1. 3 Choosing a Basis:

- A **basis** is a reference chosen by you for the calculations you plan to make in any particular problem, and a proper choice of basis frequently makes the problem much easier to solve.
- The **basis** may be a **period of time** such as **hours**, or a given **mass of material**, such as **5 kg** of CO2, or some other convenient quantity.
- For **liquids** and **solids** in which a **mass (weight)** analysis applies, a convenient basis is often **1 or 100 lb or kg**; similarly, **1 or 100 moles** is often a good choice for a **gas**.

Example 1:

Gas mixture 10.0% H_2, 40.0% CH_4, 30.0% CO, and 20.0% CO_2, what is the average molecular weight of the gas?

Solution:

Basis: 100 kg mol or lb mol of gas

Component	Percent = kg mol or lb mol	Mol wt.	Kg or lb
CO_2	20.0	44.0	880
CO	30.0	28.0	840
CH_4	40.0	16.04	642
H_2	10.0	2.02	20
Total	100.0		2382

Email: mariam.ghassan.ghaffar@uomus.edu.iq

$$\text{Average molecular weight} = \frac{2382 \text{ kg}}{100 \text{ kg mol}} = 23.8 \text{ kg/kg mol}$$

Other Method for Solution:

Average molecular weight = 0.2 * 44 + 0.3 * 28 + 0.4 * 16.04 + 0.1 * 2.02 = 23.8 kg/kg mol

Example 2:

A liquefied mixture has the following composition: n-C_4H_{10} 50% (MW=58), n-C_5H_{12} 30% (MW=72), and n-C_6H_{14} 20% (MW=86). For this mixture, calculate: (a) mole fraction of each component. (b) Average molecular weight of the mixture.

Solution:

Basis: 100 kg

	% = kg	wt fr	MW	kg mol	mol fr
n - C_4H_{10}	50	**0.50**	58	0.86	**0.57**
n - C_5H_{12}	30	**0.30**	72	0.42	**0.28**
n - C_6H_{14}	20	**0.20**	86	0.23	**0.15**
	100	**1.00**		1.51	**1.00**

$$\textbf{Average molecular weight} = \frac{\text{total mass}}{\text{total mol}} = \frac{100 \text{ kg}}{1.51 \text{ kg mol}} = \mathbf{66}$$

Email: mariam.ghassan.ghaffar@uomus.edu.iq

Example3:

In a ternary alloy such as $Nd_{4.5}Fe_{77}B_{18.5}$ the average grain size is about 30 nm. By replacing 0.2 atoms of Fe with atoms of Cu, the grain size can be reduced (improved) to 17 nm. (a) What is the molecular formula of the alloy after adding the Cu to replace the Fe? (b) What is the mass fraction of each atomic species in the improved alloy?

Solution

Basis: 100 g mol (or atoms) of $Nd_{4.5}Fe_{77}B_{18.5}$

(a) The final alloy is $Nd_{4.5}Fe_{76.8}B_{18.5}Cu_{0.2}$.

(b) Use a table to calculate the respective mass fractions

Component	Original g mol	Final g mol	MW	g	Mass fraction
Nd	4.5	4.5	144.24	649.08	0.126
Fe	77	76.8	55.85	4289.28	0.833
B	18.5	18.5	10.81	199.99	0.039
Cu		0.2	63.55	12.71	0.002
Total	100.0	100.0		5151.06	1.000

1.4 Temperature

- Temperature is a measure of the energy (mostly kinetic) of the molecules in a system. This definition tells us about the amount of energy.
- Other scientists prefer to say that temperature is a property of the state of thermal equilibrium of the system with respect to other systems because temperature tells us about the capability of a system to transfer energy (as heat).

Email: mariam.ghassan.ghaffar@uomus.edu.iq

Four types of temperature:

Two based on a relative scale, **degrees Fahrenheit (°F)** and **Celsius (°C),** and two based on an absolute scale, **degree Rankine (°R)** and **Kelvin (K).**

Temperature Conversion:

$$\Delta°F = \Delta°R$$

$$\Delta°C = \Delta K$$

Also, the Δ°C is larger than the Δ°F

$$\frac{\Delta°C}{\Delta°F} = 1.8 \qquad \text{or} \qquad \Delta°C = 1.8\ \Delta°F$$

$$\frac{\Delta K}{\Delta°R} = 1.8 \qquad \text{or} \qquad \Delta K = 1.8\ \Delta°R$$

The proper meaning of the symbols °C, °F, K, and °R, as either the temperature or the unit temperature difference, must be interpreted from the context of the equation or sentence being examined.

Suppose you have the relation:

$$T_{°F} = a + bT_{°C}$$

What are the units of a and b? The units of a must be °F for consistency. The correct units for b must involve the conversion factor (1.8 Δ°F\Δ°C), the factor that converts the size of a interval on one temperature scale

$$T_{°F} = a_{°F} + \left(\underbrace{\frac{1.8\ \Delta°F}{\Delta°C}}_{b}\right) T_{°C}$$

Unfortunately, the units for b are usually ignored; just the value of b (1.8) is employed.

- The relations between °C, °F, K, and °R are:

$$T_{°R} = T_{°F}\left(\frac{1\ \Delta°R}{1\ \Delta°F}\right) + 460°R \qquad \underline{\text{Or}} \qquad T_{°R} = T_{°F} + 460$$

$$T_{K} = T_{°C}\left(\frac{1\ \Delta K}{1\ \Delta°C}\right) + 273\ K \qquad \underline{\text{Or}} \qquad T_{K} = T_{°C} + 273$$

$$T_{°F} - 32°F = T_{°C}\left(\frac{1.8\ \Delta°F}{1\ \Delta°C}\right)$$

$$T_{°C} = (T_{°F} - 32°F)\left(\frac{1\ \Delta°C}{1.8\ \Delta°F}\right) \qquad \underline{\text{Or}} \qquad T_{°F} = 1.8\ T_{°C} + 32$$

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Example1:

Convert 100 °C to (a) K, (b) °F, and (c) °R.

Solution:

$$\text{(a)}\quad (100 + 273)^\circ\text{C}\,\frac{1\ \Delta\text{K}}{1\ \Delta^\circ\text{C}} = 373\ \text{K}$$

or with suppression of the **Δ** symbol,

$$(100 + 273)^\circ\text{C}\,\frac{1\ \text{K}}{1^\circ\text{C}} = 373\ \text{K}$$

$$\text{(b)}\quad (100^\circ\text{C})\frac{1.8\ \Delta^\circ\text{F}}{1\ \Delta^\circ\text{C}} + 32^\circ\text{F} = 212^\circ\text{F}$$

$$\text{(c)}\quad (212 + 460)^\circ\text{F}\,\frac{1\ \Delta^\circ\text{R}}{1\ \Delta^\circ\text{F}} = 672^\circ\text{R}$$

or

$$(373\ \text{K})\frac{1.8\ \Delta^\circ\text{R}}{1\ \Delta\text{K}} = 672^\circ\text{R}$$

Example 2:

The heat capacity of sulfuric acid has the units J/(g mol)(°C), and is given by the relation

Heat capacity = 139.1 + 1.56 * 10^{-1} T

Where T is expressed in °C. Modify the formula so that the resulting expression has the associated units of Btu/(lb mol) (°R) and T is in °R?

Solution:

$T_{°F} = 1.8\, T_{°C} + 32 \Rightarrow T_{°C} = (T_{°F} - 32)/1.8$

$T_{°R} = T_{°F} + 460 \Rightarrow T_{°F} = T_{°R} - 460$

$\therefore T_{°C} = [T_{°R} - 460 - 32]/1.8$

$$\text{heat capacity} = \left\{139.1 + 1.56 \times 10^{-1}\overbrace{\left[(T_{°R} - 460 - 32)\frac{1}{1.8}\right]}^{T_{°C}}\right\} \times \frac{1\ \text{J}}{(\text{g mol})(°\text{C})}\underbrace{\left|\frac{1\ \text{Btu}}{1055\ \text{J}}\right|\frac{454\ \text{g mol}}{1\ \text{lb mol}}\left|\frac{1°\text{C}}{1.8°\text{R}}\right.}_{\text{conversion factors}} =$$

$$= 23.06 + 2.07 \times 10^{-2} T_{°R}$$

Note the suppression of the **Δ** symbol in the conversion between °C and °R.

1.5 Pressure

Pressure and Its Units

Pressure is defined as "the normal (perpendicular) force per unit area (Figure 5.1). The pressure at the bottom of the static (nonmoving) column of mercury exerted on the sealing plate is

$$p = \frac{F}{A} = \rho g h + p_0 \qquad (5.1)$$

Where p = pressure at the bottom of the column of the fluid, F = force, A = area, ρ = density of fluid g = acceleration of gravity, h = height of the fluid column, and p_0 = pressure at the top of the column of fluid

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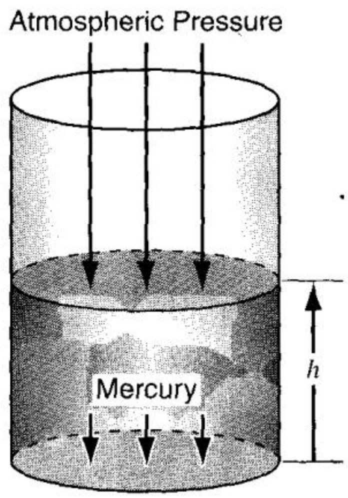

Figure1: Pressure is the normal force per unit area. Arrows show the force exerted on the respective areas

For Example, suppose that the cylinder of fluid in Figure 5.1 is a column of mercury that has an area of 1 cm^2 and is 50 cm high. The density of the Hg is 13.55 g/cm^3. Thus, the force exerted by the mercury alone on the 1 cm^2 section of the bottom plate by the column of mercury is

$$F = \frac{13.55\ \text{g}}{\text{cm}^3}\left|\frac{980\ \text{cm}}{\text{s}^2}\right|\frac{50\ \text{cm}}{}\left|\frac{1\ \text{cm}^2}{}\right|\frac{1\ \text{kg}}{1000\ \text{g}}\left|\frac{1\ \text{m}}{100\ \text{cm}}\right|\frac{1(\text{N})(\text{s}^2)}{1(\text{kg})(\text{m})}$$
$$= 6.64\ \text{N}$$

The pressure on the section of the plate covered by the mercury is the force per unit area of the mercury plus the pressure of the atmosphere

$$p = \frac{6.64\ \text{N}}{1\ \text{cm}^2}\left|\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^2\right|\frac{(1\ \text{m}^2)(1\ \text{Pa})}{(1\ \text{N})}\left|\frac{1\ \text{kPa}}{1000\ \text{Pa}}\right. + p_0 = 66.4\ \text{kPa} + p_0$$

If we had started with units in the AE system, the pressure would be computed as [the density of mercury is 845.5 lb_m/ft^3]

Email: mariam.ghassan.ghaffar@uomus.edu.iq

$$p = \frac{845.5\ \text{lb}_m}{1\ \text{ft}^3}\left|\frac{32.2\ \text{ft}}{\text{s}^2}\right|\frac{50\ \text{cm}}{}\left|\frac{1\ \text{in.}}{2.54\ \text{cm}}\right|\frac{1\text{ft}}{12\ \text{in.}}\left|\frac{(\text{s})^2(\text{lb}_f)}{32.174(\text{ft})(\text{lb}_m)}\right. + p_0$$

$$= 1388\frac{\text{lb}_f}{\text{ft}^2} + p_0$$

Measurement of Pressure

Pressure, like temperature, can be expressed using either an absolute or a relative scale.

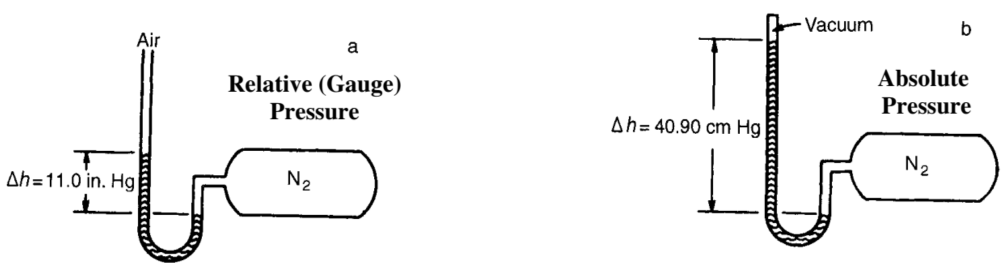

Figure2: (a) **Open-end manometer** showing a pressure above atmospheric pressure. (b) **Manometer** measuring an **absolute pressure**.

The relationship between **relative** and **absolute pressure** is given by the following expression:

Gauge Pressure + Barometer Pressure = Absolute Pressure …2

The **standard atmosphere** is defined as the pressure (in a standard gravitational field) equivalent to 1 atm or

760 mm Hg at 0°C or other equivalent. The **standard atmosphere** is equal to

♦ 1.00 atmospheres (atm)

♦ 33.91 feet of water (ft H_2O)

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♦ 14.7 pounds (force) per square inch absolute (psia)

♦ 29.92 inches of mercury (in. Hg)

♦ 760.0 millimeters of mercury (mm Hg)

♦ $1.013 * 10^5$ pascal (Pa) or newtons per square meter (N/m^2); or 101.3 kPa

For Example, convert 35 psia to inches of mercury and kPa.

$$\frac{35 \text{ psia}}{} \left| \frac{29.92 \text{ in. Hg}}{14.7 \text{ psia}} \right. = 71.24 \text{ in Hg}$$

$$\frac{35 \text{ psia}}{} \left| \frac{101.3 \text{ kPa}}{14.7 \text{ psia}} \right. = 241 \text{ kPa}$$

For Example, What is the equivalent **pressure** to **1 kg/cm²** (i.e., **kgf/cm²**) in pascal ($g = 9.8\ m/s^2$)

$[1\ kg/cm^2] * [9.8\ m/s^2] * [(100\ cm/1\ m)^2] = 9.8 * 10^4\ N/m^2$ (or Pa)

Example1:

What is the equivalent pressure to 60 Gpa (gigapascal) in

(a) atmospheres (b) psia (c) inches of Hg (d) mm of Hg

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Solution

Basis: 60 GPa

(a) $$\frac{60\ \text{GPa}}{} \left| \frac{10^6\ \text{kPa}}{1\ \text{GPa}} \right| \frac{1\ \text{atm}}{101.3\ \text{kPa}} = 0.59 \times 10^6\ \text{atm}$$

(b) $$\frac{60\ \text{GPa}}{} \left| \frac{10^6\ \text{kPa}}{1\ \text{GPa}} \right| \frac{14.696\ \text{psia}}{101.3\ \text{kPa}} = 8.70 \times 10^6\ \text{psia}$$

(c) $$\frac{60\ \text{GPa}}{} \left| \frac{10^6\ \text{kPa}}{1\ \text{GPa}} \right| \frac{29.92\ \text{in. Hg}}{101.3\ \text{kPa}} = 1.77 \times 10^7\ \text{in. Hg}$$

(d) $$\frac{60\ \text{GPa}}{} \left| \frac{10^6\ \text{kPa}}{1\ \text{GPa}} \right| \frac{760\ \text{mm Hg}}{101.3\ \text{kPa}} = 4.50 \times 10^8\ \text{mm Hg}$$

Example 2

The pressure gauge on a tank of CO_2 used to fill soda-water bottles reads 51.0 psi. At the same time the barometer reads 28.0 in. Hg. What is the absolute pressure in the tank in psia? See Figure 5.2.

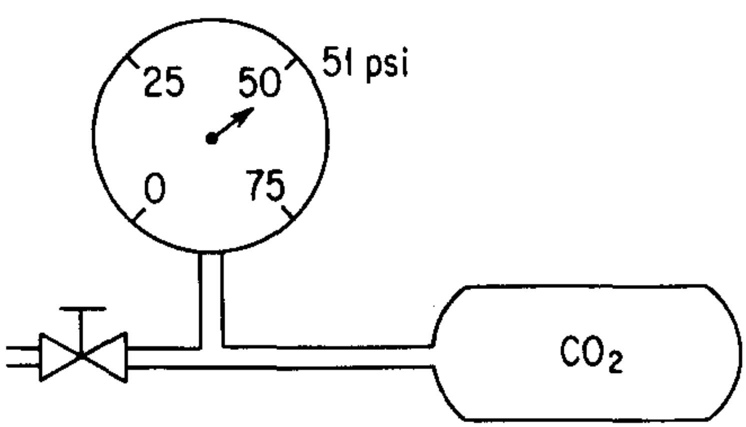

Figure E5.2

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Solution:

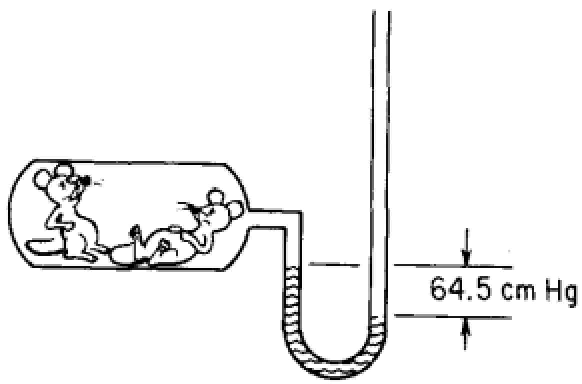
$$\text{Atmospheric pressure} = \frac{28.0 \text{ in. Hg}}{} \left| \frac{14.7 \text{ psia}}{29.92 \text{ in Hg}} \right. = 13.76 \text{ psia}$$

The absolute pressure in the tank is

$$51.0 \text{ psia} + 13.76 \text{ psia} = 64.8 \text{ psia}$$

Example 3:

Small animals such as mice can live (although not comfortably) at reduced air pressures down to 20 kPa absolute. In a test, a mercury manometer attached to a tank, as shown in Figure , reads 64.5 cm Hg and the barometer reads 100 kPa. Will the mice survive?



Solution

You are expected to realize from the figure that the tank is below atmospheric pressure because the left leg of the manometer is higher than the right leg, which is open to the atmosphere. Consequently, to get the absolute pressure you subtract the 64.5 cm Hg from the barometer reading. The absolute pressure in the tank is:

$$100\ \text{kPa} - 64.5\ \text{cm Hg} \left| \frac{101.3\ \text{kPa}}{76\ \text{cm Hg}} \right. = 100 - 86 = 14\ \text{kPa absolute}$$

The mice probably will not survive.

Email: mariam.ghassan.ghaffar@uomus.edu.iq