HARVEY MUDD COLLEGE

E82

Mass, Mole, Fractions

E82 – Basic Process Variables

1

1

HARVEY MUDD COLLEGE

E82

Mass

Mass is both a property of a physical body and a measure of its resistance to acceleration (a change in its state of motion) when a net force is applied. An object's mass also determines the strength of its gravitational attraction to other bodies. (https://en.wikipedia.org/wiki/Mass)

The SI unit of mass, the kilogram, is defined from Planck's constant

$$h = 6.626070150 \times 10^{-34}\ \text{kg} \cdot \text{m}^2 / \text{s}$$

or

$$1\ \text{kg} = \frac{h}{6.626070150 \times 10^{-34}\ \text{m}^2 / \text{s}}$$

2

2

Mass (cont.)

HARVEY MUDD COLLEGE

E82

For the curious, the *second* is defined as 9,192,631,770 times the period of the unperturbed ground-state hyperfine transition of the cesium 133 atom. And the *meter* is defined as 1/299,792,458th of the distance light travels in a vacuum in one second.

The American engineering unit of mass, the *pound mass*, or lb_m is defined as

$$1\ lb_m \equiv 0.45359237\ kg$$

3

3

Mole

HARVEY MUDD COLLEGE

E82

Avogadro's number is defined as

$$N_A \equiv 6.02214076 \times 10^{23}\ \text{(exact)}$$

- If you have exactly that many molecules of a given compound, you have a *gram-molecule* (g-mol or mol) of the compound. Its mass in grams would be exactly one molecular weight of the compound.
- If you have exactly 1000 times that many molecules you have one *kilogram-mole* or *kilomole* (kmol) of the compound.
- If you had exactly 453.59237 times Avogadro's number, you would have one *pound-mole* (lb-mol) of the compound.
- A mole without a prefix, i.e., *mol* is assumed to be a gram mole.

4

4

Mole (cont.)

HARVEY MUDD COLLEGE

E82

You should *NEVER* convert your mass in kg or lb_m to g, and then to g-mol. You should *ALWAYS* use the kind of mole your mass is in. The conversion factor is simply the molecular weight. The molecular weight of methane is:

$$M_{CH_4} = 16.0425\frac{\text{g}}{\text{g-mol}} = 16.0425\frac{\text{kg}}{\text{kg-mol}} = 16.0425\frac{\text{lb}_\text{m}}{\text{lb-mol}}$$

To calculate the pounds of oxygen ($M = 31.9988$) required to completely burn three pounds of methane:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \Rightarrow \frac{2\text{ lb-mol } O_2}{1\text{ lb-mol } CH_4}$$

5

5

Mole (cont.)

HARVEY MUDD COLLEGE

E82

$$\frac{3\text{ lb}_\text{m}\text{CH}_4}{16.0425\dfrac{\text{lb}_\text{m}\text{CH}_4}{\text{lb-mol CH}_4}}\frac{2\text{ lb-mol O}_2}{1\text{ lb-mol CH}_4}\frac{31.9988\text{ lb}_\text{m}\text{O}_2}{1\text{ lb-mol O}_2} = 11.9678\text{ lb}_\text{m}\text{O}_2$$

Calculating it any other way is just a waste of time and brain effort.

6

6

Mass Fraction and Mole Fraction

HARVEY MUDD COLLEGE

E82

F, R, & B use x_A for *mass fraction* and y_A for *mole fraction*.
They later use x_A for *liquid mole fraction* and y_A for *gas mole fraction*.
You have been warned.

To convert from mass fraction to mole fraction

$$y_A = \frac{\frac{x_A}{M_A}}{\sum \frac{x_i}{M_i}}$$

To convert from mole fraction to mass fraction

$$x_A = \frac{y_A M_A}{\sum y_i M_i}$$

For a binary, $x_A, y_A > 0$

$$y_A = \frac{1}{\left(\frac{1}{x_A} - 1\right)\frac{M_A}{M_B} + 1}$$

$$x_A = \frac{1}{\left(\frac{1}{y_A} - 1\right)\frac{M_B}{M_A} + 1}$$

7

7

Mole-Averaged and Mass-Averaged Molecular weight

HARVEY MUDD COLLEGE

E82

The mole-averaged (or number-averaged) molecular weight is

$$\bar{M} = \sum y_i M_i = \left(\sum \frac{x_i}{M_i} \right)^{-1}$$

The mass-averaged molecular weight is

$$\bar{M}_m = \sum x_i M_i = \frac{\sum y_i M_i^2}{\sum y_i M_i}$$

The mole-averaged molecular weight is most often used for mixtures of gases. The mass-averaged molecular weight is most often used for polymers.

8

8