COLLEGE OF ENGINEERING, ARCHITECTURE AND TECHNOLOGY

西南交通大學
Southwest Jiaotong University

INTRODUCTION TO ENGINEERING (ENGR 1111)

Joint Bachelors Degree Program of Oklahoma State University & Southwest Jiaotong University

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Fundamental Dimensions and Units

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Fundamental Dimensions and Units

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Dimensions

Basketball player

- Q: "How tall are you?"
- A: "I'm 1.8 meters tall".

- Dimension we consider is length (height)
- Unit used to describe the dimension *'length'* is meters.
- **Dimension** describes the measurement of interest, which in the above case is *length*.
- No other "dimension to height" necessary.
- Multiple different units can be used (i.e. *feet, inch etc*)

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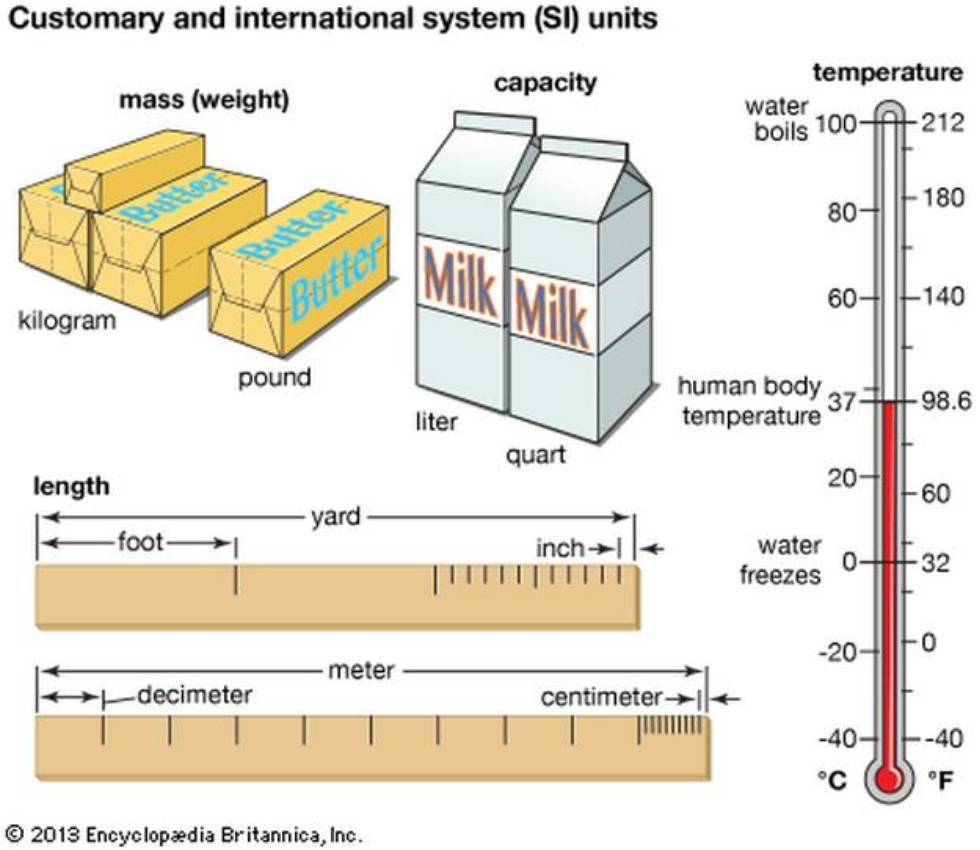
Fundamental Dimensions and Units

Primary Units （Base Units）

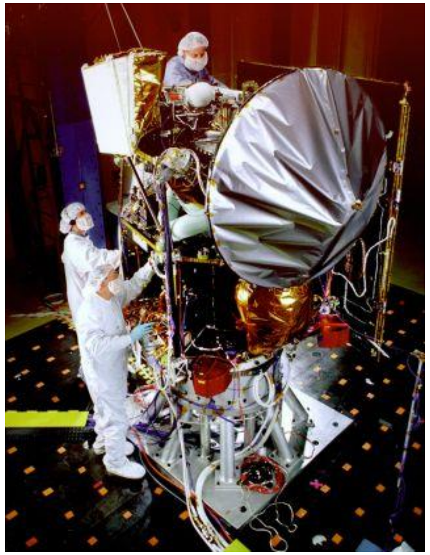
- The Primary Units are used to measure each of the fundamental dimensions.
- Two primary unit systems are predominantly used in engineering applications throughout the world:
  - International System of Units (SI units)
  - United States customary system (USCS or US System)



Fundamental Dimensions and Units

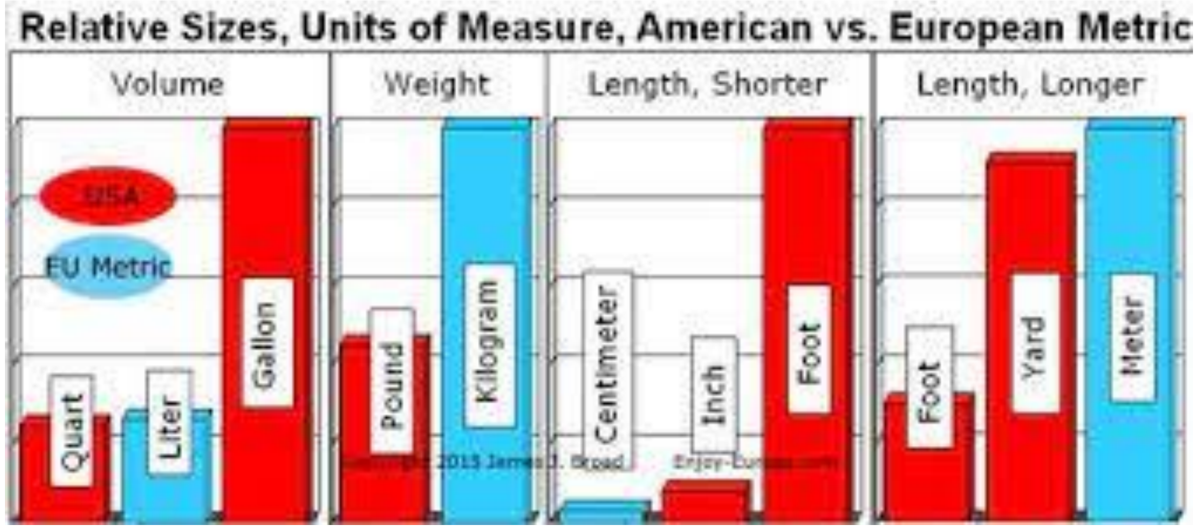
- **Why are units important?**
  - A number without units has no meaning in engineering
  - A number with improper units has a misleading meaning

- **Example:**
  - 1999 Mars Climate Orbiter
    - Launched in December 1998, communication lost in September 1999
    - Measurement mismatch failure
    - NASA used metric while the manufacturer used US customary units



Fundamental Dimensions and Units

- Dimensions – used to describe the measurable aspects of an object
- Units – increments necessary to quantify dimensions
- Common dimensions:
  - Length
  - Mass
  - Time
  - Temperature
- Derived units:
  - Volume
  - Density
  - concentration



Fundamental Dimensions and Units

Primary Units （Base Units）

International System of Units (SI units)

- Most commonly used system of measurement, except USA, Liberia, & Myanmar.
- Modern form of the metric system, built on seven base units, which correspond to the seven fundamental dimensions.
- Standard units used in medicine, science, engineering, & military

Fundamental Dimensions and Units

Primary Units （Base Units）

United States customary system (USCS or US System)

- The system evolved from the British Imperial unit system
- Used for measurement in commercial activities, consumer products, construction, & manufacturing

Fundamental Dimensions and Units

U.S. Customary Units

- In the US, most engineers still use U.S. Customary system of units

TABLE 6.5 Examples of U.S. Customary Units in Everyday Use

Examples of U.S. Customary Unit Usage	U.S. Customary Units Used
Fuel tank capacity	20 gallons or 2.67 ft^3 ($1\ ft^3 = 7.48$ gallons)
Sports (length of a football field)	100 yd or 300 ft
Power capacity of an automobile	150 hp or 82500 lb·ft/s (1 hp = 550 lb·ft/s)
Distance between two cities	100 miles (1 mile = 5280 ft)

Fundamental Dimensions and Units

British Gravitational (BG) System

1lb = (1slug)(1ft/s^2)

Primary Units	SI	BG
Mass M	kg	slug=32.2lbm
Length L	m	ft
Time t	s	s
Temperature T	°C (°K)	°F (°R)

In the BG system, the unit of temperature is expressed in °F or in terms of absolute temperature degree Rankine ($°R$).

$$°R = °F + 459.67$$

$$T(°F) = \frac{9}{5}T(°C) + 32$$

$$T(°R) = \frac{9}{5}T(K)$$

Fundamental Dimensions and Units

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TABLE 6.6 Systems of Units and Conversion Factors

Dimension	SI	BG	U.S. Customary	Conversion Factors
	System of Units			
Length	Meter (m)	Foot (ft)	Foot (ft)	1 ft = 0.3048 m 1 m = 3.2808 ft
Time	Second (s)	Second (s)	Second (s)	
Mass	Kilogram (kg)	Slugs*	Pound mass (lb_m)	1 lb_m = 0.4536 kg 1 kg = 2.2046 lb_m 1 slug = 32.2 lb_m
Force	Newton (N) $1N = (1\,kg)\left(1\frac{m}{s^2}\right)$	$1\,lb_f^{**} = (1\,slug)\left(1\frac{ft}{s^2}\right)$	One pound mass*** weighs one pound force at sea level	1 N = 224.809E-3lb_f 1 lb_f = 4.448N
Temperature	Degree Celsius (°C) or Kelvin (K)**** K = °C + 273.15	Degree Fahrenheit (°F) or degree Rankine (°R) °R = °F + 459.67	Degree Fahrenheit (°F) or degree Rankine (°R) °R = °F + 459.67	°C = $\frac{5}{9}$[°F − 32] °F = $\frac{9}{5}$°C + 32 K = $\frac{5}{9}$°R °R = $\frac{9}{5}$K
Work, Energy	Joule (J) = (1N)(1m)	$lb_f \cdot ft = (1\,lb_f)(1\,ft)$ Commonly written as ft · lb_f	$lb_f \cdot ft = (1\,lb_f)(1\,ft)$	1 J = 0.7375 ft · lb_f 1 ft · lb_f = 1.3558 J 1 Btu = 778.17 ft · lb_f
Power	$Watt(W) = \frac{1\ Joule}{1\ second}$ kW = 1000 W	$\frac{lbf \cdot ft}{second} = \frac{(1 lbf)(1 ft)}{1\ second}$	$\frac{lbf \cdot ft}{second} = \frac{(1 lbf)(1 ft)}{1\ second}$	$1\,W = 0.7375\frac{ft \cdot lb_f}{s}$ $1\,hp = 550\frac{ft \cdot lb_f}{s}$ 1 hp = 0.7457 kW

*Derived or secondary dimension

**Fundamental dimension

***Note unlike SI and BG systems, the relationship between pound force and pound mass is not defined using Newton's second law

****Note a Temperature value expressed in K reads Kelvin not degree Kelvin

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Fundamental Dimensions and Units

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Dimension	Symbol	SI unit	AES (USCS)
Mass	[M]	Kilogram (Kg)	Pound – mass (lbm)
Length	[L]	Meter (m)	Foot (ft)
Time	[T]	Second (s)	Second (s)
Amount of Substance	[n]	Mole (mol)	Pound-mole (lbmol)
Light intensity	[J]	Candela (cd)	Candela (cd)
Electric intensity	[I]	Ampere (A)	Ampere (A)
Temperature	[θ]	Kelvin (K)	Rankine (°R)

AES: American Engineering System
USCS: United States Customary System

[ ] means "dimensions of".

Fundamental Dimensions and Units

Table 2.2 Commonly Used SI Unit Prefixes

Prefix name	Symbol	Factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deka	da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Fundamental Dimensions and Units

International System (SI) of Units

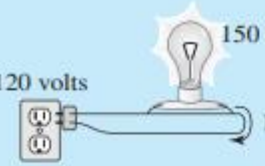
Physical Quantity		Name of SI Base Unit	SI Symbol
Length	 1.6 m–2.0 m Range of height for most adults	Meter	m
Mass	 50 kg–120 kg Range of mass for most adults	Kilogram	kg
Time	 Fastest person can run 100 meters in approximately 10 seconds	Second	s
Thermodynamic temperature	Ice water: 273 kelvin  Comfortable room temperature: 295 kelvin	Kelvin	K
Electric current	 150 watts 120 volts 1.25 amps	Ampere	A
Amount of substance	Uranium 238 ← One of the Gold 197 heaviest Silver 108 atoms known Copper 64 Calcium 40 Aluminum 27 Carbon 12 ← Common Carbon is Helium 4 used as a standard Hydrogen 1 ← Lightest atom	Mole	mol
Luminous intensity	 A candle has luminous intensity of approximately 1 candela	Candela	cd

Table: A List of SI Base (Fundamental) Units

Fundamental Dimensions and Units

Secondary Units (Derived Units)

Energy [=] joule [J]

$1\ J = (1N)(1m)$

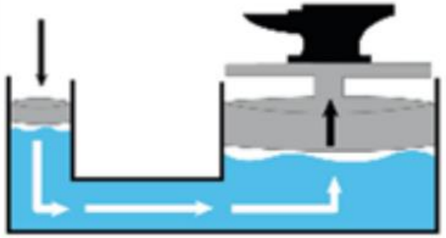
Power [=] watt [W]

$1\ W = 1\ J\,/\,s$

Force [=] newton [N]

$1N = (kg)\left(1\ \frac{m}{s^2}\right)$

Pressure [=] pascal [P]



$1\ Pa = \frac{1N}{1m^2}$

Voltage [=] volt [V]

$1V = \frac{1W}{1A}$

Special names for certain derived SI units

Fundamental Dimensions and Units

TABLE: Examples of **Derived Units** in Engineering

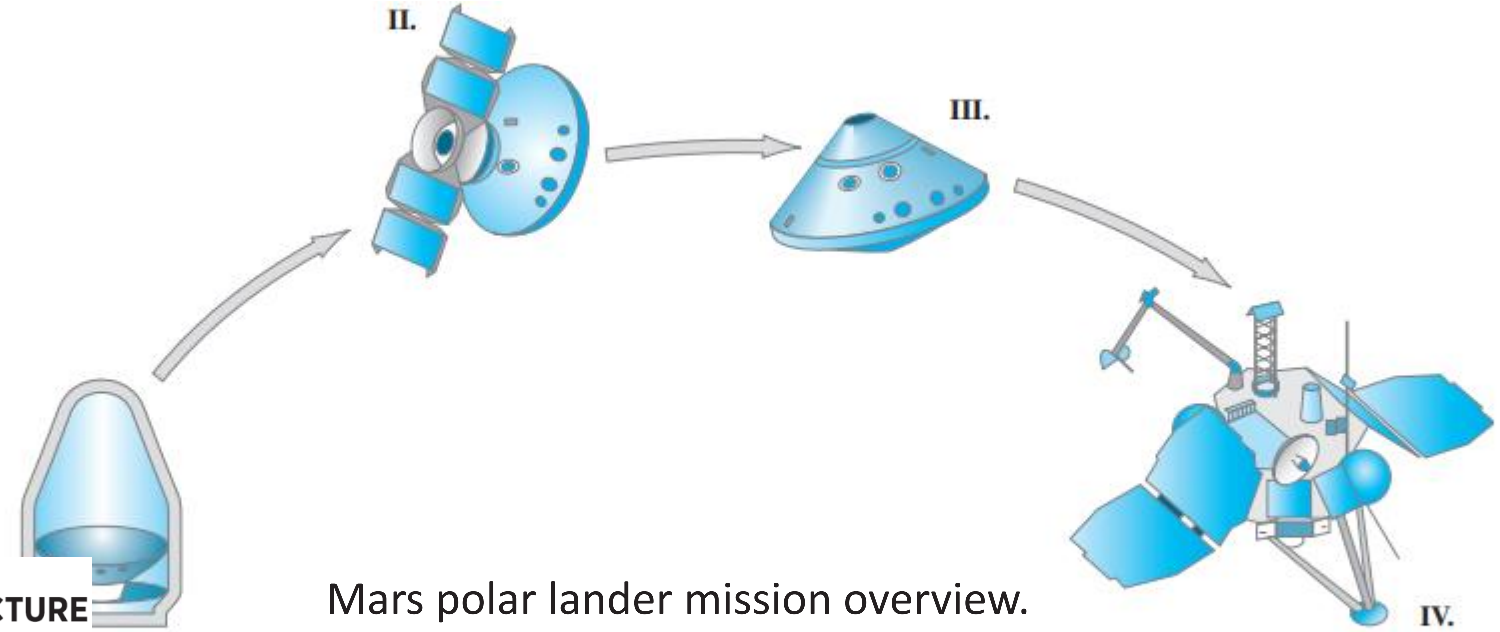
Physical Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of Base Units
Acceleration			m/s^2
Angle	Radian	rad	
Angular acceleration			rad/s^2
Angular velocity			rad/s
Area			m^2
Density			kg/m^3
Energy, work, heat	Joule	J	$N \cdot m$ or $kg \cdot m^2/s^2$
Force	Newton	N	$kg \cdot m/s^2$
Frequency	Hertz	Hz	s^{-1}
Impulse			$N \cdot S$ or $kg \cdot m/s$
Moment or torque			$N \cdot m$ or $kg \cdot m^2/s^2$
Momentum			$kg \cdot m/s$
Power	Watt	W	J/s or $N \cdot m/s$ or $kg \cdot m^2/s^3$
Pressure, stress	Pascal	Pa	N/m^2 or $kg/m \cdot s^2$
Velocity			m/s
Volume			m^3
Electric charge	Coulomb	C	$A \cdot s$
Electric potential	Volt	V	J/C or $m^2 \cdot kg/(s^3 \cdot A^2)$
Electric resistance	Ohm	Ω	V/A or $m^2 \cdot kg/(s^3 \cdot A^2)$
Electric conductance	Siemens	S	$1/\Omega$ or $s^3 \cdot A^2/(m^2 \cdot kg)$
Electric capacitance	Farad	F	C/V or $s^4 \cdot A^2/(m^2 \cdot kg)$
Magnetic flux density	Tesla	T	$V \cdot s/m^2$ or $kg/(s^2 \cdot A)$
Magnetic flux	Weber	Wb	$V \cdot s$ or $m^2 \cdot kg/(s^2 \cdot A)$
Inductance	Henry	H	$V \cdot s/A$
…diation	Gray	Gy	J/kg or m^2/s^2

- Unit for force is the *Newton* (N)
- Newton is derived from Newton's second law of motion.
- 1N is a magnitude of a force that when applied to 1 kg of mass, will accelerate the mass at a rate of 1 m/s^2
- **1N = (1kg)(1m/s^2)**

Fundamental Dimensions and Units

Unit Conversion

- NASA lost a spacecraft called Mars Climate Orbiter because two groups of engineers working on the project neglected to communicate correctly their calculations with appropriate units.
- One team used U.S. Customary units (e.g., ft and lb) while other used SI units (e.g., m and kg) for a key spacecraft operation.



Mars polar lander mission overview.

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CONVERSION FACTORS		
Quantity	**SI → U.S. Customary**	**U.S. Customary → SI**
Length	1 mm = 0.03937 in. 1 mm = 0.00328 ft 1 cm = 0.39370 in. 1 cm = 0.0328 ft 1 m = 39.3700 in. 1 m = 3.28 ft	1 in. = 25.4 mm 1 ft = 304.8 mm 1 in. = 2.54 cm 1 ft = 30.48 cm 1 in. = 0.0254 m 1 ft = 0.3048 m
Area	1 mm^2 = 1.55E-3 in^2 1 mm^2 = 1.0764E-5 ft^2 1 cm^2 = 0.155 in^2 1 cm^2 = 1.07E-3 ft^2 1 m^2 = 1550 in^2 1 m^2 = 10.76 ft^2	1 in^2 = 645.16 mm^2 1 ft^2 = 92,903 mm^2 1 in^2 = 6.4516 cm^2 1 ft^2 = 929.03 cm^2 1 in^2 = 6.4516E-4 m^2 1 ft^2 = 0.0929 m^2
Volume	1 mm^3 = 6.1024E-4 in^3 1 mm^3 = 3.5315E-8 ft^3 1 cm^3 = 0.061024 in^3 1 cm^3 = 3.5315E-5 ft^3 1 m^3 = 61024 in^3 1 m^3 = 35.315 ft^3	1 in^3 = 16387 mm^3 1 ft^3 = 28.317E6 mm^3 1 in^3 = 16.387 cm^3 1 ft^3 = 28317 cm^3 1 in^3 = 1.6387E-5 m^3 1 ft^3 = 0.028317 m^3
Second Moment of Area $(\text{length})^4$	1 mm^4 = 2.402E-6 in^4 1 mm^4 = 115.861E-12 ft^4 1 cm^4 = 24.025E-3 in^4 1 cm^4 = 1.1586E-6 ft^4 1 m^4 = 2.40251E6 in^4 1 m^4 = 115.86 ft^4	1 in^4 = 416.231E3 mm^4 1 ft^4 = 8.63097E9 mm^4 1 in^4 = 41.623 cm^4 1 ft^4 = 863110 cm^4 1 in^4 = 416.231E-9 m^4 1 ft^4 = 8.631E-3 m^4

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CONVERSION FACTORS (*Continued*)

Quantity	SI → U.S. Customary	U.S. Customary → SI
Mass	1 kg = 68.521E-3 slug 1 kg = 2.2046 lb_m	1 slug = 14.593 kg 1 lb_m = 0.4536 kg
Density	1 kg/m^3 = 0.001938 $slug/ft^3$ 1 kg/m^3 = 0.06248 lb_m/ft^3	1 $slug/ft^3$ = 515.7 kg/m^3 1 lb_m/ft^3 = 16.018 kg/m^3
Force	1 N = 224.809E-3 lb_f	1 lb_f = 4.448 N
Moment	1 N·m = 8.851 in·lb 1 N·m = 0.7376 ft·lb	1 in·lb = 0.113 N·m 1 ft·lb = 1.356 N·m
Pressure, Stress, Modulus of Elasticity, Modulus of Rigidity	1 Pa = 145.0377E-6 lb/in^2 1 Pa = 20.885E-3 lb/ft^2 1 kPa = 145.0377E-6 ksi	1 lb/in^2 = 6.8947E3 Pa 1 lb/ft^2 = 47.880 Pa 1 ksi = 6.8947E3 kPa
Work, Energy	1 J = 0.7375 ft·lb 1 kWh = 3.41214E3 Btu	1 ft·lb = 1.3558 J 1 Btu = 293.071E-6 kWh
Power	1 W = 0.7375 ft·lb/s 1 kW = 3.41214E3 Btu/h 1 kW = 1.341 hp	1 ft·lb/s = 1.3558 W 1 Btu/h = 293.07E-6 kW 1 hp = 0.7457 kW
Temperature	$°C = \frac{5}{9}(°F - 32)$	$°F = \frac{9}{5}°C + 32$

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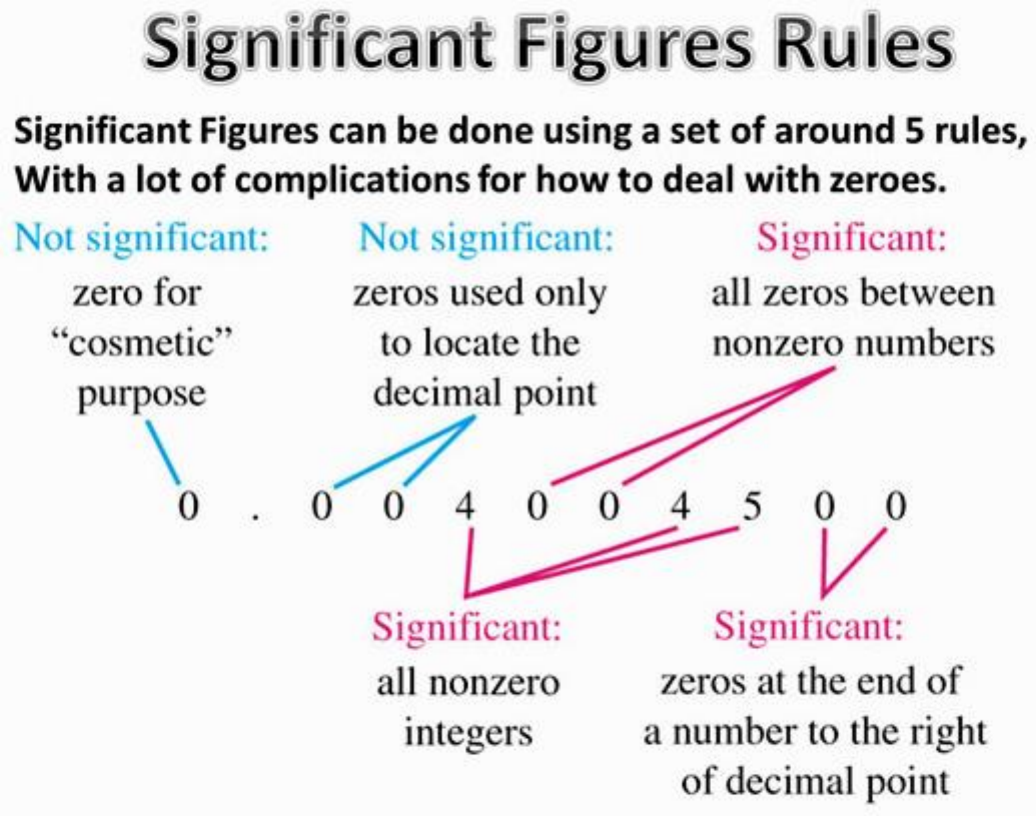
Significant Figures

- Measurements are uncertain, therefore only meaningful numbers are used.
- Three rules in determining significant figures:
  - Non-zero digits are always significant.
  - Any zeros between two significant digits are significant.
  - A final zero or trailing zeros in the decimal portion ONLY are significant.

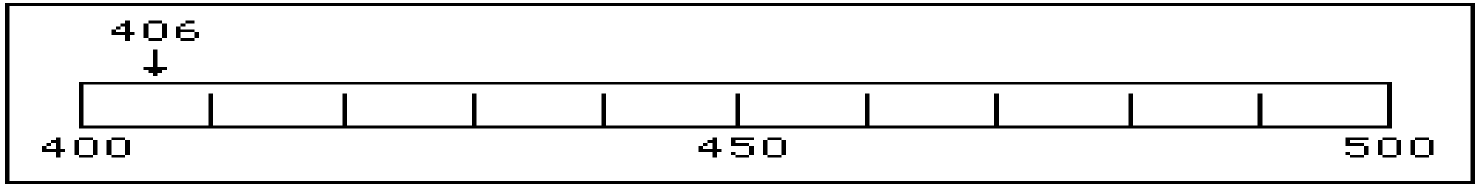


Fundamental Dimensions and Units

- **Significant Figures**
  - Non-zero digits are always significant.
    - How many significant figures are in the following?
      - 25.74
        - 4 sig figs
      - 66.4
        - 3 sig figs
      - 7.3
        - 2 sig figs
      - 12.5
        - 3 sig figs

Fundamental Dimensions and Units

- Significant Figures
  - Any zeros between two significant digits are significant.
    - Given the number 406, how many numbers are significant?



Fundamental Dimensions and Units

- **Significant Figures**
- A final zero or trailing zeros in the decimal portion ONLY are significant.
  - How many significant figures are in the following?
    - 0.00600 – 3 sig figs
    - 0.03040
      - 4 sig figs
    - 2.50×10^{-5}
      - 3 sig figs
    - 4.300×10^{14}
      - 4 sig figs

Fundamental Dimensions and Units

Significant Figures

- Addition and Subtraction
  - Count the number of significant figures in the decimal portion of each number in the problem.
  - Add or subtract in the normal fashion.
  - Round the answer to the LEAST number of places in the decimal portion of any number in the problem

```
  101.25
+3536.2      <- least precise number, only one digit after decimal
+ 123.448
---------
 3760.898    digits to be dropped: 98; last digit retained: 8
    |
 3760.9      <- answer round to one digit after the decimal
```

85.6	3 sig figs
7.25	3 sig figs
95.7	3 sig figs
+ 0.5	1 sig fig
189.05 = 189.1	**4 sig figs**

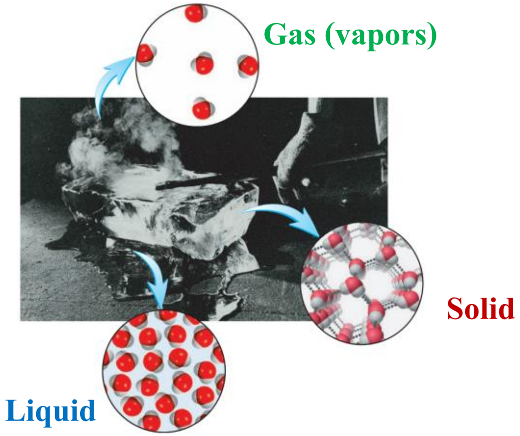
Fundamental Dimensions and Units

- **Density** – the ratio of mass to a unit volume

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

- Where,
  - ρ = density, kg/m^3
  - m = mass, kg
  - V = volume, m^3

- Density is independent of sample size but varies with temperature or the concentration of impurities
- Example: saltwater vs fresh water



Fundamental Dimensions and Units

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Density

Table 2.4 Densities of Common Substances

Substance	Density (g/cm^3)
Air @ STP	0.001293
Southern pine	0.65
Gasoline	0.72
Ethanol	0.802
Ice @ 0°C	0.92
Water @ 4°C	1.00
Rubber	1.5
Glass	2.6
Aluminum	2.7
Wrought iron	7.6
Uranium	18.7

Fundamental Dimensions and Units

Density

- Example 1:
  - A 2 L graduated cylinder initially contains 500 ml of water. An irregularly shaped object having a mass of 105 g is submerged into the water. The final volume of the water in the cylinder is 1025 ml. Determine the density of the object.

Solution:

V1 H_2O: 500 mL

V2 H_2O: 1025 mL

Volume of the object = V1 − V2 = 1025 mL − 500 mL = 525 mL

Mass of the object: 105 g

$\boldsymbol{\rho}$ = m/V = 105 g/525 mL = **0.20 g/mL**

Density

- **Example 2:**

  During an environmental assessment of a natural wetland in the Everglades, it was determined that 1.5 cubic meters of the dry native soil had a mass of 420 kg. Determine the mass of a cubic foot of that same soil.

Solution:

Volume of soil: 1.5 cubic meters (m^3)

Mass of soil: 420 kg

$$\boldsymbol{\rho} = m/V = 420\ kg/1.5\ m^3 = 280\ kg/m^3$$

$$1m^3 = 35.3147\ ft^3$$

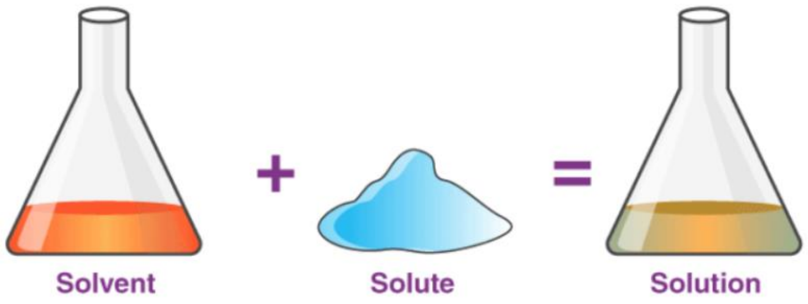
$$\text{Density } (kg/ft^3) = \frac{280\ kg/m^3}{35.3147\ ft^3/m^3} = 7.92\ kg/ft^3$$

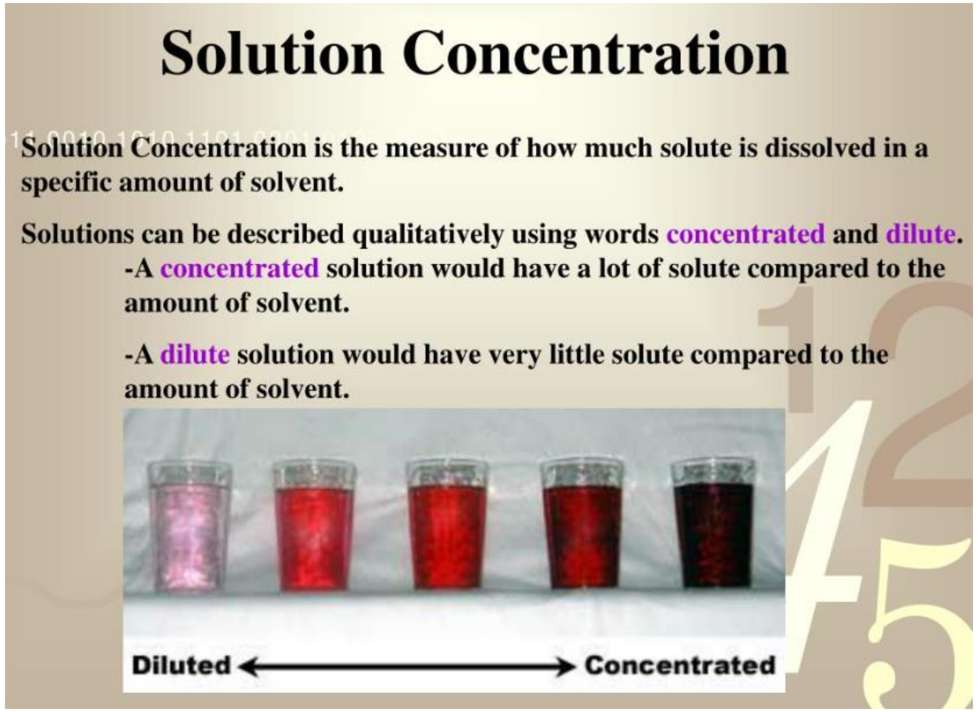
Fundamental Dimensions and Units

- **Concentration** –
  - The amount of a substance in a defined space.
  - The ratio of solute in a solution to either solvent or total solution.
  - Concentration is often described on a mass-per-unit-volume basis

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

  - Where,
    - C = concentration of dissolved substance, mg/L
    - m = mass of solute or dissolved substance, mg
    - V = total volume, L





Fundamental Dimensions and Units

Concentration –

CALCULATING CONCENTRATION OF SOLUTIONS

1. Mass Percent = (mass of solute/mass of solution)100
2. Parts per million = (mass of solute/mass of solution)10^6
3. Mass/volume percent = (mass of solute/mL solution)100
4. Volume percent = (mL solute / mL solution)100
5. Molarity = moles solute / L solution

- A 350 mL sample of drinking water was analyzed and found to contain 0.0046 g of sulfate salts. Calculate the concentration of sulfate salts in this water sample?
- $Mass_{water}$ = $density_{water}$ ($Volume_{water}$)
  = 1.00 g/mL (350 mL)
  = 350 g solution

  ppm = ($mass_{solute}$/$mass_{solution}$) 10^6

  ppm = (0.0046g / 350 g) 10^6

  ppm = 13 ppm

Fundamental Dimensions and Units

Mass-per-unit-mass basis

- The most common mass-based units are parts per million (ppm) and parts per billion (ppb).
- For perspective, the maximum contaminant level goal (MCLG) of mercury in drinking water allowed by the Environmental Protection Agency (EPA) is 0.002 ppm. This means that there can be no more than 0.002 grams of mercury in every million grams of drinking water purified and distributed by your local municipality.
- Assuming the density of water is 1.0 g/ml, this is equivalent to allowing only 2 grams of mercury in approximately 264,000 gallons of drinking water.

Mass-per-unit-mass basis

- **Example 3:**
  - In many environmental aqueous systems, it is appropriate to make the simplifying assumption that 1 mg/L is equal to 1 ppm, provided that the fluid in question is primarily water, so that the density of the solution is essentially 1 g/ml. Show that 1 mg/L = 1 ppm.

Solution:

Converting mg/L to ppm

1 mg/L:

Mass of solute: 1 mg = 0.001 g

Volume of solution: 1 L = 1 kg (since the density of water is 1 mg/L)

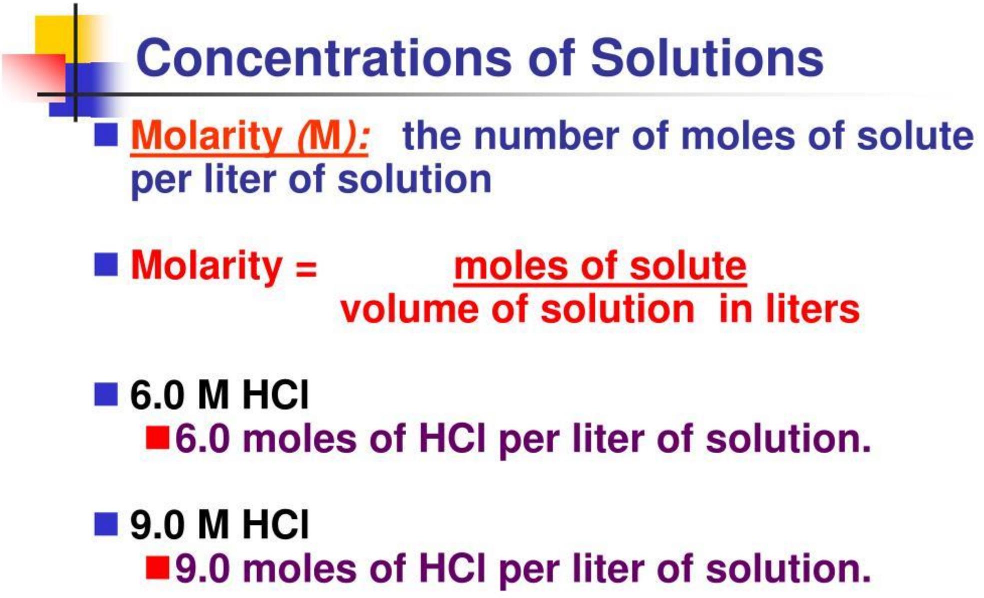
ppm = $\frac{mass\ of\ solute\ (g)}{mass\ of\ solution\ (g)} \times 10^6$

ppm = $\frac{0.001\ g}{1000\ g} \times 10^6$ = 1

1 mg/L = 1 ppm

Fundamental Dimensions and Units

- **Molarity** (M = moles per liter) – one mole per unit volume of substance
  - Avogadro's number defines a mole (mol)
    - 6.02×10^{23} molecules of any material per mole
  - The atomic mass of an element or substance is equal to the mass of one mole of that substance



Mass Percent and Volume Percent

- Mass percent of species A:

$$\text{mass A}\,(\%) = \frac{M_A}{M_A + M_B} \times 100$$

- Where,
  - M_A = mass of compound A, lb_m (g)
  - $M_A + M_A$ = total mass of the solution, lb_m (g)

- Mass Percent and Volume Percent
  - Volume percent of species A:

$$x_A = \frac{\text{moles A in solution}}{\text{total moles of solution}}$$

Mass Percent and Volume Percent

Mass Percent

- Parts of solute in every 100 parts solution.
  - ✓ If a solution is 0.9% by mass, then there are 0.9 grams of solute in every 100 grams of solution.
    - ➢ Or 10 kg solute in every 100 kg solution.
- Since masses are additive, the mass of the solution is the sum of the masses of solute and solvent.

$$\text{Mass Percent} = \frac{\text{Mass of Solute, g}}{\text{Mass of Solution, g}} \times 100\%$$

$$\text{Mass of Solute} + \text{Mass of Solvent} = \text{Mass of Solution}$$

Percent by Volume

Percent volume is the solution concentration that is the volume of solute divided by volume of solution, multiplied by 100.

$$\text{vol\%} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100$$

Find the vol% of a solution of 5.0 ml HCl diluted to 100 ml with water.

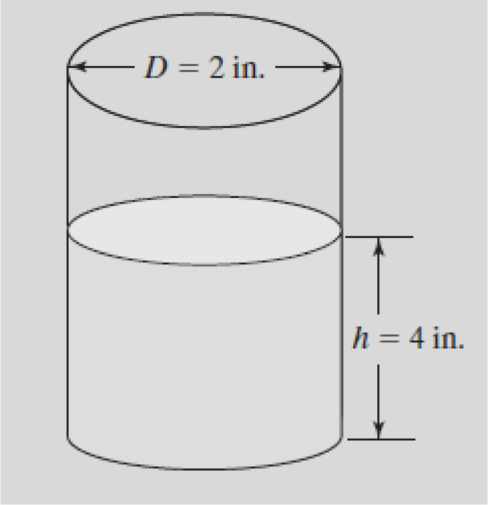
vol% = 5.0 ml / 100 ml x 100
vol% = 5.0%

Percent volume is also called vol% or % v/v.

Mass Percent and Volume Percent

Example 4:

- A researcher has added 2.06 g of the salt sodium nitrate to a cylinder containing water. The cylinder diameter is 2 inches and the depth of the water in the cylinder is 4 inches. Determine the concentration of salt in solution, showing your answer in the units specified.
- a) mg/L
- b) mass %
- c) molarity



Mass of $NaNO_3$: 2.06 g = 2060 mg

Dimeter of cylinder: 2 in

Water depth (h): 4 in

Radius (r) : 2in/2 = 1 in = 2.54 cm

Water depth (h): 4 in = 4 * 2.54 = 10.16 cm

$V = \pi r^2 h$ $\boxed{\pi = 31.4}$

V = 206.23 cm^3 = 206.23 mL = 0.02623 L

a) mg/L

Concentration = 2060 mg/0.20623 L

= **9997.66 mg/L**

b) Mass

Mass (%) = Mass of solute/ Mass of solution * 100

Mass of water = 206.23 mL * 1g/mL = 206.23 g

Mass of solution = 206.23 g + 2.06 g = 208.29 g

Mass % = 2.06 g/208.29 g * 100 = **0.988%**

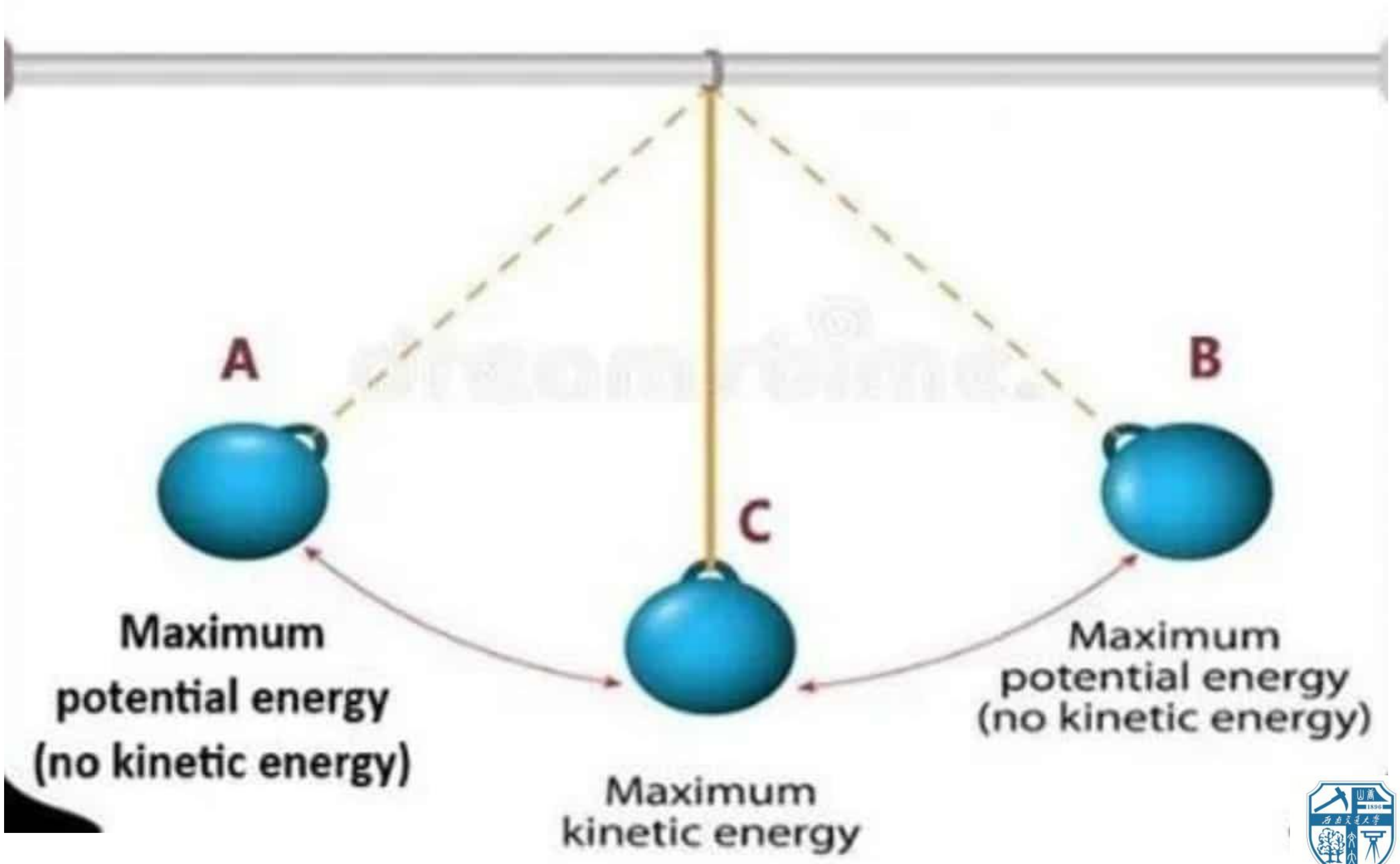
c) Molarity

0.02424 mol/0.20623 L = **0.1176 M**

Physical Laws and Observations in Engineering

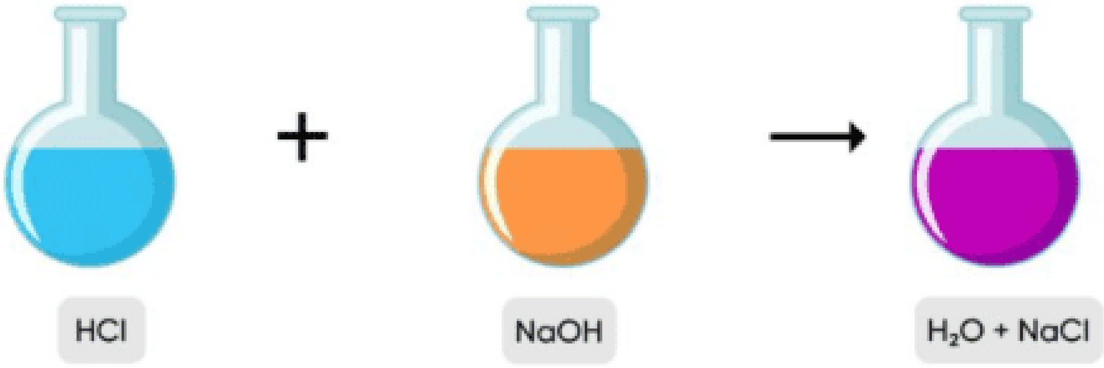
- Engineers apply physical and chemical laws and principles along with mathematics to design, develop, test, and mass-produce products and services that we use in our everyday lives.
- Physical laws are based on observations

Conservation of energy



Conservation of Mass

LAW OF CONSERVATION OF MASS



The Law of Conservation of Mass

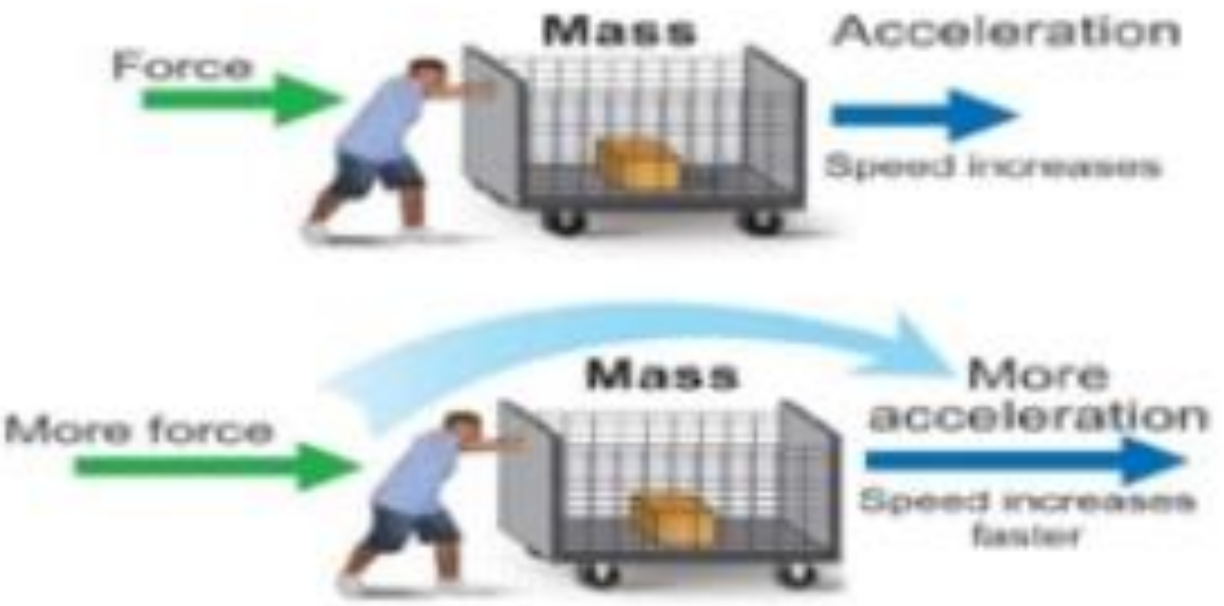
$$\text{mass}_{\text{reactants}} = \text{mass}_{\text{products}}$$

Mass is conserved in a chemical reaction; products have the same mass as reactants.

The law of conservation of mass states that mass is neither created nor destroyed during a chemical reaction—it is conserved.

Newton's Second Law

- If you apply more force to an object, it accelerates at a higher rate.



Thank you