**INTRODUCTION**

The word Thermodynamics combines the Greek word therme (heat) and Dynamics (power) for the field involves “heat “and “work “interactions. Thermodynamics is an axiomatic science concerned with the transformation of energy from one form to another. However, energy and matter are closely related, in as much as the transfer of energy results in a change of the state of matter.

Thermodynamics may be defined as follows:

* Thermodynamics is an axiomatic science which deals with the relations among heat, work and properties of the system which are in equilibrium. It describes state and changes in the state of physical systems.

Or

* Thermodynamics is the science of the regularities governing processes of energy conversion.

Or

* Thermodynamics is the science that deals with the interaction between energy and material systems.

Thermodynamics entails four laws or axioms known as Zeroth, First, Second and Third law of thermodynamics.

* The Zeroth law deals with thermal equilibrium and establishes a concept of temperature.
* The First law throws light on the concept of internal energy.
* The Second law indicates the limit of converting heat into work and introduces the principle of increase of entropy.
* The Third law defines the absolute zero of entropy.

1. **BASIC CONCEPTS AND DEFINITIONS**

To deal with the subject of Thermodynamics rigorously it is necessary to define the concepts used.

**1.** **SYSTEM**: is defined as a quantity of matter or a region in space chosen for the study. The mass or region outside the system is called the surroundings. The real or imaginary surface that separates the system from its surroundings is called the boundary. There are many types of systems such as:

**a. OPEN SYSTEM**: is one in which matter flows into or out of the system. Most of the engineering systems are open.

**b. ISOLATED SYSTEM**: is that system that exchanges neither energy nor matter with any other system or with the environment.

**c. ADIABATIC SYSTEM**: is one which is thermally insulated from its surroundings. It can, however, exchange work with its surroundings. If it does not, it becomes an isolated system.

**d.** **HOMOGENEOUS SYSTEM**: a system that consists of a single-phase is termed as a homogeneous system.

**e.** **HETEROGENEOUS SYSTEM**: a system that consists of two or more phases is called a heterogeneous system. Examples: Water plus steam, ice plus water and water plus oil.

**2. PHASE**: is a quantity of matter which is homogeneous throughout in chemical composition and physical structure.

**3. THERMAL EQUILIBRIUM**: a system is in thermodynamic equilibrium if the temperature and pressure at all points are the same; there should be no velocity gradient; the chemical equilibrium is also necessary.

**4. PURE SUBSTANCE**: is one that has a homogeneous and invariable chemical composition even though there is a change of phase. In other words, it is a system that is (a) homogeneous in composition, (b) homogeneous in chemical aggregation. Examples: liquid, water, a mixture of liquid water and steam, a mixture of ice and water. The mixture of liquid air and gaseous air is not a pure substance.

**5. STATE**: is the condition of the system at an instant of time as described or measured by its properties. Or each unique condition of a system is called a state. The thermodynamic state of a system is defined completely by the knowledge of two independent and intensive properties such as (pressure, specific volume, temperature).

**6. PROCESS**: The process occurs when the system changes a state or an energy transfer at a steady state. There are two types of processes in thermodynamics:

**a. NON-FLOW PROCESS**: a fixed mass of fluid changes state with no mass transfer across the boundaries.

**b. FLOW PROCESS**: a uniform mass flow rate from one state to another where the mass must cross the control surface (boundary) at inlet and exit.

**7. CYCLE**: any process or series of processes whose end states are identical is termed a cycle.

**2. UNITS**

Units are specified magnitudes of dimensions that are used for measurement purposes. The following table contains some important dimensions in thermodynamics as well as their units in different systems:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantity** | **symbol** | **SI Units** | **English Units** | **To Convert from English to SI Units Multiply by** |
| Lenth | L | m (meter) | ft | 0.3048 |
| Mass | m | kg (Kilogram) | Ibm (buond mass) | 0.4536 |
| Time | t | s (Second) | sec | - |
| Area | A | m2 | ft2 | 0.0929 |
| Volume | V | m3 | ft3 | 0.02832 |
| Velocity | v | m/s | ft/sec | 0.3048 |
| Temperature | T | °C (Centigrade) | °F (Fahrenheit) |  |
| Force | F | N (Newton) | Ibf (Pound force) ) | 4448 |
| Energy | E | J (Joule) | ft.Ibf (Foot-pound force) | 1.356 |
| Heat transfer | Q | J (Joule) | Btu | 1055 |
| Pressure | P | Pa (Pascal) | Psi (Pound-force per square inch) | 145.05×10-6 |

When expressing a quantity in SI units certain letter prefixes may be used to represent multiplication by a power of 10, see table below:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Prefix** | **Factor** | **Symbol** | **Prefix** | **Factor** | **Symbol** |
| deca | 10 | da | deci | 10-1 | d |
| hecto | 102 | h | centi | 10-2 | c |
| kilo | 103 | k | milli | 10-3 | m |
| mega | 106 | M | micro | 10-6 | μ |
| giga | 109 | G | nano | 10-9 | n |
| tera | 1012 | T | pico | 10-12 | p |
| peta | 1015 | P | femto | 10-15 | f |
| exa | 1018 | E | atto | 10-18 | a |

**3. THERMODYNAMIC PROPERTIES**

A property of a system is a characteristic of the system which depends upon its state, but not upon how the state is reached. There are two general types of properties:

**1. INTENSIVE PROPERTY**: These properties do not depend on the mass (size or the amount of material) of the system it is a physical property of a system. of intensive properties include (Temperature and pressure).

**2. EXTENSIVE PROPERTY**: These properties depend on the mass of the system. Examples of extensive properties include (volume, internal energy, enthalpy and entropy). Extensive properties have two values (Total and Specific), total values have the usual units of that property while specific values have the same units divided by the units of mass. Extensive properties are often divided by mass associated with them to obtain the intensive properties.

For example, if the volume of a system of mass m (kg) is V (m3), then the specific volume of matter within the system is (ʋ (m3/ kg) which is an intensive property. The following properties are some of the most important thermodynamic properties:

1. **TEMPERATURE (T):** is a thermal state of a body which distinguishes a hot body from a cold body. The temperature of a body is proportional to the stored molecular energy i.e., the average molecular kinetic energy of the molecules in a system. (A particular molecule does not have a temperature, it has energy. The gas as a system has temperature).Instruments for measuring ordinary temperatures are known as thermometers and those for measuring high temperatures are known as pyrometers. A number of temperature measuring scales came up from time to time. Different temperature scales have different names based on the names of persons who originated them and have different numerical values assigned to the reference states.
2. **CELSIUS SCALE OR CENTIGRADE SCALE**: Anders Celsius gave this Celsius or Centigrade scale using ice point of (0 °C) as the lower fixed point and steam point of (100 ºC) as upper fixed point for developing the scale. It is denoted by the letter (C). Ice point refers to the temperature at which freezing of water takes place at standard atmospheric pressure. Steam point refers to the temperature of water at which its vaporization takes place at standard atmospheric pressure. The interval between the two fixed points was equally divided into 100 equal parts and each part represented (1ºC).
3. **FAHRENHEIT SCALE**: Daniel Gabriel Fahrenheit gave another temperature scale known as Fahrenheit scale and has the lower fixed point as (32 ºF) and the upper fixed point as (212ºF). The interval between these two is equally divided into 180 parts. It is denoted by the letter F. Each part represents (1ºF). Fahrenheit Scale is related to Celsius scale as follows:
4. **KELVIN SCALE**: Kelvin scale proposed by Lord Kelvin is very commonly used in thermodynamic analysis. It also defines the absolute zero temperature. Zero degree Kelvin or absolute zero temperature is taken as (-273 ºC). It is denoted by the letter K. It is related to Celsius scale as given below:
5. **RANKINE SCALE**: it was developed by William John Macquorn Rankine, a Scottish engineer. It is denoted by the letter R. It is related to Fahrenheit scale as given below:
6. **PRESSURE:** it is the effect of a normal force acting on an area. If a force acts at an angle to an area, only the normal component enters into the definition of pressure. The fundamental SI unit of pressure is (N/m2), which is called a Pascal (Pa) or bar.

1bar = 105 N/m2 = 105 Pa.

1 atm =101325 Pa= 1.01325 bar = 0.76 m (or 760 mm) Hg.

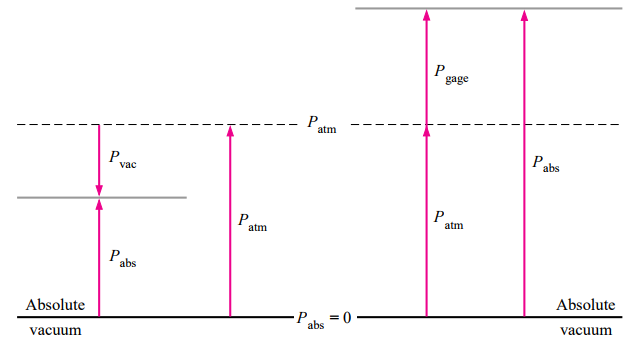
The pressure unit Pascal is too small for pressures encountered in practice. Therefore, its multiples kilo Pascal (1 kPa = 103 Pa) and mega Pascal (1 MPa = 106 Pa) are commonly used. Three other pressure units commonly used in practice which are: bar, standard atmosphere (atm) and pound-force per square inch (psi). The relationships between these units are:

1 atm = 101325 Pa = 14.696 psi

Most pressure measuring instrument measure the difference between the pressure of a fluid and the pressure of the atmosphere. This pressure difference is called a gauge pressure. In most thermodynamic relations absolute pressure must be used. Absolute pressure is gage pressure plus the local atmospheric pressure:

The word “gage” is generally used in statements of gage pressure; e.g., (P = 200 kPa) gage. If “gage” is not present, the pressure will, in general, be an absolute pressure. Atmospheric pressure is an absolute pressure, and will be taken as (100 kPa) (at sea level), unless otherwise stated. A negative gage pressure is often called a vacuum pressure , and gages capable of reading negative pressures are vacuum gages , which indicates the magnitude of the difference between the atmospheric and absolute pressure so that:

Figure (1) shows the relationships between absolute and gauge pressure,



**Figure (1) Absolute, gage, and vacuum pressures.**

**Example (1):** A vacuum gage connected to a chamber reads (5.8 psi) at a location where the atmospheric pressure is (14.5 psi). Determine the absolute pressure in the chamber.

**Solution:**

1. **VOLUME (V):** is the quantity of three-dimensional space enclosed by a closed surface, for example: the space that a substance (solid, liquid, gas or plasma) occupies or contains. Volume is an independent property.
2. **INTERNAL ENERGY (U):** is a property consisting of the combined molecular kinetic and potential energies. This property is derived from the first law of thermodynamics. Internal energy is a dependent property.
3. **ENTHALPY (H):** is a thermodynamic quantity equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume. Enthalpy is a dependent property.
4. **ENTROPY (S):** is a thermodynamic quantity representing the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of disorder or randomness in the system. This property is derived from the second law of thermodynamics. Entropy is a dependent property.

**4. ZEROTH LAW OF THERMODYNAMICS**

Zeroth law of thermodynamics’ states that if two systems are each equal in temperature to a third, they are equal in temperature to each other.

For example we have three systems, System ‘1’ may consist of a mass of gas enclosed in a rigid vessel fitted with a pressure gauge. If there is no change of pressure when this system is brought into contact with system ‘2’ a block of iron, then the two systems are equal in temperature (assuming that the systems 1 and 2 do not react each other chemically or electrically). Experiment reveals that if system ‘1’ is brought into contact with a third system ‘3’ again with no change of properties then systems ‘2’ and ‘3’ will show no change in their properties when brought into contact provided they do not react with each other chemically or electrically. Therefore, ‘2’ and ‘3’ must be in equilibrium. This law was enunciated by R.H. Fowler in the year 1931. However, since the first and second laws already existed at that time, it was designated as zeroth law so that it precedes the first and second laws to form a logical sequence.

**5. ENERGY, WORK, HEAT AND POWER**

**5.1 ENERGY**

Energy is defined as the ability to do work. It comes in different forms, heat (thermal), light (radiant), mechanical, electrical, chemical, and nuclear energy. All these energy we need to live our busy lives. Energy is a general term include energy in transition and stored energy. The stored energy of a substance may be in the forms of mechanical energy and internal energy (other forms of stored energy may be chemical energy and electrical energy). The unit of energy is Joule (J). There are three types of energy:

1. **POTENTIAL ENERGY (P.E):** It is the energy stored in a system (mass) as a result of its location in a gravitational field, and its magnitude is given by:

where: m is the mass (kg).

g: is the gravitational acceleration (m/s2).

Z: is the elevation (m).

**Forms of Potential Energy are:**

1. **CHEMICAL ENERGY:** is the energy stored in food, wood, coal, petroleum, and other fuels.
2. **MECHANICAL ENERGY:** is the energy possessed by an object due to its stored energy of position .Rubber bands and springs are good examples.
3. **NUCLEAR ENERGY:** is the energy locked in the nucleus of the atom. Nuclear power plants split atoms in process called fission.
4. **GRAVITATIONAL ENERGY:** is the energy stored as a result of gravitational forces concentrated by the earth for the object. Water held back by a dam is an example.
5. **KINETIC ENERGY:** it is the energy that a system possesses as a result of its motion relative to some reference frame. It is denoted (K.E) and is expressed as:

where: m is the mass (kg).

V: is the velocity (m/s).

**Forms of Kinetic energy are:**

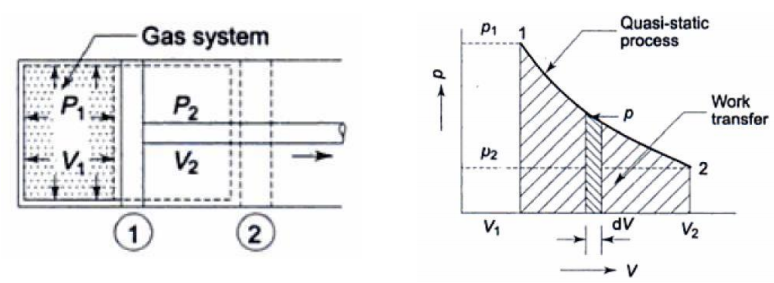
1. **ELECTRICITY**: is the energy produced when something upsets the balancing force between electrons and protons in atoms.
2. **LIGHT OR RADIANT ENERGY**: waves that omit energy. Examples include, radio and television waves .Gamma rays and x-rays.
3. **HEAT OR THERMAL ENERGY:** is the energy created by heat.
4. **MOVEMENT:** as the power of potential energy uncoils, it transforms the energy source into kinetic energy.
5. **INTERNAL ENERGY**: it is the sum of all energy associated with molecules which may have translational, vibrational and rotational motions etc., and respective energies causing these motions. It is denoted (U).

The total energy of a system is denoted (E) in (J) and it is the sum of all forms of energy within the system:

The total energy of a system on a unit mass basis is denoted by (e) in (J/Kg) and is expressed as:

**5.2 WORK**

Work is defined as the product of a force and the distance moved in the direction of the force and is denoted by (W). Consider a simple closed system as a gas trapped between a piston and cylinder, as shown in the Figure (2), the system having initially the pressure (P1) and volume (𝑉1). The system is in thermodynamic equilibrium, the state of which is described by the coordinates (P1) and (𝑉1). The piston is the only boundary which moves due to the gas pressure. Let the piston move out to a new final position (2), which is also a thermodynamic equilibrium state specified by pressure (P2) and volume (𝑉2). At any intermediate point in the travel of the piston, let the pressure be (𝑃) and the volume be (𝑉). This must also be an equilibrium state, since macroscopic properties (𝑃) and (𝑉) are significant only for equilibrium states. When the piston moves an infinitesimal distance (𝑑𝑙), and if (𝐴) is the area of the piston, the force acting on the piston (𝐹) and the infinitesimal amount of work done by the gas on the piston:



**Figure (2) Closed System and PV-Diagram.**

where is the force acting on the piston.

𝑑𝑉 = 𝐴. 𝑑𝑙 is the infinitesimal displacement volume.

When the piston moves out from position (1) to position (2) with the volume changing from (𝑉1) to (𝑉2), the amount of work done by the system will be:

The magnitude of the work done is given by the area under the path 1-2, as shown on the (P-V) diagram. It should be noted that when work is done by the system, it will have a positive sign, and when work is done on the system, it will have a negative sign, (i.e. 𝑊 out is positive and 𝑊 in is negative).

**5.3 HEAT**

Heat is the energy transferred without transfer of mass across the boundary of the system due to the difference in temperature between the system and its surroundings. It is denoted (𝑄). If there is no temperature difference there is no heat transfer, thus heat is not a property. The unit of heat is Joule (J = N.m).

For one kilogram of the substance is the specific heat and denoted (𝑞):

**5.4 POWER**

Power is the time rate of energy transfer by work, or work done per unit time, and is denoted by .

**6. SPECIFIC HEAT CAPACITY**

The specific heat capacity of a substance is defined as the amount of heat which transfers into or out of a unit mass of the substance, while the temperature of the substance changes by one degree. Thus if:

𝐶: Specific heat capacity of the substance.

𝑚: Mass of the substance.

𝑄: Heat transfer.

𝑇1: Initial temperature.

𝑇2: Final temperature.

Then:

Specific heat capacity may vary with temperature. It should also be noted that when heat is transferred to the system, it will have a positive sign, and when it is transferred from the system, it will have a negative sign, (i.e. 𝑄 gained is positive and 𝑄 rejected is negative).

**Example (2):** An unknown metal weighing (0.9 kg) at an initial temperature of (140 °C) is placed into an insulated container holding (3 kg) of water at an initial temperature of (60 °C). After thermal equilibrium the water rose to (65 °C). Knowing that (*C*water = 4186 J/kg.°C), what is the specific heat capacity of the metal?

**Solution**:

The amount of heat lost by the metal equals the amount of heat gained by the water, thus:

**Example (3):** A (10 g) iron bar at (80 °C) is dropped into (70 g) of water at (25 °C). Knowing that (*C*water = 4.186 J/g.°C) and (*C*iron = 0.47 J/g.°C), what is the final temperature after thermal equilibrium?

**Solution:**

The amount of heat lost by the iron bar equals the amount of heat gained by the water, thus:

**7. ENTHALPY**

Enthalpy is a property of a substance and a form of energy. It is denoted (H) and is equal to the combined internal energy and flow energy:

where

U: is the internal energy.

PV is the flow energy.

Like internal energy, enthalpy is an extensive property and can have a specific value:

Enthalpy is equivalent to the total heat content of a system and it is a dependent property.

**8. THE IDEAL-GAS EQUATION OF STATE**

A gas is made of molecules that move around with random motion. In a perfect gas, the molecules may collide but they have no tendency to stick together or repel each other. In reality, there is a slight force of attraction between gas molecules but this is so small that gas laws formulated for an ideal gas work quite well for a real gas.

Any equation that relates the pressure, temperature, and specific volume of a substance is called an equation of state. Property relations that involve other properties of a substance at equilibrium states are also referred to as equations of state. There are several equations of state, some simple and others very complex. The simplest and best-known equation of state for substances in the gas phase is the ideal-gas equation of state. This equation predicts the (P-υ-T) behavior of a gas quite accurately within some properly selected region.

Gas and vapor are often used as synonymous words. The vapor phase of a substance is customarily called a gas when it is above the critical temperature. Vapor usually implies a gas that is not far from a state of condensation. In 1662, Robert Boyle, an Englishman, observed during his experiments with a vacuum chamber that the pressure of gases is inversely proportional to their volume. In 1802, J. Charles and J. Gay-Lussac, Frenchmen, experimentally determined that at low pressures the volume of a gas is proportional to its temperature. That is,

where

R: is called the gas constant and it is different for each gas. Table (1) shows the values of the gas constant for different gases.

P: is the absolute pressure.

T: is the absolute temperature (K).

V: is the volume (m3)

υ: is the specific volume (m3/kg).

Equations (18 and 19) is called the ideal-gas equation of state, or simply the ideal-gas relation, and a gas that obeys this relation is called an ideal gas.

where : is the universal gas constant.

M: is the molar mass (also called molecular weight) of the gas.

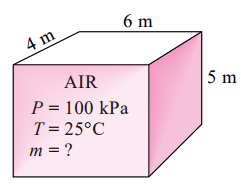
The constant is the same for all substances, and its value is

**Boyle’s law** states that the pressure of a given mass of an ideal gas is inversely proportional to its volume at a constant temperature. It is expressed as:

**Charles’s law** states that the volume of an ideal gas at constant pressure is directly proportional to the absolute temperature. It is expressed as:

**Gay-Lussac’s law** states that, for a given mass and constant volume of an ideal gas, the pressure exerted on the sides of its container is directly proportional to its absolute temperature. It is expressed as:

**Example (4):** Determine the mass of the air in a room whose dimensions are (4 m ×5 m × 6 m) at (100 kPa) and (25 °C).

**Solution:**

From Table (1), the gas constant of air is

**Example (5):** An amount of gas has a pressure of (350 kPa), a volume of (0.03 m3) and a temperature of (35 °C). If (R = 0.29 kJ/kg.K), calculate the mass of the gas and the final temperature if the final pressure is (1.05 MPa) and the volume remains constant.

**Solution:**

The absolute temperature:

Applying the equation of state between two conditions at constant volume:

**Example (6):** A tank has a volume of (0.5 m3) and contains (10 kg) of an ideal gas having a molecular weight of (24). The temperature is (25 °C). What is the pressure of the gas?

**Solution:**

The absolute temperature:

**Home Work (1):**

1. A container of (0.2 m3) contains nitrogen at a pressure of (1.013 bar) and at a temperature of (15 °C). (2 kg) of nitrogen was pumped by a special pump to the tank. Calculate the new gas pressure when the tank returns to its initial temperature. Nitrogen was considered an ideal gas, take R = 296.9 J / kg. K.

Ans. (1.87 bar)

1. Air in an internal combustion engine has (227°C), (1000 kPa) with a volume of (0.1 m3). Now combustion heats it to (1500 K) in a constant volume process. What is the mass of air and how high does the pressure become?

Ans. (0.697 kg, 3000 kPa)

1. A rigid tank of 1 m3 contains nitrogen gas (molecular weight 28) at 600 kPa, 400 K. By mistake someone lets 0.5 kg flow out. If the final temperature is 375 K what is the final pressure?

Ans. (506.9 kPa)

1. A (1 m3) rigid tank contains propane (molecular weight 44) at (100 kPa), (300 K) and connected by a valve to another tank of (0.5 m3) with propane at (250 kPa), (400 K). The valve is opened and the two tanks come to a uniform state at (325 K). What is the final pressure?

Ans. (139.9 kPa)

1. (0.1) kg of ideal gas occupies a volume of (0.003 m3) at a pressure of (7 bar) and a temperature (131 °C) when the gas was expand to a pressure of (1 bar), its final volume became (0.02 m3). Calculate the final temperature.

Ans. (384.6 K)

1. Air is at (25 º C) and (101.325 kPa). If the gas constant (R = 287 J / kg. k), find the specific volume and the molar mass of this gas, assuming it behaves as an ideal gas.

Ans. (0.8445 m3/kg, 28.97 kg/kmol)

Table (1) Ideal-gas specific heats of various common gases at (300 K)

