1. Basic Terminology
   1. [Thermodynamics](https://en.wikipedia.org/wiki/Thermodynamics)

The term *Thermodynamics* stems from the two Greek words *therme* and *dynamikos* which respectively translate to English as *heat* and *power*. Put together, these two words define a, **“branch of *physics* dealing with the *transformation* of heat into or from other forms of energy such as mechanical, magnetic, electrical etc. as well as the laws which govern such transformations”** (Laughlin, 2018). The addition of *chemical work* by Gibbs has allows for thermodynamics to apply to chemical reactions.

In studying thermodynamics, it is important to note how it differs from traditional Newtonian mechanics as that *Equilibrium Thermodynamics* deal with the same quantities with the exception of time. In Newtonian mechanics we have to deal with specific units such as *mass* (kg), *distance* (m), *volume* (m3), *time* (s), *velocity* (m/s), and *momentum* (kg m/s). These variables can be put together into formulas for:

In equilibrium thermodynamics, time is not used as a running variable, rather the states of systems are defined in two different periods: *Now* (t = 0, the state of a system) and *Future* (t = ∞, equilibrium state of a system). In addition to these quantities of mechanics three other quantities are also used in thermodynamics: *temperature* (T), *thermal energy* (Q), and *entropy* (S). The central focus of applied thermodynamics is to determine the effect that the *surroundings* have on the *equilibrium state* of a given *system*. The other focus is the, “establishment of relationships which exist between the equilibrium state of a given system and the influences which have been brought to bear on it” (Gaskell & Laughlin, 2017, p.4). Or in other words, is to look at the relationships that exist between the system’s equilibrium state and its influences.

* 1. [Systems](https://en.wikipedia.org/wiki/Thermodynamic_system)

A *System* simply defined is the, **“part of the universe with which we are interested in investigating”** (Laughlin, 2018). The surrounding areas which may interact with the system through either energy or matter exchange are denoted as either the *surroundings* or *environment*. A system is allowed to perform work on the surroundings or have work performed on it from the surrounding. In the context of materials science, the system is typically a material and the interactions between the system and surrounds depends of the *boundary* or *wall* of the system. All of this is encapsulated in what is called the *universe* which in the context of thermodynamics is defined as everything.

Boundary

Surroundings

(Universe)

System

Figure 1: Diagram of a system’s relationship with its surroundings

Examples of systems can range from simple heat engines to devices such as transducers, however in the study of thermodynamics a system is usually composed of matter which can be anything that contains mass and occupies space. *Matter* in the context of thermodynamics, “has a given temperature, pressure, and chemical composition, as well as physical properties such as thermal expansion, compressibility, heat capacity, viscosity, and so on” (Gaskell & Laughlin, 2017, p.4).

* + 1. Classifications
       1. Simple Systems vs. Complex Systems

A *simple system* **is a system that is, “closed in which only two variables (usually T and P) are needed to define the equilibrium state”** (Laughlin, 2018). In this type of system, we only have to consider pressure as the work term and temperature as the thermal energy term.

* + - 1. Simple Systems vs. Complex Systems
      2. Closed Systems vs. Open Systems

A *closed system* **is a system which may give or receive energy to or from its surroundings, respectively.** It has boundaries which are *diathermal* in that the transfer of thermal energy between the system and surroundings are not prohibited but the transfer of matter is prohibited. This causes the amount of matter within the system to remain constant.

* + - 1. Closed Systems vs. Open Systems

An *open system* **is a system that allows for the both energy and matter to be exchanged between the system and its surroundings.** With this neither the energy nor the composition of these systems will need to remain constant as the boundaries are both permeable and diathermal.

* + - 1. Non-reacting Systems vs. Reacting Systems
      2. Non-reacting Systems vs. Reacting Systems
      3. Homogeneous Systems vs. Heterogeneous Systems
      4. Homogeneous Systems vs. Heterogeneous Systems
      5. Unary Systems vs. Multicomponent Systems
      6. Unary Systems vs. Multicomponent Systems
    1. Isolated Systems

An *isolated system* **is a system where energy and overall composition remain constant.** In this system, energy and matter cannot enter or leave and also no work is done on or by the system. Thus, changes in the surroundings will not have an effect on the system.

* 1. [Boundaries (Walls)](https://en.wikipedia.org/wiki/Thermodynamic_system#Walls)

The *boundaries* or *walls* of a system **is the barrier in which selectively determine which interactions may take place between a system and its surrounding.** With this there are several different types of walls, each of which allow for selective types of interactions.

* + 1. Adiabatic

An *adiabatic* wall **does not allow for thermal energy to pass through**

* + 1. Diathermal

A *diathermal* wall **allows of thermal energy to pass through**

* + 1. Permeable

A *permeable* wall **allows for matter to pass through**

* + 1. Impermeable

An *impermeable* wall **does not allow for matter to pass through**

* + 1. Semipermeable

A *semipermeable* wall **allows for some component to pass through while prohibiting others.**

* 1. [State (Thermodynamic State)](https://en.wikipedia.org/wiki/Thermodynamic_state)

*State* is a part of the system which can be defined in two aspect; *microscopic* and *macroscopic*. The overall *state* of a system is defined as the, **“condition at a specific time, that is fully identified by values of a suitable set of parameters known as state variables, state parameters or thermodynamic variables.”** (Thermodynamic State, n.d.). A system’s state may change either from outside influences such as the flow of energy or chemicals or from internal processes that may occur.

TA -> TB

PA -> PB

VA -> VB

TA, PA, VA

TB, PB, VB

Process

Figure 2: Diagram depicting a system’s change in state

* + 1. Microscopic State

*Microscopic state* **is the *state* thatwould encapsulate all the possible known masses, velocities, positions of all the known constituent particles in a system.** This would also include all modes of motion such as translational, rotational, and etc. Together, this knowledge of the system would be the microscopic state of the system that would attribute to all measurable thermodynamic variables of the system such as energy, temperature, and pressure. This is impractical for use in macroscopic systems as it would require the humanly impossible task of knowing up to more than 1024 coordinates.

* + 1. Macroscopic State

Since detailed knowledge of the microscopic state of a system is difficult to produce, classical thermodynamics begins with the **consideration of variables within the system**. Thus, when determined, these variables will make up the *macroscopic state* of the system. Once, “all of the thermodynamic variables are fixed, then the macroscopic state of the system is fixed and said to be in equilibrium” (Gaskell & Laughlin, 2017, p.5).

* 1. [Thermodynamic Variables (Conjugate Variables)](https://en.wikipedia.org/wiki/Conjugate_variables_(thermodynamics))

Wikipedia defines thermodynamic *variables* in the general mathematic context of [*conjugate variables*](https://en.wikipedia.org/wiki/Conjugate_variables) which mathematically speaking have some defined relationship between the two; such as time & frequency or doppler & range. **“In thermodynamics, the internal energy of a system is expressed in terms of pairs of conjugate variables such as temperature & entropy or pressure & volume”** (Conjugate Variables (Thermodynamics), n.d.).

* + 1. Independent Variables

*Independent variables* in a thermodynamic system **are the variables which do not depend on any other variable in the system** and are sometimes fixed. For example, in a simple system that fixes the values of two thermodynamic variables, those fixed variables subsequently fix the values of the rest thermodynamic variables. Therefore, in this case there are only two thermodynamic variables that are independent as their values do not depend on any other variable in the system, rather they affect the value of other thermodynamic variables in the system.

* + 1. Dependent Variables

*Dependent variables* are the **variables whose values that depend on the values of other variables in the system** such as independent variables. In the context of the previous example, the variables that depend on all the values of other variables in the system are dependent variables. Usually independent and dependent variables are used as follows:

* + 1. Intrinsic Variables

*Intrinsic variables* are variables whose values are, **“independent of the path over which the process has taken the system in changing it from its previous state to its present state”** (Gaskell & Laughlin, 2017, p.5). In other words, these variables are intrinsic to the state of the system and are function of state which can be expressed as exact differentials of their dependent variables. Examples of partial and exact differentials are as follows:

* + 1. Extrinsic Variables

*Extrinsic variables* are variables **whose values are dependent on the history of the system**. In other words, these variables are path dependent and are not the equilibrium properties of a system as with the progression of time, these values may change.

* 1. [Equilibrium](https://en.wikipedia.org/wiki/Thermodynamic_equilibrium)

*Equilibrium* **is defined as an internal state of one or more thermodynamic systems where there are no net macroscopic flows of matter or energy within or between systems.** It is a state of rest where there are no changes that are observed at the macroscopic level and properties seem to remain constant. At equilibrium, variables within a system such as temperature (T), pressure (P), composition (ni), volume (V), and energy (U) are unchanging and uniform throughout the system.

However, at a microscopic level there can all sorts of action can occur, but the average value of such microscopic features will remain fairly constant. This would mean that deviation from the average are too small to be observed at the macroscopic level. Lastly, it does not matter how the system reached equilibrium as once it reaches that point, many aspects regarding the history of the system are wiped.

1. Mathematic Transforms
   1. Total Derivative
   2. Inverse Relation Among Partial Derivatives
   3. Ratio Relation for Partials
   4. Relation for Partials with Three Variables

* 1. Chain Rule
  2. Exact Equation Criteria
  3. Legendre Transformations
  4. Stirling’s Approximation
  5. Other Approximations

1. Relevant Examples