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# **MECHANICS (MEKANIKA)**

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# MECHANICS

*Mechanics* is a branch of the physical sciences that is concerned with the state of **rest** or **motion** of bodies that are subjected to the action of forces.

In general, mechanics may be divided into three branches:

rigid-body mechanics

deformable-body mechanics

fluid mechanics

Rigid-body mechanics is a basic requirement for the study of the mechanics of deformable bodies and the mechanics of fluids.

Furthermore, rigid-body mechanics is subdivided into:

Statics



*Statics* deals with the equilibrium of bodies, that is, those that are either at rest or move with a constant velocity;

We will study this guy in this unit!

Dynamics

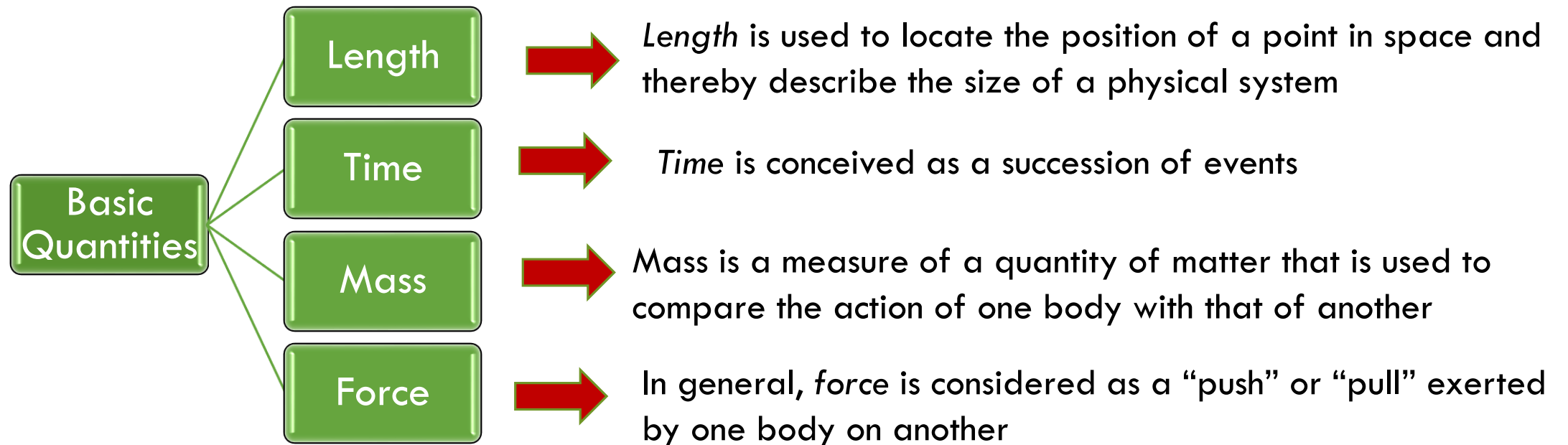


*Dynamics* is concerned with the accelerated motion of bodies.

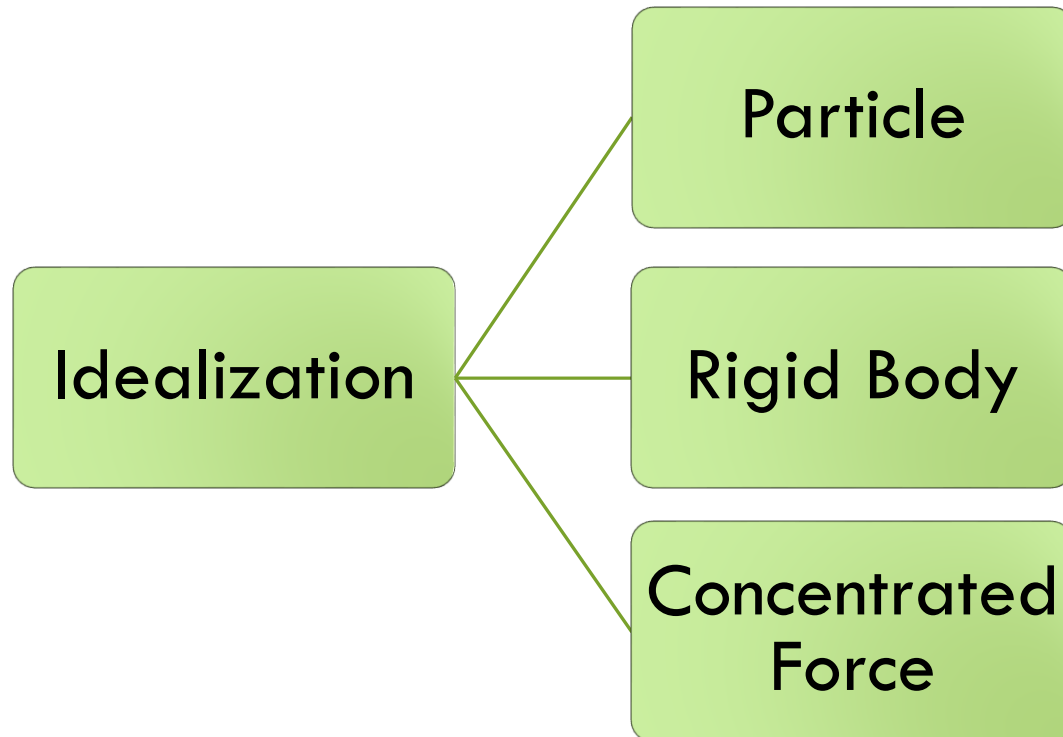
We will discuss this in the other units (Kinematics and Dynamics)

# FUNDAMENTAL CONCEPTS

Before we start our study in engineering mechanics, it is critical to understand the meaning of several fundamental concepts and principles.



# FUNDAMENTAL CONCEPTS (CONTINUED)



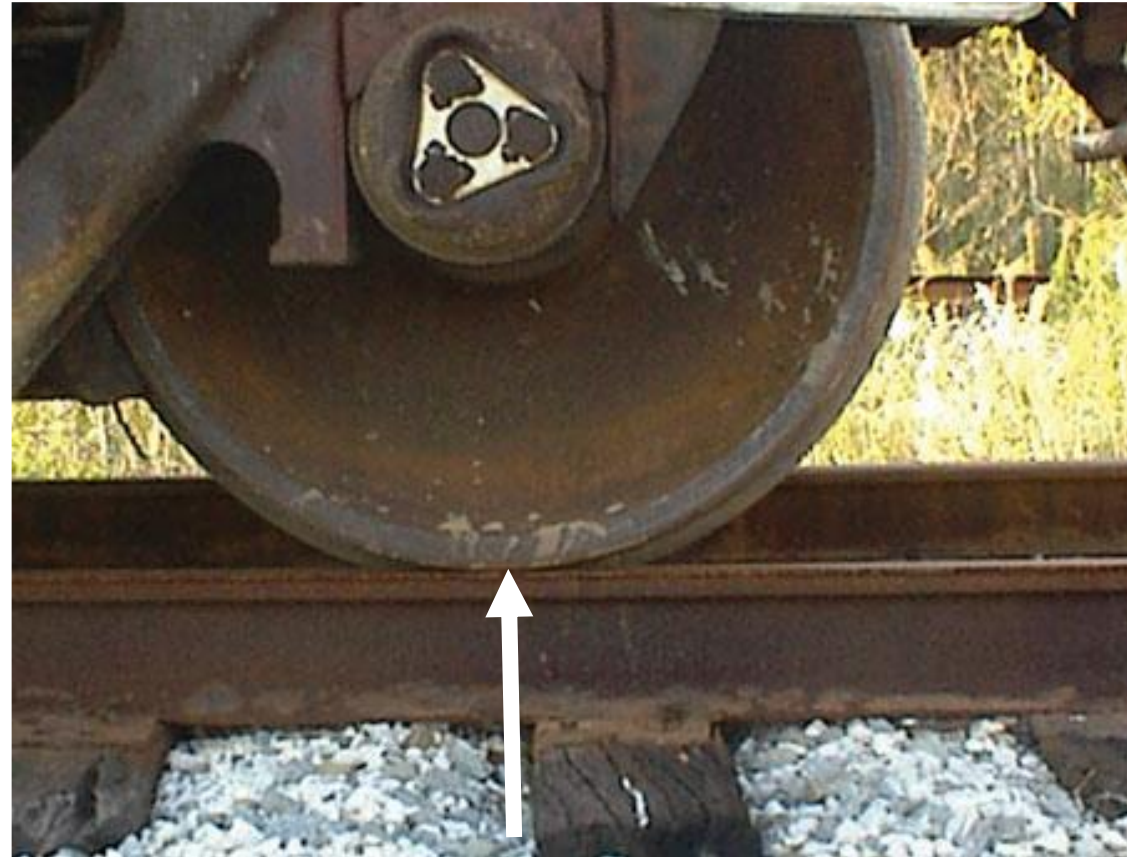
A *particle* has a mass, but a size that can be neglected.  
Examples ?

A *rigid body* can be considered as a combination of a large number of particles in which all the particles remain at a fixed distance from one another, both before and after applying a load

A *concentrated force* represents the effect of a loading which is assumed to act at a point on a body



For any force analysis, we can assume the hook as a particle.



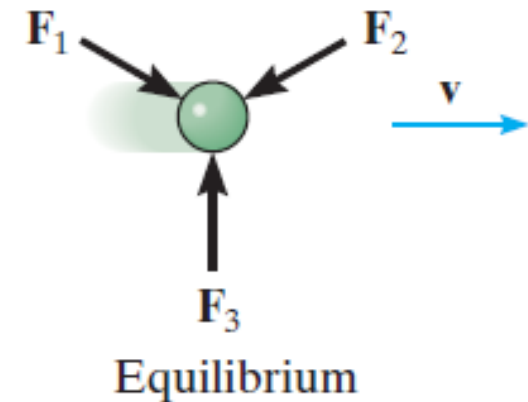
We may consider the steel railroad wheel as a rigid body since it does not deform very much under load and the force acting on it can be considered as a concentrated load.

# FUNDAMENTAL CONCEPTS (CONTINUED)

## Newton's Three Laws of Motion

### First Law

- A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this state provided the particle is not subjected to an unbalanced force



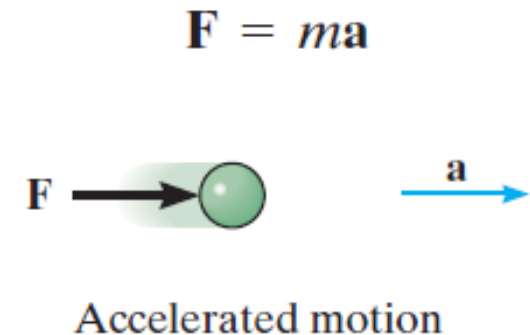


# FUNDAMENTAL CONCEPTS (CONTINUED)

## Newton's Three Laws of Motion

### Second Law

- A particle acted upon by an unbalanced force  $\mathbf{F}$  experiences an acceleration  $\mathbf{a}$  that has the same direction as the force and a magnitude that is directly proportional to the force



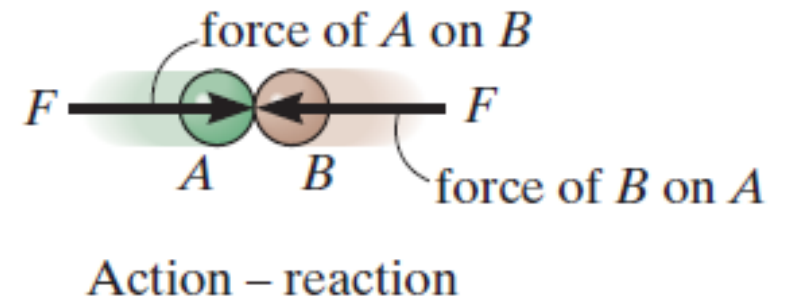
# FUNDAMENTAL CONCEPTS (CONTINUED)

## Newton's Three Laws of Motion

### Third Law

- The mutual forces of action and reaction between two particles are equal, opposite, collinear, and acting on different body

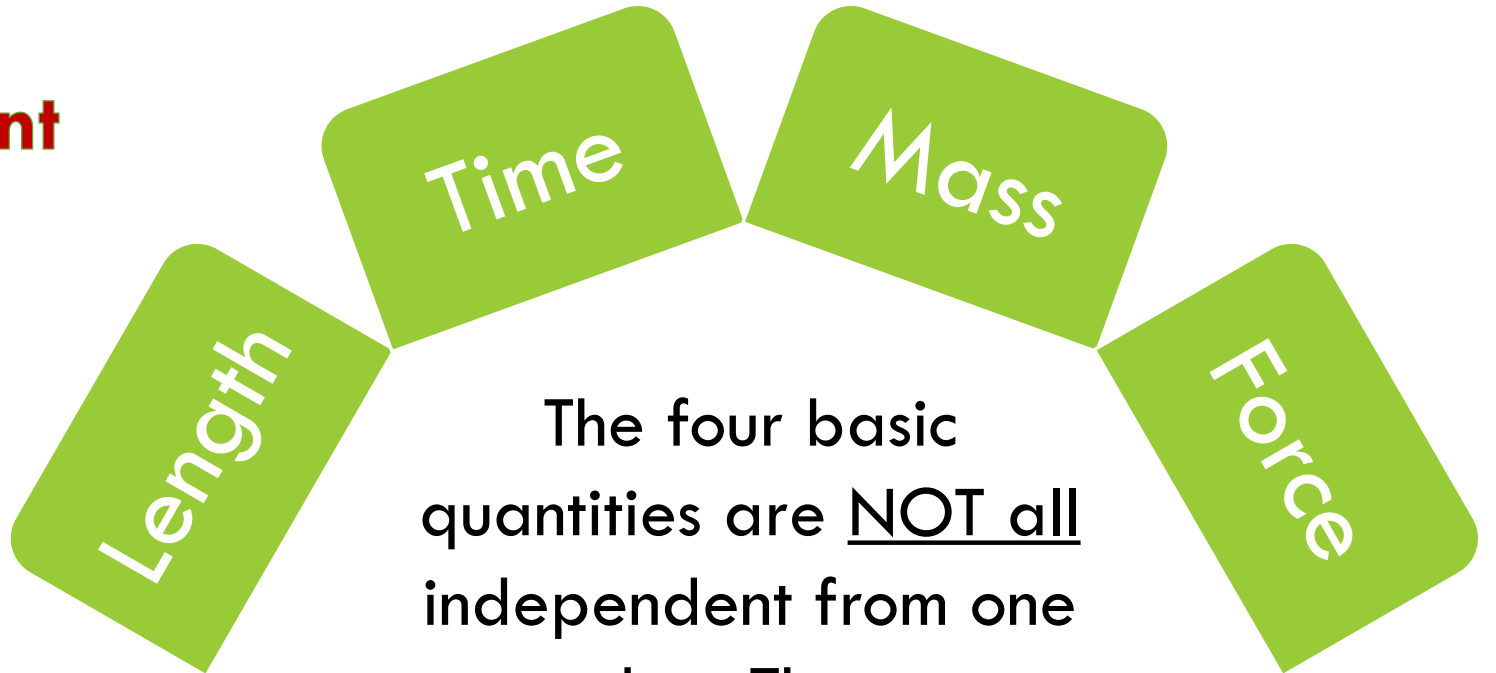
We will use Newton's first and third law extensively in statics!



# FUNDAMENTAL CONCEPTS (CONTINUED)

## Units of Measurement

Because of this, the *units* used to measure these quantities cannot ALL be selected arbitrarily



The four basic quantities are NOT all independent from one another. They are related by Newton's second law;  $\mathbf{F} = m\mathbf{a}$

# FUNDAMENTAL CONCEPTS (CONTINUED)

## Units of Measurement

In consequence,  $\mathbf{F=ma}$  is maintained  
ONLY IF

The three of the four  
units, called based units  
are DEFINED

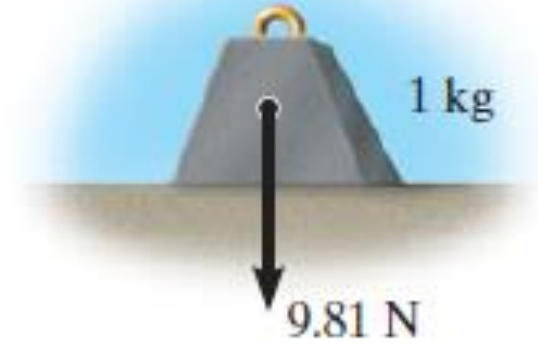
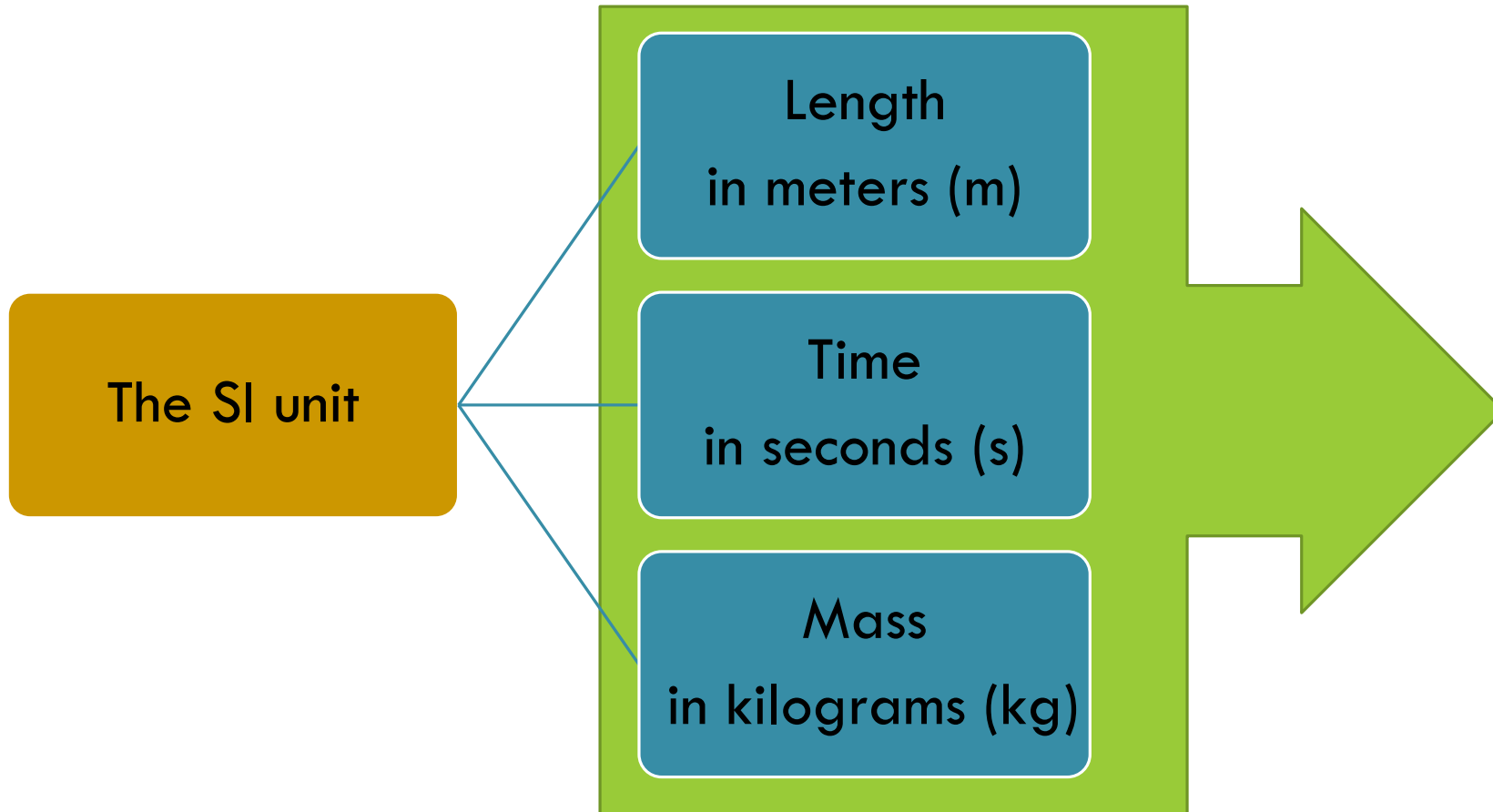


And then the fourth unit is  
DERIVED from equation

# FUNDAMENTAL CONCEPTS (CONTINUED)

## SI Units

### Defined/based units



### Derived unit

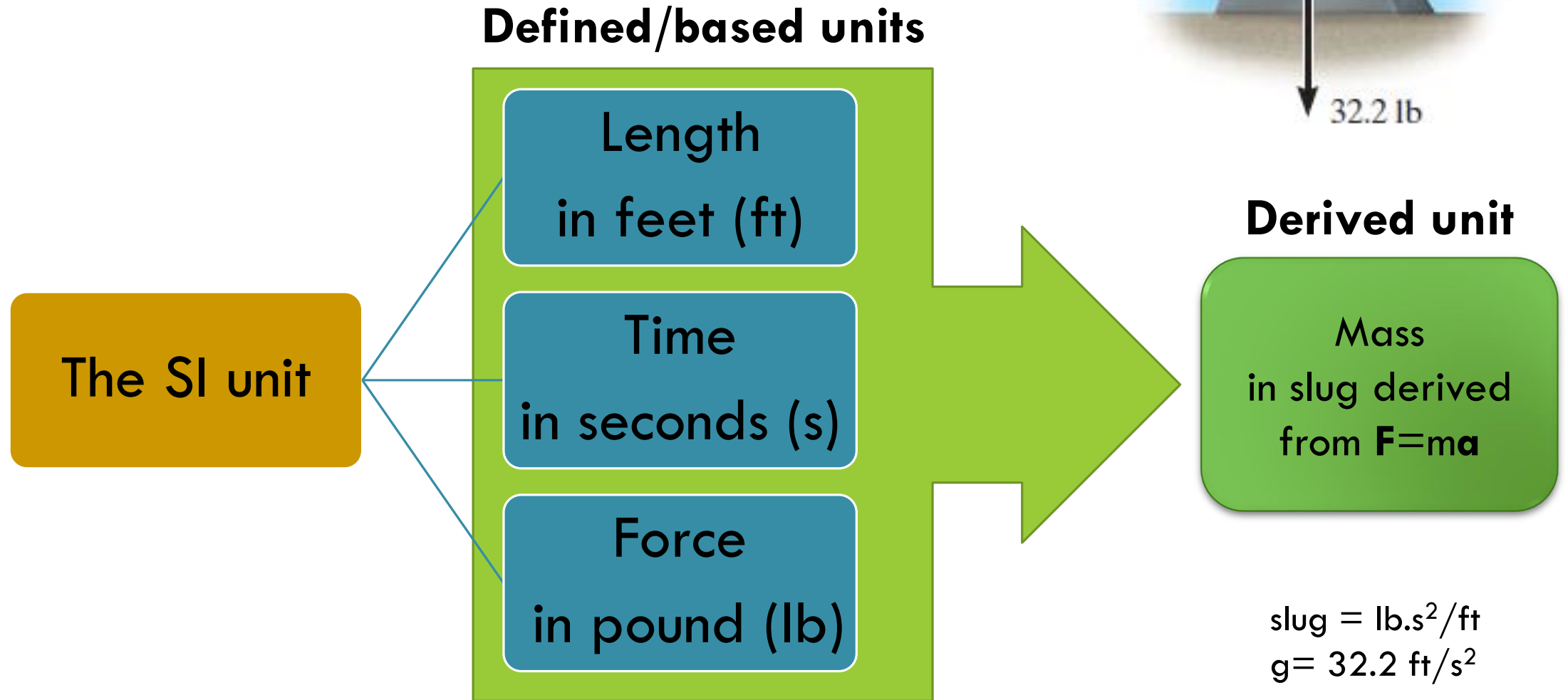
Force in Newton (N) derived from  $F=ma$

$$N = \text{kg}\cdot\text{m}/\text{s}^2$$

$$g = 9.81 \text{ m}/\text{s}^2$$

# FUNDAMENTAL CONCEPTS (CONTINUED)

## U.S. Customary (FPS)



# FUNDAMENTAL CONCEPTS (CONTINUED)

**TABLE 1–1** Systems of Units

Name	Length	Time	Mass	Force
International System of Units SI	meter m	second s	kilogram kg	newton* N $\left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2}\right)$
U.S. Customary FPS	foot ft	second s	slug* $\left(\frac{\text{lb} \cdot \text{s}^2}{\text{ft}}\right)$	pound lb

\*Derived unit.

# FUNDAMENTAL CONCEPTS (CONTINUED)

## Prefixes

	Exponential Form	Prefix	SI Symbol
<i>Multiple</i>			
1 000 000 000	$10^9$	giga	G
1 000 000	$10^6$	mega	M
1 000	$10^3$	kilo	k
<i>Submultiple</i>			
0.001	$10^{-3}$	milli	m
0.000 001	$10^{-6}$	micro	$\mu$
0.000 000 001	$10^{-9}$	nano	n

\* The kilogram is the only base unit that is defined with a prefix.



# FUNDAMENTAL CONCEPTS (CONTINUED)

## Conversion of Units

TABLE 1–2 Conversion Factors

Quantity	Unit of Measurement (FPS)	Equals	Unit of Measurement (SI)
Force	lb		4.448 N
Mass	slug		14.59 kg
Length	ft		0.304 8 m

# FUNDAMENTAL CONCEPTS (CONTINUED)

## Dimensional Homogeneity

Each term of any equation used to describe a physical process must be expressed in the same units

$$s = vt + \frac{1}{2} at^2$$

prove that each term  
has the same units !

“The most effective way of learning the principles of engineering mechanics is to *solve problems*”  
(*R.C. Hibbeler*)

# EXAMPLES

## EXAMPLE 1.1

Convert 2 km/h to m/s How many ft/s is this?

### SOLUTION

Since 1 km = 1000 m and 1 h = 3600 s, the factors of conversion are arranged in the following order, so that a cancellation of the units can be applied:

$$\begin{aligned} 2 \text{ km/h} &= \frac{2 \text{ km}}{\text{h}} \left( \frac{1000 \text{ m}}{\text{km}} \right) \left( \frac{1 \text{ h}}{3600 \text{ s}} \right) \\ &= \frac{2000 \text{ m}}{3600 \text{ s}} = 0.556 \text{ m/s} \end{aligned} \quad \text{Ans.}$$

From Table 1-2, 1 ft = 0.3048 m. Thus,

$$\begin{aligned} 0.556 \text{ m/s} &= \left( \frac{0.556 \text{ m}}{\text{s}} \right) \left( \frac{1 \text{ ft}}{0.3048 \text{ m}} \right) \\ &= 1.82 \text{ ft/s} \end{aligned} \quad \text{Ans.}$$

**NOTE:** Remember to round off the final answer to three significant figures.

## EXAMPLE 1.2

Convert the quantities  $300 \text{ lb} \cdot \text{s}$  and  $52 \text{ slug}/\text{ft}^3$  to appropriate SI units.

### SOLUTION

Using Table 1-2,  $1 \text{ lb} = 4.448 \text{ N}$ .

$$\begin{aligned} 300 \text{ lb} \cdot \text{s} &= 300 \cancel{\text{ lb}} \cdot \text{s} \left( \frac{4.448 \text{ N}}{1 \cancel{\text{ lb}}} \right) \\ &= 1334.5 \text{ N} \cdot \text{s} = 1.33 \text{ kN} \cdot \text{s} \quad \textit{Ans.} \end{aligned}$$

Since  $1 \text{ slug} = 14.593 \text{ kg}$  and  $1 \text{ ft} = 0.304 \text{ m}$ , then

$$\begin{aligned} 52 \text{ slug}/\text{ft}^3 &= \frac{52 \cancel{\text{ slug}}}{\cancel{\text{ft}}^3} \left( \frac{14.59 \text{ kg}}{1 \cancel{\text{ slug}}} \right) \left( \frac{1 \cancel{\text{ ft}}}{0.304 \text{ m}} \right)^3 \\ &= 26.8(10^3) \text{ kg}/\text{m}^3 \\ &= 26.8 \text{ Mg}/\text{m}^3 \quad \textit{Ans.} \end{aligned}$$

## EXAMPLE 1.3

Evaluate each of the following and express with SI units having an appropriate prefix: (a)  $(50 \text{ mN})(6 \text{ GN})$ , (b)  $(400 \text{ mm})(0.6 \text{ MN})^2$ , (c)  $45 \text{ MN}^3/900 \text{ Gg}$ .

### SOLUTION

First convert each number to base units, perform the indicated operations, then choose an appropriate prefix.

#### Part (a)

$$\begin{aligned}(50 \text{ mN})(6 \text{ GN}) &= [50(10^{-3}) \text{ N}][6(10^9) \text{ N}] \\ &= 300(10^6) \text{ N}^2 \\ &= 300(10^6) \cancel{\text{N}}^2 \left( \frac{1 \text{ kN}}{10^3 \cancel{\text{N}}} \right) \left( \frac{1 \text{ kN}}{10^3 \cancel{\text{N}}} \right) \\ &= 300 \text{ kN}^2 \qquad \text{Ans.}\end{aligned}$$

**NOTE:** Keep in mind the convention  $\text{kN}^2 = (\text{kN})^2 = 10^6 \text{ N}^2$ .

**Part (b)**

$$\begin{aligned}(400 \text{ mm})(0.6 \text{ MN})^2 &= [400(10^{-3}) \text{ m}][0.6(10^6) \text{ N}]^2 \\ &= [400(10^{-3}) \text{ m}][0.36(10^{12}) \text{ N}^2] \\ &= 144(10^9) \text{ m} \cdot \text{N}^2 \\ &= 144 \text{ Gm} \cdot \text{N}^2\end{aligned}$$

*Ans.*

We can also write

$$\begin{aligned}144(10^9) \text{ m} \cdot \text{N}^2 &= 144(10^9) \text{ m} \cdot \text{N}^2 \left(\frac{1 \text{ MN}}{10^6 \text{ N}}\right) \left(\frac{1 \text{ MN}}{10^6 \text{ N}}\right) \\ &= 0.144 \text{ m} \cdot \text{MN}^2\end{aligned}$$

*Ans.*

**Part (c)**

$$\begin{aligned}\frac{45 \text{ MN}^3}{900 \text{ Gg}} &= \frac{45(10^6 \text{ N})^3}{900(10^6) \text{ kg}} \\ &= 50(10^9) \text{ N}^3/\text{kg} \\ &= 50(10^9) \text{ N}^3 \left(\frac{1 \text{ kN}}{10^3 \text{ N}}\right)^3 \frac{1}{\text{kg}} \\ &= 50 \text{ kN}^3/\text{kg}\end{aligned}$$

*Ans.*

# SELECTED PROBLEMS

**1-1.** Round off the following numbers to three significant figures: (a) 4.65735 m, (b) 55.578 s, (c) 4555 N, and (d) 2768 kg.

**1-2.** Represent each of the following combinations of units in the correct SI form using an appropriate prefix: (a)  $\mu\text{MN}$ , (b)  $\text{N}/\mu\text{m}$ , (c)  $\text{MN}/\text{ks}^2$ , and (d)  $\text{kN}/\text{ms}$ .

**1-3.** Represent each of the following quantities in the correct SI form using an appropriate prefix: (a) 0.000431 kg, (b)  $35.3(10^3)$  N, and (c) 0.00532 km.



# SELECTED PROBLEMS

**1–9.** The *pascal* (Pa) is actually a very small unit of pressure. To show this, convert  $1 \text{ Pa} = 1 \text{ N/m}^2$  to  $\text{lb/ft}^2$ . Atmospheric pressure at sea level is  $14.7 \text{ lb/in}^2$ . How many pascals is this?

**1–10.** What is the weight in newtons of an object that has a mass of: (a) 10 kg, (b) 0.5 g, and (c) 4.50 Mg? Express the result to three significant figures. Use an appropriate prefix.

**1–11.** Evaluate each of the following to three significant figures and express each answer in SI units using an appropriate prefix: (a)  $354 \text{ mg}(45 \text{ km})/(0.0356 \text{ kN})$ , (b)  $(0.00453 \text{ Mg})(201 \text{ ms})$ , and (c)  $435 \text{ MN}/23.2 \text{ mm}$ .

# SELECTED PROBLEMS

**1–13.** Convert each of the following to three significant figures: (a)  $20 \text{ lb} \cdot \text{ft}$  to  $\text{N} \cdot \text{m}$ , (b)  $450 \text{ lb}/\text{ft}^3$  to  $\text{kN}/\text{m}^3$ , and (c)  $15 \text{ ft}/\text{h}$  to  $\text{mm}/\text{s}$ .

**1–14.** The density (mass/volume) of aluminum is  $5.26 \text{ slug}/\text{ft}^3$ . Determine its density in SI units. Use an appropriate prefix.

**1–15.** Water has a density of  $1.94 \text{ slug}/\text{ft}^3$ . What is the density expressed in SI units? Express the answer to three significant figures.

*All materials for these slides were taken after some modifications from “Engineering Mechanics, Statics and Dynamics, twelfth edition, R.C. Hibbeler”*