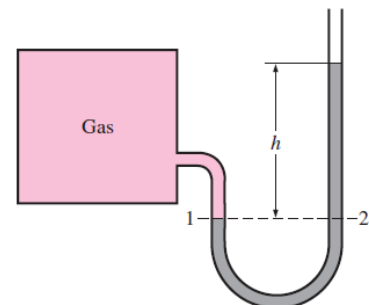
Δz = vertical distance between the points or pressure head (m).

γ = specific weight of the fluid
 $= \rho g \quad (\text{N/m}^3)$



The pressure of a fluid at rest increases with depth (as a result of added weight).

The pressure is measured by many devices. The **manometer** is a pressure measuring instrument which is commonly used to measure the small and moderate pressure differences. The manometer depends on a fluid column to measure pressure differences.



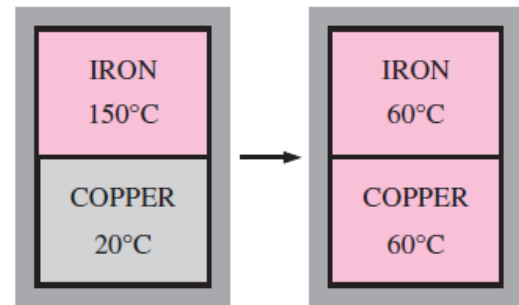
$$P_2 = P_1 = P_{\text{atm}} + \rho g h$$

Also, there are other devices for pressure measurements such as **Bourdon tube**, **pressure transducers**, **Strain-gage pressure transducers**, etc.

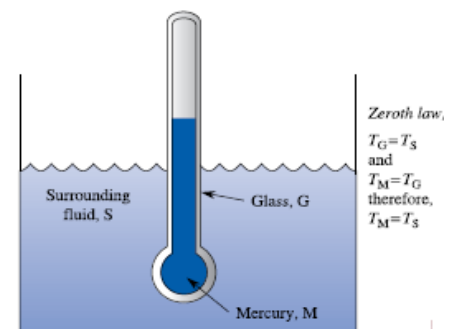
Temperature and the zeroth law of thermodynamics

Although temperature is a familiar property, defining it exactly is difficult. The temperature is defined as a sense of hotness or coldness.

when two bodies at different temperatures are brought into contact, heat is transferred from the body at higher temperature to the one at lower temperature until both bodies attain the same temperature. At that point, the heat transfer stops, and the two bodies are said to have reached **thermal equilibrium**. Therefore, equality of temperature is the only requirement for thermal equilibrium.



The **zeroth law of thermodynamics** states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.



Temperature scales

All temperature scales are based on the freezing (ice point) and boiling (steam point) points of water.

A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure is said to be at the **ice point**, and a mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure is said to be at the **steam point**.

Celsius scale (*centigrade scale*) is the temperature scales used in the SI system in which the ice and steam points were originally assigned the values of 0 and 100°C, respectively.

Fahrenheit scale is the temperature scales used in the English system in which the ice and steam points were originally assigned the values of 32 and 212°F, respectively.

The relations between two scales are:

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

$$\Delta T(^{\circ}\text{F}) = 1.8 \Delta T(^{\circ}\text{C})$$

In thermodynamics, it is very desirable to have a temperature scale that is independent of the properties of any substances. Such a temperature scale is called a **thermodynamic temperature scale**.

The thermodynamic temperature scale in the SI is the **Kelvin scale** as:

$$T(K) = T(^{\circ}C) + 273.15$$

$$\Delta T(K) = \Delta T(^{\circ}C)$$

And, the thermodynamic temperature scale in the English system is the **Rankin scale** as:

$$T(R) = T(^{\circ}F) + 459.67$$

$$\Delta T(R) = \Delta T(^{\circ}F)$$

The relation between two thermodynamics scales is:

$$T(R) = 1.8 T(K)$$