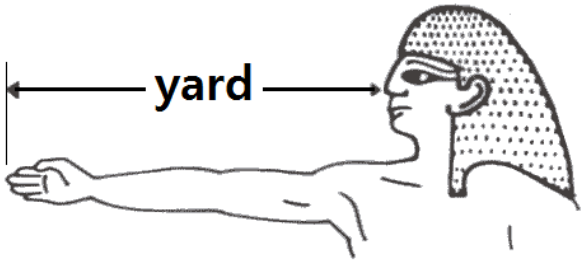
Chapter 4

Describing Physical Quantities

UNITS

- Metric system
  - cgs system: cm, gram, second
  - SI system (Systeme Internationale d'Unites)
- American engineering system
  - Based on cultural definitions from British history
  - e.g. a yard
    - the length from the king's nose to the tip of his middle finger on his fully-extended right arm



UNITS

Table 4.1 Base or Sample Units for Three Measurement Systems

System	Mass	Length	Time	Temperature
cgs	*g*	*cm*	*s*	Celsius
SI	*kg*	*m*	*s*	Kelvin
American	lb_m	*ft*	*s*	Fahrenheit

Conversion Factors

Acceleration	$1\ m/s^2 = 3.2808\ ft/s^2$	$1\ ft/s^2 = 0.3048\ m/s^2$
Area	$1\ cm^2 = 0.155\ in^2$	$1\ in^2 = 6.4516\ cm^2$
	$1\ m^2 = 10.764\ ft^2$	$1\ ft^2 = 0.092903\ m^2$
Density	$1\ g/cm^3 = 62.43\ lb_m/ft^3$	$1\ lb_m/ft^3 = 0.016019\ g/cm^3$
	$1\ kg/m^3 = 0.06243\ lb_m/ft^3$	$1\ lb_m/ft^3 = 16.019\ kg/m^3$
Energy	$1\ J = 0.7376\ ft\ lb_f$	$1\ ft\ lb_f = 1.3558\ J$
	$1\ J = 9.478 \times 10^{-4}\ Btu$	$1\ Btu = 1055.0\ J = 778.1\ ft\ lb_f$
	$1\ J = 2.778 \times 10^{-7}\ kW\ hr$	$1\ kW\ hr = 3.600 \times 10^6\ J$
	$1\ J = 10^7\ ergs$	$1\ hp\ s = 550\ ft\ lb_f$
	$1\ J = 0.2390\ cal$	
Force	$1\ N = 0.22481\ lb_f$	$1\ lb_f = 4.4482\ N$
	$1\ N = 10^5\ dynes$	
Length	$1\ cm = 0.3937\ in$	$1\ in = 2.540\ cm$
	$1\ m = 3.2808\ ft$	$1\ ft = 12\ in = 0.3048\ m$
	$1\ km = 0.6214\ mi$ (statute)	$1\ yd = 3\ ft$
	$1\ km = 0.5400\ nmi$ (nautical)	$1\ mi$ (statute) $= 1609\ m = 5280\ ft$
		$1\ nmi$ (nautical) $= 1.8520\ km$
Mass	$1\ g = 0.03527\ oz$	$1\ oz = 28.35\ g$
	$1\ kg = 2.2046\ lb_m$	$1\ lb_m = 16\ oz = 453.6\ g$
	$1\ metric\ ton = 1000\ kg = 2205\ lb_m$	$1\ ton = 2000\ lb_m = 907.2\ kg$

Conversion Factors

Power	$1\ W = 0.7376\ ft\ lb_f/s$	$1\ ft\ lb_f/s = 1.3558\ W$
	$1\ W = 9.478 \times 10^{-4}\ Btu/s$	$1\ Btu/s = 1055.0\ W = 778.1\ ft\ lb_f/s$
	$1\ W = 1.341 \times 10^{-3}\ hp$	$1\ hp = 745.7\ W = 550\ ft\ lb_f/s$
Pressure	$1\ Pa = 1.450 \times 10^{-4}\ lb_f/in^2\ (psi)$	$1\ lb_f/in^2 = 6894.8\ Pa$
	$1\ Torr = 1\ mm\ Hg\ (@\ 0°C)$	$1\ atm = 101{,}325\ Pa$
		$1\ atm = 760\ mm\ Hg\ (@\ 0°C)$
		$1\ atm = 14.696\ lb_f/in^2\ (psi)$
		$1\ atm = 33.9\ ft\ H_2O\ (@\ 4°C)$
Temperature	$T(°C) = 5/9\ [T(°F) - 32]$	$T(°F) = 1.8\ T(°C) + 32$
	$T(K) = T(°C) + 273.15$	$T(R) = T(°F) + 459.67$
		$T(R) = 1.80\ T(K)$
Viscosity	$1\ cp = 6.7197 \times 10^{-4}\ lb_m/ft\ s$	$1\ lb_m/ft\ s = 1488.2\ cp = 14.882\ Poise$
Volume	$1\ cm^3 = 1\ mL = 0.06102\ in^3$	$1\ in^3 = 16.387\ cm^3$
	$1\ m^3 = 35.3145\ ft^3$	$1\ ft^3 = 0.028317\ m^3$
	$1\ m^3 = 1000\ liters$	$1\ ft^3 = 7.4805\ gal$
	$1\ m^3 = 264.17\ gal$	$1\ ft^3 = 28.317\ liters$
	$1\ L = 0.26417\ gal$	$1\ gal = 3.785 \times 10^{-3}\ m^3 = 3.785\ L$
Volume Flow	$1\ m^3/s = 15{,}850\ gal/min$	$1\ gal/min = 6.309 \times 10^{-5}\ m^3/s$
		$1\ gal/min = 2.228 \times 10^{-3}\ ft^3/s$
		$1\ ft^3/s = 448.8\ gal/min$

Conversion Factors

$$1\ \mathit{ft} = 12\ \mathit{in}, \quad 28\ \mathit{in} = ?\ \mathit{ft}$$

$$\frac{28\ \mathit{in}}{} \left| \frac{1\ \mathit{ft}}{12\ \mathit{in}} \right| = 2.333\ \mathit{ft}$$

Moles

- One mole = Avogadro's number of particles

  (6.02×10^{23})

- Molecular weight (MW) of H_2O

  2(1.01) + 16.00 = 18.02

  H O

- gmol (gram-mole)
  - 18 *g* water = 1 *gmol* water

- lbmol (pound-mole)
  - 18 lb_m water = 1 *lbmol*

Symbols

- m = mass
- m_A = mass of “A”
- n = the number of moles
- n_A = the number of moles of “A”
- MW_A = molecular weight of “A”

Combined Units

Table 4.2 Examples of Combined Units for Three Measurement Systems

System	cgs System	SI Systems	American System
density	g/cm^3	kg/m^3	lb_m/ft^3
velocity	cm/s	m/s	ft/s
acceleration	cm/s^2	m/s^2	ft/s^2
volumetric flow rate	cm^3/s	m^3/s	ft^3/s
mass flow rate	g/s	kg/s	lb_m/s
concentration	$gmol/L$*	$kgmol/m^3$	$lbmol/ft^3$

*often abbreviated *M* (i.e., molarity)

Force & Defined Units

- Newton's 2nd law

  $F = m\,a$

- Weight

  $F_{weight} = m\,g$

- lb_m "pound-mass"
- lb_f "pound-force"

Table 4.3 Gravitational Acceleration (at Sea Level) and Defined Units of Force

System	g	Defined Unit of Force
cgs	980.66 cm/s^2	1 *dyne* ≡ 1 $g\ cm/s^2$
SI	9.8066 m/s^2	1 *Newton* (*N*) ≡ 1 $kg\ m/s^2$
American	32.174 ft/s^2	1 *pound-force* (lb_f) ≡ 32.174 $lb_m\ ft/s^2$

Pressure & Defined Units

- Pressure
  - Force exerted per area
- *psi*

  "pound per square inch"

Table 4.4 Commonly Used Units of Pressure

System	Units of Pressure	Abbreviation	Defined and Equivalent Units
cgs	*Pascals*	*Pa*	$1\,Pa \equiv 1\,N/m^2 = 10\,g/cm\,s^2$
SI	*kiloPascals*	*kPa*	$1\,kPa \equiv 1000\,N/m^2 = 1000\,kg/m\,s^2$
American	lb_f/in^2	*psi*	$1\,lb_f/in^2 = 4633\,lb_m/ft\,s^2$

Symbols

- Density

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

- Flow rate
  - mass flow rate ($\dot{m}$)
  - molar flow rate ($\dot{n}$)
  - volumetric flow rate ($\dot{V}$)

$$\dot{m} = \rho \dot{V}$$

Mixture Composition

- Mole Concentration of A

$$c_A = \frac{moles\ of\ A}{volume\ of\ mixture} = \frac{n_A}{V}$$

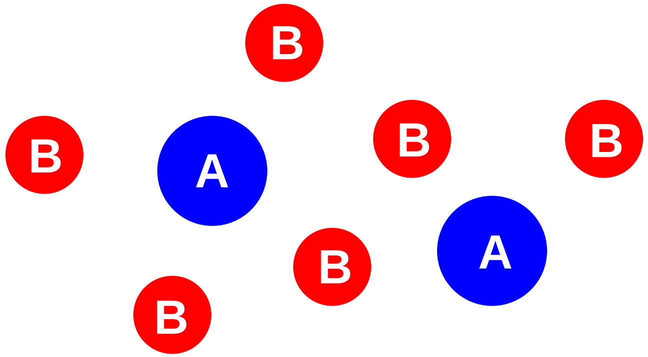
- Mass Fraction of A

$$x_A = \frac{mass\ of\ A}{mass\ of\ mixture} = \frac{m_A}{m}$$

- Mole Fraction of A

$$y_A = \frac{moles\ of\ A}{moles\ of\ mixture} = \frac{n_A}{n}$$

Mole Fraction & Mass Fraction



$$m_A = 2\ m_B$$

- Mole Fraction of A = 2/8 = 0.25
- Mass Fraction of A = 4/10 = 0.4

Mixture Composition

- Mass Percent of A

  (commonly expressed as *wt%*)

  $= 100\ x_A$

- Mole Percent of A

  $= 100\ y_A$

Dimensional Consistency

- Terms that are added together (or subtracted) must have the same units.

$$Q = ab + c^2$$

- Exponents must be unitless.
  - The units in the term *ab/c* must all cancel out to leave no units.

$$y = x^{ab/c}$$