# Introduction and Basic Concepts

Thermodynamics can be defined as the science of *energy*. The name *thermodynamics* stems from the Greek words *thermo* (heat) and *dynamic* (power), which is most descriptive of the early efforts to convert heat into power. Today the same name is broadly interpreted to include all aspects of energy and energy transformations, including power generation, refrigeration, and relationships among the properties of matter.

**Important Definitions**

These are some terms that need to be introduced before we can understand the basics of thermodynamics:

1. **System**: is defined as a quantity of matter or a region in space chosen for 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.
2. **Working substance**: is the matter contained within the boundaries of a system. All the thermodynamics systems require some working substance in order to perform various operations.
3. **Phase**: when a substance is in the same nature through its mass, then it is said to be in phase.
4. **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).
5. **Process**: when the state of substance is changed by means of an operation carried out on the substance, then the substance is said to be undergone a process.
6. **Cycle**: if processes are carried out on a working substance so that, at the end, the substance is returned to its original state, then the substance is said to have been taken through a cycle.

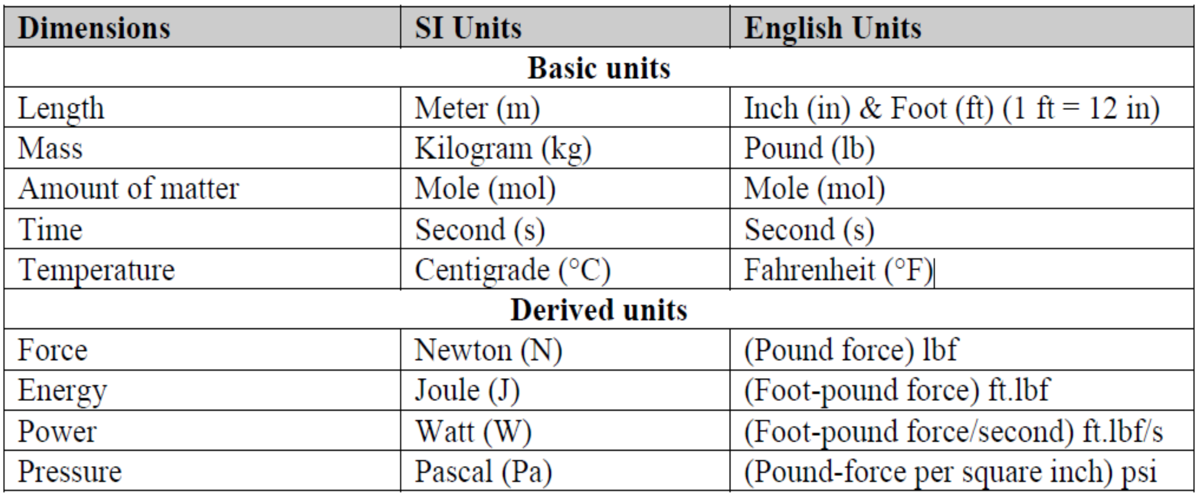
## IMPORTANCE OF DIMENSIONS AND UNITS

Any physical quantity can be characterized by **dimensions.** The magnitudes assigned to the dimensions are called **units.** Some basic dimensions such as mass $m$, length $L$, time $t$, and temperature $T$ are selected as **primary** or **fundamental dimensions,** while others such as velocity $V$, energy $E$, and volume $V$ are expressed in terms of the primary dimensions and are called **secondary dimensions,** or **derived dimensions.**

Two sets of units are still in common use today: the **English system,** which is also known as the *United States Customary System* (USCS), and the metric **SI** (from *Le Système International d'Unités*), which is also known as the *International System.* The SI is a simple and logical system based on a decimal relationship between the various units, and it is being used for scientific and engineering work.

The fundamental (or primary) dimensions and their units in SI are illustrated in the following table (1).

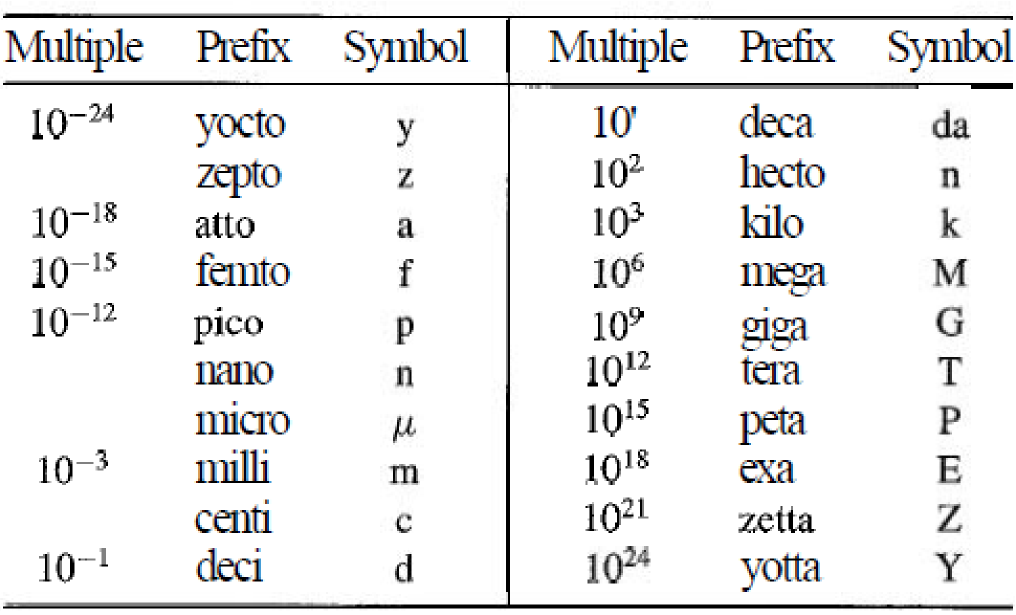
Table (1): The fundamental (or primary) dimensions and their units in SI and English unit



| **Dimensions** | **SI Units** | **English Units** |
|---|---|---|
| | **Basic units** | |
| Length | Meter (m) | Inch (in) & Foot (ft) (1 ft = 12 in) |
| Mass | Kilogram (kg) | Pound (lb) |
| Amount of matter | Mole (mol) | Mole (mol) |
| Time | Second (s) | Second (s) |
| Temperature | Centigrade (°C) | Fahrenheit (°F) |
| | **Derived units** | |
| Force | Newton (N) | (Pound force) lbf |
| Energy | Joule (J) | (Foot-pound force) ft.lbf |
| Power | Watt (W) | (Foot-pound force/second) ft.lbf/s |
| Pressure | Pascal (Pa) | (Pound-force per square inch) psi |

The prefixes used to express the multiples of the various units are listed in Table 2.

Table (2): Standard prefixes in SI units.



| Multiple | Prefix | Symbol | Multiple | Prefix | Symbol |
|---|---|---|---|---|---|
| $10^{-24}$ | yocto | y | $10^1$ | deca | da |
|  | zepto | z | $10^2$ | hecto | n |
| $10^{-18}$ | atto | a | $10^3$ | kilo | k |
| $10^{-15}$ | femto | f | $10^6$ | mega | M |
| $10^{-12}$ | pico | p | $10^9$ | giga | G |
|  | nano | n | $10^{12}$ | tera | T |
|  | micro | $\mu$ | $10^{15}$ | peta | P |
| $10^{-3}$ | milli | m | $10^{18}$ | exa | E |
|  | centi | c | $10^{21}$ | zetta | Z |
| $10^{-1}$ | deci | d | $10^{24}$ | yotta | Y |

## Thermodynamic Properties

For defining any system certain parameters are needed. Properties are those observable characteristics of the system which can be used for defining it. Thermodynamic properties are observable characteristics of the thermodynamic system. Pressure, temperature, volume, viscosity, etc. are examples of properties. These properties are sometimes observable directly **independent properties** and sometimes indirectly **dependent properties**. Properties can be further classified as **intensive properties** and **extensive properties**. The following are some of the most important thermodynamic properties:

**1. Temperature (*T*):** is a physical quantity expressing hot and cold. It is a proportional measure of the average kinetic energy of the random motions of the constituent particles of matter (such as atoms and molecules) in a system.

**2. Pressure (*P*):** is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Pressure is an independent property.

**3. 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.

**4. 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.

**5. 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.

**6. 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.

## Musuring Of Temperature

Temperature is commonly measured with liquid-in-glass thermometers, wherein the liquid expands when heated. Thus a uniform tube, partially filled with mercury, alcohol, or some other fluid, can indicate degree of "hotness" simply by the length of the fluid column. However, numerical values are assigned to the various degrees of hotness by arbitrary definition.

**Kelvin temperatures**

$$t^{\circ}C = T\,K - 273.15$$

**Fahrenheit tempreture**

$$\boldsymbol{t}(^{\circ}\mathrm{F}) = 1.8\,t^{\circ}C + 32$$

## PRESSURE

The pressure P exerted by a fluid on a surface is defined as the normal force exerted by the fluid per unit area of the surface. If force is measured in N and area in $m^2$, the unit is the newton per square meter or N $m^{-2}$, called the pascal, symbol Pa, the basic SI unit of pressure.

The primary standard for pressure measurement is the dead-weight gauge in which a known force is balanced by a fluid pressure acting on a known area; whence P = F/A. A simple design is shown in Fig. 1 The piston is carefully fitted to the cylinder making the clearance small. Weights are placed on the pan until the pressure of the oil, which tends to make the piston rise, is just balanced by the force of gravity on the piston and all that it supports. With this force given by Newton's law, the pressure of the oil is:

$$P = \frac{F}{A} = \frac{mg}{A}$$

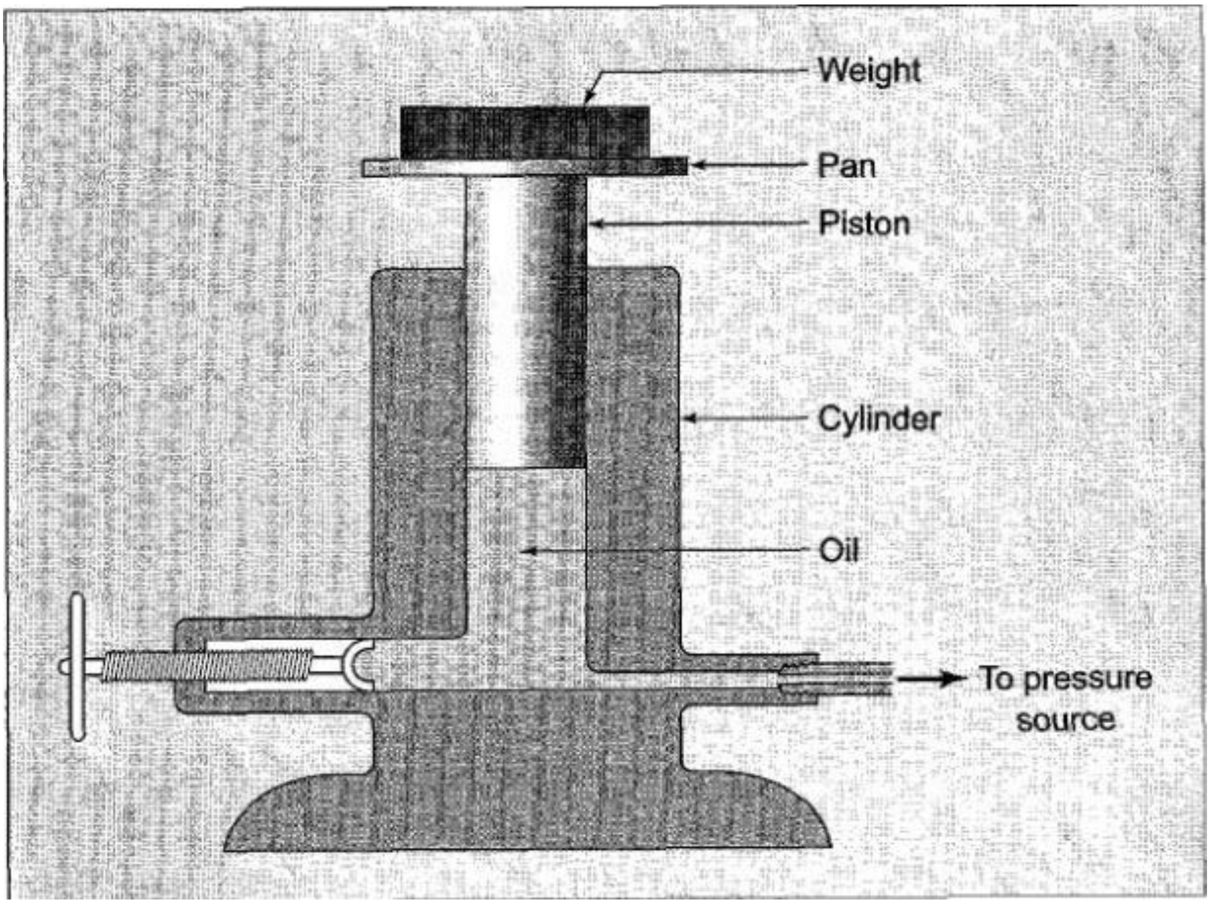


**Figure 1** Dead-weight gauge

where $m$ is the mass of the piston, pan, and weights; g is the local acceleration of gravity; and $A$ is the cross-sectional area of the piston. Gauges in common use, such as Bourdon gauges, are calibrated by comparison with dead-weight gauges. Since a vertical column of a given fluid under the influence of gravity exerts a pressure at its base in direct proportion to its height, pressure is also expressed as the equivalent height of a fluid column. This is the basis for the use of manometers for pressure measurement. Conversion of height to force per unit area follows from Newton's law applied to the force of gravity acting on the mass of fluid in the column. The mass is given by:

$$m = Ahp$$

where $A$ is the cross-sectional area of the column, $h$ is its height, and $p$ is the fluid density. Therefore,

$$P = \frac{F}{A} = \frac{mg}{A} = \frac{Ah\rho g}{A} = h\rho g$$

The pressure to which a fluid height corresponds is determined by the density of the fluid (which depends on its identity and temperature) and the local acceleration of gravity. Thus the (torr) is the pressure equivalent of 1 millimeter of mercury at 273.15 K (0°C) in a standard gravitational field, and is equal to 133.322 Pa.

Another unit of pressure is the standard atmosphere (atm), the approximate average pressure exerted by the earth's atmosphere at sea level, defined as 101 325 Pa, 101.325 kPa, or 0.101 325 MPa. The bar, an SI unit defined as $10^5$ Pa, is equal to 0.986 923 atm.

Most pressure gauges give readings which are the difference between the pressure of interest and the pressure of the surrounding atmosphere. These readings are known as *gauge* pressures, and can be converted to *absolute* pressures by addition of the barometric pressure. Absolute pressures must be used in thermodynamic calculations.

## Example 1

A dead-wieght gauge with a 1cm piston is used to measure pressures very accurately. In a particular instance a mass of 6.14 Kg (including piston and pan) brings it into balance. If the local acceleration of gravity is 9.82 m. s$^{-2}$, what is the gauge pressure being measured. If the barometric pressure is 748 (torr), what is the absolute pressure.

## Solution

$$Gauge\ pressure\ = \frac{F}{A}$$

$$F = mg$$

$$= 6.14 \times 9.82 = 60.295\ N$$

$$Gauge\ Prss. = \frac{60.295}{1/4 \times \pi \times (0.01)^2} = 76.81 \times 10^4 \frac{N}{m^2} (Pa)$$

Absolute Pressure

$$P_{abs} = (76.81) \times 10^4 + (748)(0.013332) \times 10^4$$

$$= 86.78 \times 10^4 \frac{N}{m^2} = 867.8 \times 10^3\ Pa$$

$$= 867.8\ kPa$$

**Example 2**

Pressures up to 3000 bar are measured with a dead-weight gauge. The piston diameter is 4 mm. What is the approximate mass in kg of the weights required?

**Solution**

$$P = \frac{F}{A} \rightarrow F = PA$$

$$A = \frac{1}{4} \times \pi \times (D)^2$$

$$= \frac{1}{4} \times \pi \times (0.04)^2$$

$$A = 12.566 \times 10^{-6}\, m^2$$

$$F = 3000 \times 10^5 \times 12.566 \times 10^{-6}$$

$$= 3769.8\, kg.\frac{m}{s^2}\ (N)$$

$$F = mg \rightarrow m = \frac{F}{g}$$

$$m = \frac{3769.8}{9.82} = 383.89\, Kg$$

## Home work

The reading on a mercury manometer at 298.15 K (25°C) (open to the atmosphere at one end) is 56.38 cm. The local acceleration of gravity is 9.832 m $s^{-2}$. Atmospheric pressure is 101.78 kPa. What is the absolute pressure in kPa being measured? The density of mercury at 298.15 K (25°C) is 13.534 g $cm^{-3}$.