System: Quantity of matter (constant mass) or region in space (constant volume) chosen for study.
   Closed system: Can exchange energy but not mass; mass is constant (control mass).
   Open system: Can exchange both energy and mass, and is often a fixed volume (control mass)

Surroundings: Region outside the system or not included in the system.

Boundary: Surface or interface between the system and surroundings, and may be real or imaginary; does not have to be a physical barrier. The concept of a boundary in thermodynamics is very important when considering heat and work, as both must cross a boundary.

State: Condition of a system described by giving values to its properties at a given time.

Property: A quantity used to describe a system. Properties can be related to each other through equations (equation of state), diagrammatically (property diagrams), or through tables (property tables).
   Intensive properties: Properties independent of the size or extent of the system (temperature, pressure, density, specific volume, specific energy quantities)
   Extensive properties: Properties that depend on the size or extent of the system (mass, volume, various forms of energy).
   Specific properties: An extensive property divided by mass (specific volume – V/kg = \( \text{v} \))

State Postulate: The state of a simple compressible pure substance is defined by two independent, intensive system properties

Phase: A physically separable homogeneous quantity, such as a solid, liquid, or vapor that has the same composition throughout.

Process: Series of successive states through which a system passes, expressed diagrammatically as a path.
   Reversible processes: A process which, when reversed, leaves no effect on either the system or the surroundings.
   Irreversible processes: a process that is not reversible.

Isothermal process: Processes that occur at constant temperature; isobaric processes that occur at constant pressure; isenthalpic processes that occur at constant enthalpy; isentropic processes that occur at constant entropy (internally reversible, adiabatic).

Thermodynamic equilibrium: There is no apparent change in the number or mass of coexisting phases, and the properties do not vary from point to point in a system.
**Compressed liquid:** The properties of the liquid are such that it would not vaporize as a result of small changes in temperature and/or pressure.

**Saturated liquid:** Liquid on the liquid-vapor curve in pressure-temperature space that would vaporize as a result of increase temperature or decrease in pressure.
**Saturated vapor:** Vapor on the liquid-vapor curve in pressure-temperature space that would condense as a result of decrease temperature or increase in pressure.

**Saturated mixture:** A physical mixture of two separate phases, saturate liquid and saturated vapor, where the properties of the individual liquid and vapor are those on the saturated liquid and saturated vapor curves, respectively, in temperature-volume or pressure-volume space.

**Superheated vapor:** The properties of the vapor are such that condensation would not occur as a result of small changes in temperature and/or pressure.

**Saturation temperature:** Temperature at which a pure substance begins to vaporize at a given pressure.

**Saturation pressure:** Pressure at which a pure substance begins to vaporize at a given temperature.

**Quality (x):** A measure of the proportion of the total mass of a substance occurring in the vapor state. \( x = \frac{m_g}{m_{\text{total}}} \)

**Triple point:** A unique set of conditions where the three phases, solid, liquid and vapor coexist.

**Critical point:** A unique set of conditions where the properties of the liquid and vapor phases are identical, and there is no apparent physical distinction between to two.

**Ideal gas:** A gas where the individual atoms or molecules are assumed to occupy no space, and exert no force on each other.

**Polytropic process:** State to state pressure-volume process where the relationship between pressure and volume is given by \( PV^n = \text{constant} \), where \( n \) is not equal to 1.

**Boundary work:** The work done as a result of movement of a boundary as a result of an applied force against the boundary, as in the change of volume in a piston-cylinder device under pressure, \( P \), which is always positive.

- Constant Pressure: \( W_b = \int PdV \)
- For \( PV = \text{constant} \): \( W_b = P_1V_1\ln(V_2/V_1) \) (\( T \) constant for ideal gas)
- Polytropic: \( W_b = (P_2V_2 - P_1V_1)/(1-n) \)

**First law of thermodynamics:** During a given process, the net heat transfer (\( Q \)) minus the net work (\( W \)) output equals the change in energy. It is impossible to create or destroy energy. \( Q - W = \Delta E \)
**Heat and Work** are path functions whereby their values during a particular process depend on the paths taken between two states. Both intensive and extensive properties are state functions whereby they depend only on the initial and final state of the system.

**Sign convention for heat and work:** Heat transferred to the system is positive; heat lost by the system is negative. Work done by the system is positive ($\Delta V$ positive); work done on the system is negative ($\Delta V$ negative).

**Second law of thermodynamics:** Thermal energy (heat) will spontaneously flow from a high temperature reservoir to a low temperature reservoir down a thermal gradient.

**Adiabatic process:** A process where there is no heat transferred. The system in which case is described as *insulated*.

**Cycle:** A series of processes where during the final process the system returns to its original state. Since energy is a state function, the change in energy during a cycle is zero, and: $\sum Q = \sum W$,

Where: $\sum Q$ and $\sum W$ are the sum of the heat and work exchanged for each of the processes in the cycle.

**Thermal energy reservoir:** A mass or body that can supply or absorb finite amounts of heat without changing its temperature.
- **Source:** Reservoir that supplies heat.
- **Sink:** Reservoir that absorbs heat.

**Heat engine:**

Insert heat engine (HE) into the heat flow to capture some of the heat from a high T source, and put it to work.

*Part of the heat received by the heat engine (HE) is converted to work.*

Some of the heat must be lost to a sink (surroundings)

Heat engine operates on a cycle
**Thermal efficiency:** Fraction of heat input to cycle converted to work.

\[
\eta = \frac{\text{(desired)}}{\text{(required)}} = \frac{\text{(net work output)}}{\text{(total heat input)}} = \frac{W_{\text{net}}}{Q_{\text{in}}} = \frac{W_{\text{net}}}{Q_{H}}
\]

**Carnot cycle (Carnot heat engine):** Hypothetical totally reversible power cycle consisting of four processes

1) Reversible isothermal expansion at high temperature, \(T_H\);
2) Reversible adiabatic expansion from \(T_H\) to \(T_L\);
3) Reversible isothermal compression at \(T_L\);
4) Reversible adiabatic compression from \(T_L\) to \(T_H\).

**Carnot principles:**

1) Efficiency of an irreversible heat engine is always less than the efficiency of a reversible cycle;
2) Efficiencies of all reversible heat engines operating between the same two reservoirs are equal.

\[
\eta_{\text{Carnot}} = \frac{W_{\text{net}}}{Q_{\text{in}}} = \frac{(T_H - T_L)}{T_H} = [1 - (T_L/T_H)] > [1 - (Q_L/Q_H)]
\]

**Reversed Carnot cycle:** Carnot refrigeration cycle.

**Gas power cycles:** Power is generated and working fluid remains in the gaseous state throughout the cycle. Air is the most common working fluid, and property changes occur as a result of temperature and/or pressure changes (Otto, Diesel, Brayton, jet propulsion).
**Vapor power cycle:** Power is generated and working fluid experiences a change in state from liquid to vapor and back to liquid (steam power generating systems, i.e. Rankine cycle).

**Vapor compression cycle:** Power is consumed and fluid (i.e. refrigerant) changes state from vapor to liquid (refrigeration devices and heat pumps).

**Closed cycle:** Working fluid is returned to initial state at the end of the cycle (internal combustion cycles).

**Open cycle:** Working fluid is renewed at the end of each cycle (Rankine, Brayton, Jet propulsion).

**Internal combustion:** Fuel is ignited within the system (piston-cylinder devise), (Otto – spark ignition, Diesel – compression ignition).

**External combustion:** Heat is supplied from a source outside the system such as through a heat exchanger (i.e. boiler).

**Assumptions in the thermodynamic analysis of cycles:** 1) no friction is involved; 2) pipes and other components connecting the various parts of the cycle are adiabatic; 3) expansion and compression are quasi-equilibrium processes.

**Air standard assumptions for ideal gas power cycles (air standard cycles):**

1) The working fluid is air (or another gas) that circulates in a closed loop, and behaves as an ideal gas;
2) All the processes that make up the cycle are assumed to be internally reversible;
3) Combustion is modeled as a heat addition process;
4) Exhaust is modeled as a heat rejection process.

**Cold air standard assumption (cold air standard cycles):** Working fluid has a constant specific heat where the value is assumed to be that at ambient conditions (i.e. 25°C)

**Compression ratio:** Ratio of the maximum volume over the minimum volume for the closed internal combustion cycles (Otto and Diesel cycles): \( r = \frac{v_{\text{max}}}{v_{\text{min}}} \)

**Cutoff ratio:** Ratio of the volume of the system following combustion to the volume before combustion (Diesel Cycle): \( r_c = \frac{v_3}{v_2} \)

**Mean effective pressure:** A given constant pressure acting on a piston in a closed gas power cycle during the entire power stroke that would produce the same amount of new work as that produced during the actual cycle.

\[
\text{MEP} = \frac{w_{\text{net}}}{v_{\text{max}}} \left[ 1 - \left( \frac{v_{\text{min}}}{v_{\text{max}}} \right) \right] = \frac{w_{\text{net}}}{v_{\text{max}}} (1 - (1/r))
\]