1.6 Properties of a System

Any characteristic of a system is called a property. Some familiar properties are pressure ***P***, temperature ***T***, volume ***V***, and mass ***m***. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation.

Thermodynamic properties can be divided into two general classes, **intensive** and **extensive** properties. Thus, if a quantity of matter in a given state is divided into two equal parts, each part will have the same value of intensive properties as the original, and half the value of the extensive properties.

- **Intensive property.**

  properties which are independent upon mass such as, Pressure, temperature, density……

- **Extensive properties**

  properties which are dependent upon mass such as, volume and energy into various forms. Extensive properties per unit mass such as specific volume are intensive properties.

1.7 Specific Volume and Density:

The specific volume of a substance is defined as the volume per unit mass and is given the symbol **υ.** The density of a substance is defined as the mass per unit volume, and is therefore the reciprocal of the specific volume. Density is designated by the symbol **ρ**. Specific volume and density are intensive properties.

$$v = \frac{V}{m} = \frac{1}{\rho}$$

where ***m*** is the mass in (kg), and ***V*** is the volume in (m^3). So the units of **υ=[m³/kg]** and for **ρ=[kg/m³].**

In certain applications it is convenient to express properties such as a specific volume on a molar basis rather than on a mass basis. The amount of a substance can be given on a **molar basis** in terms of the kilomole (kmol) or the pound mole (lbmol), as appropriate. In either case we use

$$n = \frac{m}{M}$$

The number of kilomoles of a substance, n, is obtained by dividing the mass, ***m***, in kilograms by the molecular weight, ***M***, in kg/kmol. Appendix Table A-1 provides molecular weights for several substances.

If the mass is measured by molecular weight so the specific volume can be designated by the symbol $\bar{v}$ and its unit becomes [m^3/kmol] or [m^3/mol]. And the density also becomes $\bar{\rho}$, and its unit becomes [kmol/m^3] or [mol/m^3].

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called **specific gravity**, or **relative density**, and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which ρ_{H2O}=1000 kg/m^3). That is,

$$SG = \frac{\rho}{\rho_{H_2O}}$$

Table 3 . Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3- 0.9
Gold	19.2
Bones	1.7- 2.0
Ice	0.92
Air (at 1 atm)	0.0013

1.8 Temperature and the Zeroth Law of Thermodynamics

- Equality of Temperature:

Two bodies have equality of temperature when no change in any observation property occurs when they are in thermal communication.

- Zeroth Law of Thermodynamics:

When two bodies have equality of temperature with a third body, they are in turn have equality of temperature with each other.

1.8.1. Temperature Scale:

Celcsius scale symbol ^oC or called Centigrade. The Celsius scale was based on two fixed, easily duplicated points, the ice point and the steam point, these two points are numbered 0^{o}C and 100^{o}C on the Celsius scale. And absolute scale related to Celsius is referred to as the Kelvin scale and is designated as K.

$$T(K) = T(^oC) + 273.15$$

There is other scale of temperature called Fahrenheit scale has symbol ^{o}F at which the ice point and steam point are numbered 32^{o}F and 212^{o}F.

$$0^o C \rightarrow 32^o F$$

$$100^o C \rightarrow 212^o F$$

$$T(^o F) = 32 + 1.8T(^o C)$$

And the absolute scale related to Fahrenheit scale is referred as the Rankin and designated R

$$T(R) = T(^{o}F) + 460$$

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

1.8.2. Thermodynamic Equilibrium:

Thermodynamics deals with equilibrium states. The word equilibrium implies a state of balance. In an equilibrium state there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

There are many types of equilibrium, and a system is not in thermodynamic equilibrium unless the conditions of all the relevant types of equilibrium are satisfied. For example, a system is in **thermal equilibrium** if the temperature is the same throughout the entire system, as shown in Fig.6. That is, the system involves no temperature differential, which is the driving force for heat flow. **Mechanical equilibrium** is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time. However, the pressure may vary within the system with elevation as a result of gravitational effects. For example, the higher pressure at a bottom layer is balanced by the extra weight it must carry, and, therefore, there is no imbalance of forces. The variation of pressure as a result of gravity in most thermodynamic systems is relatively small and usually disregarded. If a system involves two phases, it is in **phase equilibrium** when the mass of each phase reaches an equilibrium level and stays there. Finally, a system is in **chemical equilibrium** if its chemical composition does not change with time, that is, no chemical reactions occur. A system will not be in equilibrium unless all the relevant equilibrium criteria are satisfied.

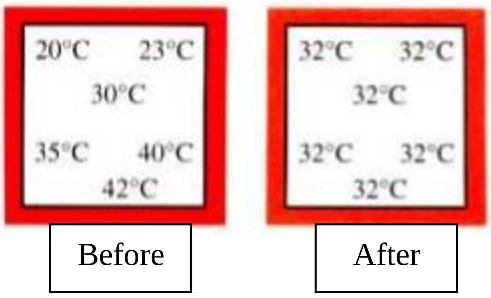


Figure 9. A closed system recharging thermal equilibrium

1.9. Pressure:

It is defined as the normal component of force per unit area. We speak of pressure only when we deal with a gas or a liquid.

$$P = \lim \frac{\delta F_n}{\delta A}$$

The unit of pressure in SI units is N/m^2 which is called the Pascal (Pa).

$$1Pa = 1\,{}^{N}\!/\!{}_{m^2}$$

Two other units continue to be widely used, and should noted here. These are the **bar**, where

$$1bar = 10^5\,Pa = 100\,kPa = 0.1MPa$$

And the standard atmosphere (**atm**), where

$$1atm = 101325\,Pa = 101.325\,kPa = 1.01325\,bar$$

In the English unit system, the pressure unit is pound-force per square inch (lb/in^2or psi), 1atm=14.696psi.

In most thermodynamic investigation we are concerned with absolute pressure. Most pressure and vacuum gage, however, read the difference between the absolute pressure and the atmospheric pressure existing at the gage, and this is referred to as gage pressure. This is shown graphically in Fig. 9.

$$P_{abs} = P_{atm} + P_g$$
$$P_{abs} = P_{atm} - P_{vac}$$

Where P_{abs}= absolute pressure
P_{atm}=atmospheric pressure
P_g= gage pressure
P_{vac}=vacuum pressure

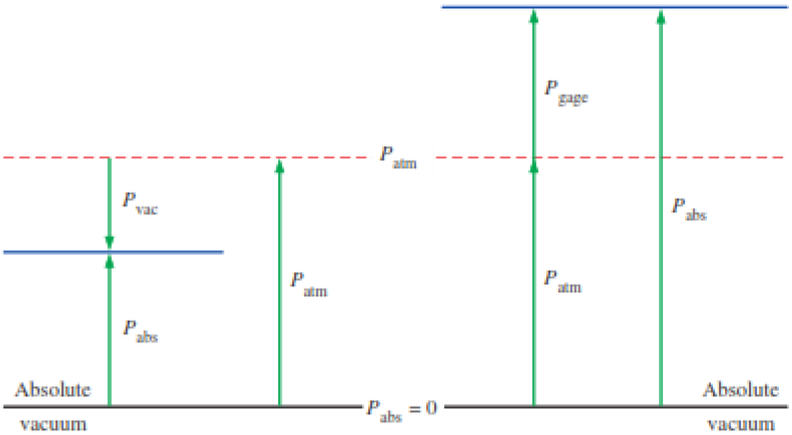


Figure10 . Absolute, gage, and vacuum pressures.

From the principle of hydrostatics one concludes that a difference in level of h meters, the pressure difference in Pascals is calculated by the relation.

$$\Delta P = \rho g h$$

where ρ is the fluid density and $g=9.81m/s^2$.

If we take point 1 to be at the free surface of a liquid open to the atmosphere (Fig. 10), where the pressure is the atmospheric pressure P_{atm}, then the pressure at a depth ***h*** from the free surface becomes Liquids are essentially incompressible substances, and thus the variation of density with depth is negligible.

$$P = P_{atm} + P_g \qquad , \qquad P_g = \rho g h$$

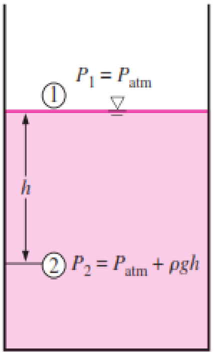


Figure11 . Pressure in a liquid at rest increases linearly with distance from the free surface.

When the variation of density with elevation is known, the pressure difference between points 1 and 2 can be determined by integration to be

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g dz$$

Pressure in a fluid at rest is independent of the shape or cross section of the container. It changes with the vertical distance, but remains constant in other directions. Therefore, the pressure is the same at all points on a horizontal plane in a given fluid.

Many techniques have been developed for the measurement of pressure and vacuum. Instruments used to measure and display pressure in an integral unit are called pressure gauges or vacuum gauges.

1.9.1. The Barometer

Atmospheric pressure is measured by a device called a barometer; thus, the atmospheric pressure is often referred to as the barometric pressure.

The Italian Evangelista Torricelli (1608–1647) was the first to conclusively prove that the atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere, as shown in Figure below. The pressure at point B is equal to the atmospheric pressure, and the pressure at point C can be taken to be zero since there is only mercury vapor above point C and the pressure is very low relative to P_{atm} and can be neglected to an excellent approximation. Writing a force balance in the vertical direction gives

$$P_{atm} = \rho g h$$

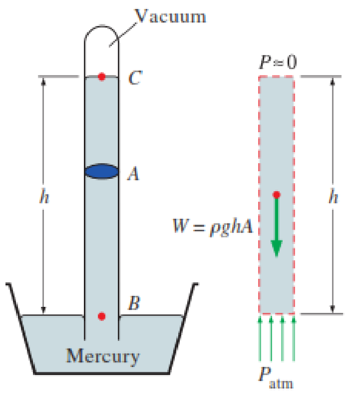


Figure 12. the basic barometer

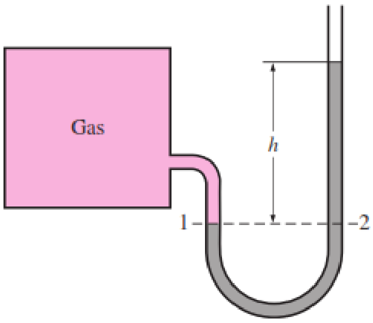
1.9.2. The Manometer

A manometer is a good example as it uses a column of liquid to both measure and indicate pressure Fig. 13a. Likewise, the widely used Bourdon gauge is a mechanical device which both measures and indicates Fig. 13b.

A vacuum gauge is an absolute pressure gauge used to measure the pressures lower than the ambient atmospheric pressure.

Other methods of pressure measurement involve sensors which can transmit the pressure reading to a remote indicator or control system.

(a)



(b)

Figure 13. a) Bourdon pressure gauge,
b) The basic manometer

1.10. Form 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 denoted by **e** and is defined as

$$e = \frac{E}{m} \quad (J/kg) \quad or \quad (kJ/kg)$$

In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups, macroscopic and microscopic. The macroscopic forms of energy, on one hand, are those a system possesses as a whole with respect to some out side reference frame, such as kinetic and potential energies. The microscopic forms of energy, on the other hand, are those related to the molecular structure of a system and the degree of the molecular activity, and they are independed of outside reference frames. The sum of all the microscopic forms of energy is called the **internal energy** of a system and is denoted by **U**.

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

1. **Kinetic Energy:** it is the energy that a system possesses as a result of its motion relative to some reference frame, when all parts of a system move with the same velocity, the kinetic energy is expressed as

$$KE = \frac{1}{2} m C^2 \quad [J]$$

Or, on a unit mass basis,

$$ke = \frac{1}{2} C^2 \qquad [J/kg]$$

And the change in kinetic energy between two states of the system

$$\Delta KE = \frac{1}{2}(m_2 C_2^2 - m_1 C_1^2) \qquad [J]$$

Or
$$\Delta KE = \frac{1}{2000}(m_2 C_2^2 - m_1 C_1^2) \qquad [kJ]$$

And for the same mass m

$$\Delta KE = \frac{1}{2000} m(C_2^2 - C_1^2) \qquad [kJ]$$

Where C denotes the velocity of the system relative to some fixed reference frame.

2. **Potential Energy:** It is the energy that a system possesses as a result of its elevation in a gravitational- field and is expressed as

$$PE = mgZ \qquad [J]$$

Or, on a unit mass basis

$$pe = gZ \qquad [J/kg]$$

and the change in the potential energy is

$$\Delta PE = mg(Z_2 - Z_1) \qquad [J]$$

Or $$\Delta PE = \frac{1}{1000} mg(Z_2 - Z_1) \quad [kJ]$$

The total energy of a system consists of the kinetic, potential, and internal energies and is expressed as

$$E = U + KE + PE \quad \text{kJ}$$

or per unit mass $$e = u + ke + pe \quad \text{kJ/kg}$$

internal energy is defined as the sum of all the microscopic forms of energy of a system. It is related to the molecular structure and the degree of molecular activity, and it may be viewed as the sum of the kinetic energy of the molecular.

Example 1.2

What is the weight of a 1 kg mass at an altitude where the local acceleration of gravity is 9.75 m/s^2?

Solution: given, mass m=1 kg

Acceleration g= 9.75 m/sec^2

weight w= m x g =1kg × 9.75m/sec^2=9.75N

Example 1.3

What is the force required to accelerate a mass of 30kg at a rate of 15m/sec^2?

Solution: given, mass m=30kg

Acceleration a = 15m/sec^2

F= m × a = 30kg × 15m/sec^2 =450N

Example 1.4

5kg plastic tank that has a volume of 0.2m^3 is filled with liquid water. Assuming the density of water is 1000kg/m^3, determine the weight of the combined system.

Solution: given mass of tank m_t=5kg

Volume of the tank V=0.2m^3

Density of water ρ_w=1000kg/m^3

Mass of water $m_w = V_w \times \rho_w$

=0.2m^3 x 1000kg/m^3 =200kg

total mass $m = m_w + m_t$

=200kg+5kg

total weight w= m × g =205kg × 9.81m/sec^2=2011N

Example 1.5

The deep body temperature of a healthy person is 37^{o}C. What is it in Kelvin.

Solution: given t=37^{o}C

T=t+273=310K

Example 1.6

Consider a system whose temperature is 18ºC. Express this temperature in R, K, and ºF.

Solution: given $t=18^{o}C$

$$t(^{o}F)=32+1.8t(^{o}C)$$
$$=32+1.8\times 18=64.4^{o}F$$
$$T(K)=t(^{o}C)+273$$
$$=18+273.15=291.15K$$
$$T(R)=t(^{o}F)+459.67$$
$$=64.4+459.67=524.07R$$

or $$T(R)=1.8T(K)=1.8\times 291.15=524.07R$$

Problems

1.1. A large fraction of the thermal energy generated in the engine of a car is rejected to the air by the radiator through the circulating water. Should the radiator be analyzed as a closed system or as an open system? Explain.

1.2. What is the difference between intensive and extensive properties?

1.3. Is the weight of a system an extensive or intensive property?

1.4. What is the weight, in N, of an object with a mass of 200 kg at a location where g 5 9.6 m/s2?

1.5. Can mass cross the boundary of a closed system? How about energy?

1.6. What is the difference between the macroscopic and microscopic?

1.7. For a system to be in thermodynamic equilibrium, do the temperature and pressure have to be the same everywhere?

1.8. What is the difference between gage pressure and absolute pressure?

1.9. What is the zeroth law of thermodynamic?

1.10. What are the ordinary and absolute temperature scale in the SI and English unit systems?

1.11. A steady force of 5kN acts on a mass of 20kg. What is the acceleration of this mass? (250m/sec^2)

1.12. The “standard “acceleration (at sea level and 45 degree latitude) due to gravity is 9.80665m/sec^2. Calculate the force due to “standard” gravity acting on a mass of 50kg.

1.13. The reading on a pressure gage is 1.75Mpa, and the local barometer reading is 94kPa. Calculate the absolute pressure that is being measured.

1.14. A gas is contained in a vertical cylinder fitted with a piston as shown in Figure below. atmospheric pressure is 1bar, and the piston area is 400mm^2. what is the mass of piston, if the gas pressure inside is 120kPa? Assume standard gravitational acceleration.

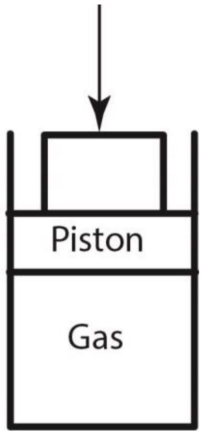


Figure 14. Sketch for Problem 11

1.15. A vacuum gage connected to a tank reads 30kPa at a location where the barometric reading is 755mm Hg. Determine the absolute pressure in the tank. Take ρHg=13590kg/m^3.

1.16. A pressure gage connected to a tank reads 3.15bar at a location where the barometric reading is 75cm Hg. Determine the absolute pressure in tank. Take ρHg=13590kg/m^3. (4.15 bar).

1.17. A pressure gage connected to a tank reads 600kPa at a location where the atmospheric pressure is 94kPa. Determine the absolute pressure in the tank.

1.18. The barometer of a mountain hiker reads 930mbar at the beginning of hiker tip and 780mbar at the end. Neglecting the effect of altitude on local gravitational acceleration, determine the vertical distance climbed? Assume an average air density of 1.2kg/m^3 and take g=9.7m/sec. (1288.65m).

1.19. The basic barometer can be used to measure the height of a building. If the barometric readings at the top and at the bottom of a building are 730 and 755mm Hg, respectively. Determine the height of the building, assume an average air density of 1.18kg/m^3. (288m).

1.20. A gas is contained in a vertical, frictionless piston-cylinder device. The piston has a mass of 4kg and cross-sectional area of 35cm^2. a compressed spring above the piston exerts a force 60N on the piston. If the atmospheric pressure is 95kPa, determine the pressure inside the cylinder. (123.35kPa)

1.21. Both a gage and a manometer are attached to a gas tank to measure its pressure. If the reading on the gage is 80kPa, determine the distance between the two fluid levels of the manometer if the fluid is (a) mercury (ρ=13600kg/m^3) or is (b) water (ρ=1000kg/m^3).

1.22. The level of the water in an enclosed water tank is 40m above ground level. The pressure in the air space above the water is 120kPa, and the density of water is 1000kg/m^3. what is the water pressure at ground level. (512.4 kPa)

1.23. A manometer contains a fluid having a density of 800kg/m3. The difference in height of the two columns 300mm. What pressure difference is indicated? What would be the height difference be if a manometer containing mercury (density of 13600kg/m3) had measured this same pressure difference?

1.24. During a heating process, the temperature of a system rises by 10^{o}C. Express this rise in temperature in K,R, and ^{o}F.

1.25. The deep body temperature of a healthy person is 98.6^{o}F. What is it in Rankine.

1.26. Consider a system whose temperature is 18^{o}C. Express this temperature in R, K, ^{o}F.

1.27. Consider two closed systems A and B. System A contains 2000kJ of thermal energy at 20^{o}C whereas system B contains 200kJ of thermal energy at 50^{o}C. Now the two systems brought into contact with each other. Determine the direction of any heat transfer between the systems.

1.28. A lift of mass 972kg moving up a distance 14.5km. Determine the minimum work required.

1.29. Determine the kinetic energy possesses by a car has a mass of 1050kg with a speed of 82km/hr.

1.30. Water is stored in a tank at a height of 85.3m over a hydraulic turbine.(a) calculate the potential energy per unit mass of the water (b)the mass flow rate to product 75000kW.

1.31. Determine the mass and the weight of the air contained in a room whose dimensions are 6m by 6m by 8m. Assume the density of the air is 1.16kg/m^3.

1.32. A 5-kg rock is thrown upward with a force of 150N at a location where the local gravitational acceleration is 9.79m/sec2. Determine the acceleration of the rock in m/sec2.