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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

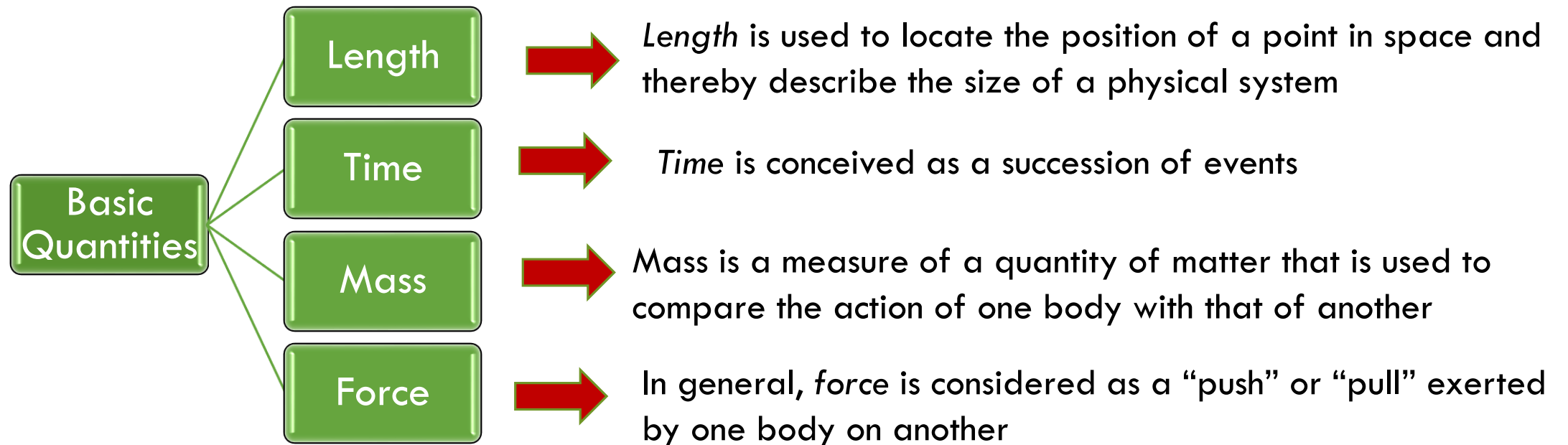


Dynamics is concerned with the accelerated motion of bodies.

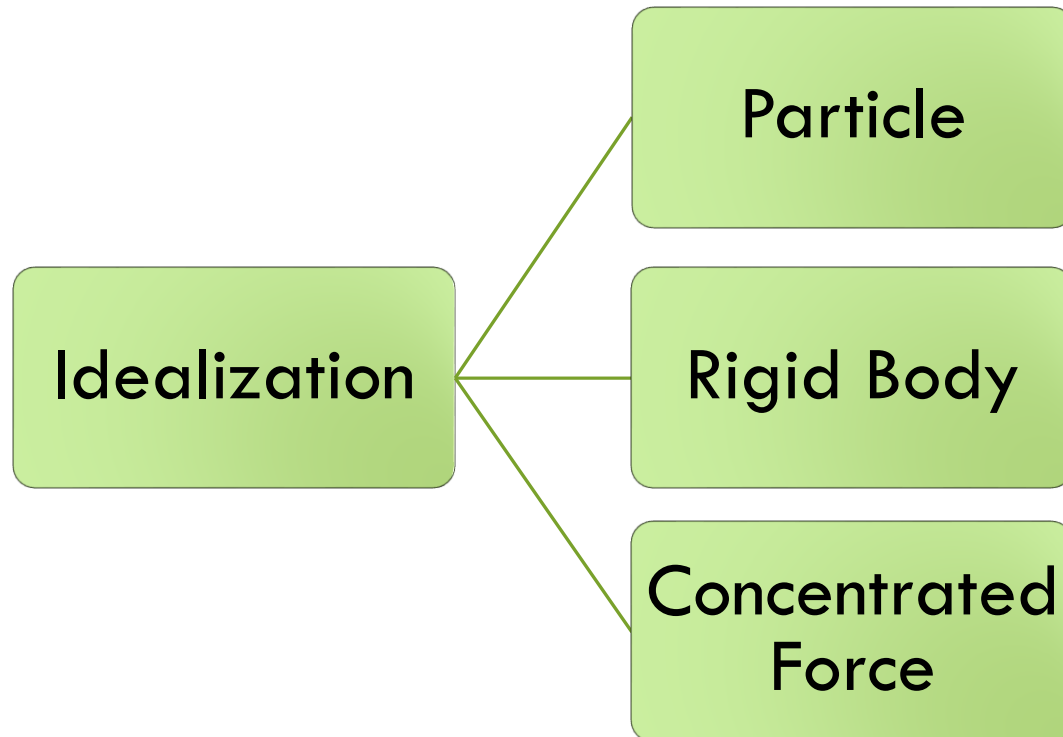
We will discuss this in the other units (Kinematics and Dynamics)

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)



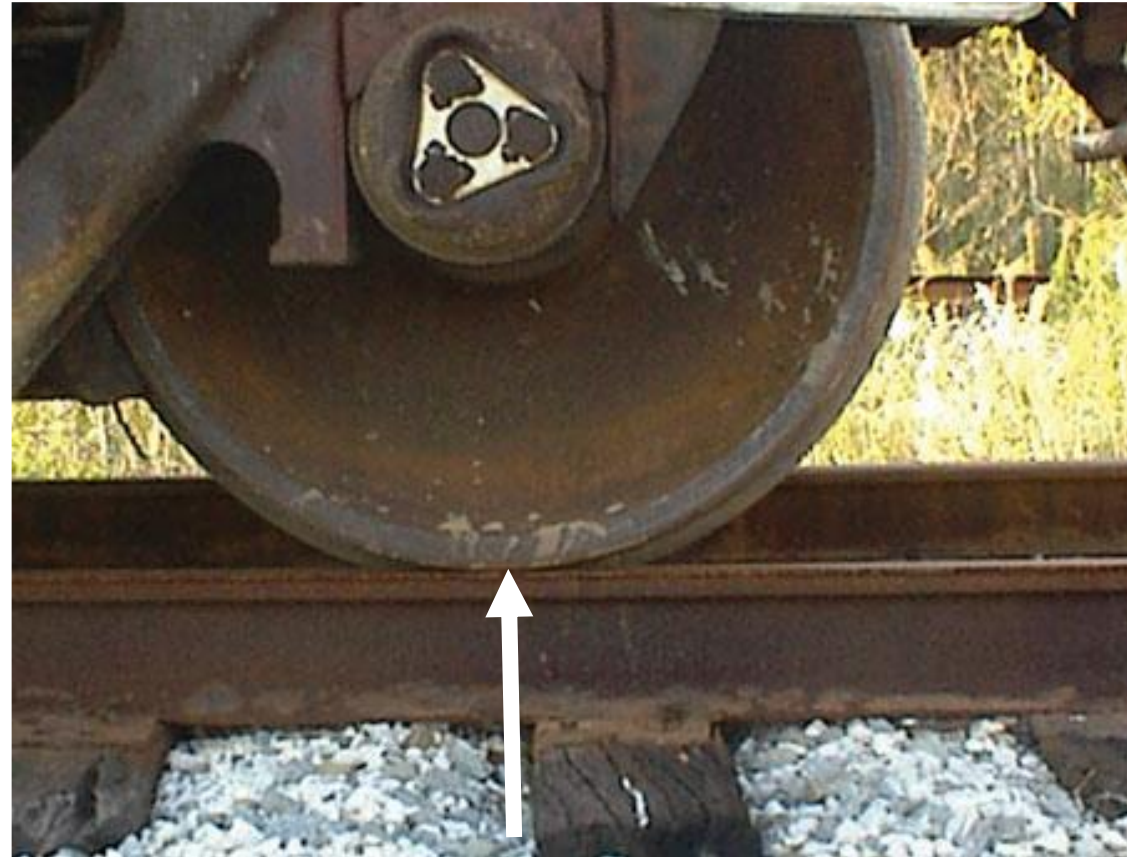
A *particle* has a mass, but a size that can be neglected.
Examples ?

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.



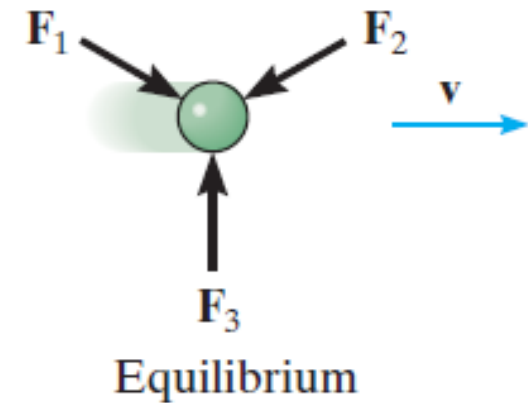
We may consider the steel railroad wheel as a rigid body since it does not deform very much under load and the force acting on it can be considered as a concentrated load.

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

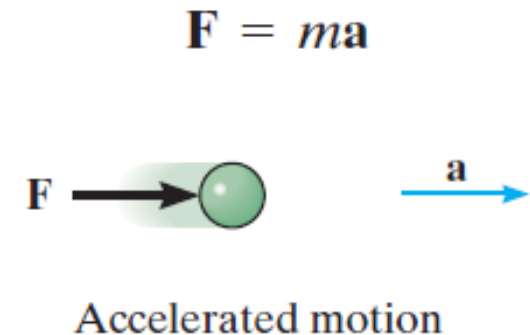


FUNDAMENTAL CONCEPTS (CONTINUED)

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



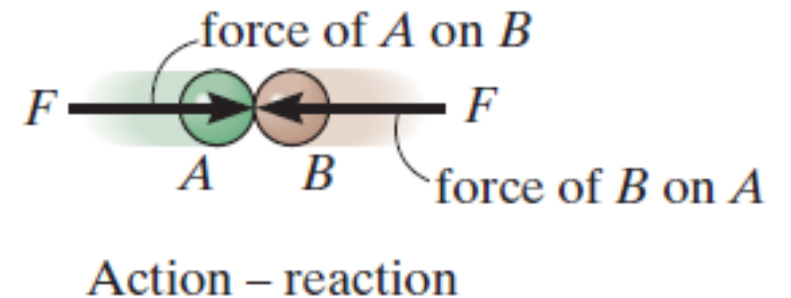
FUNDAMENTAL CONCEPTS (CONTINUED)

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

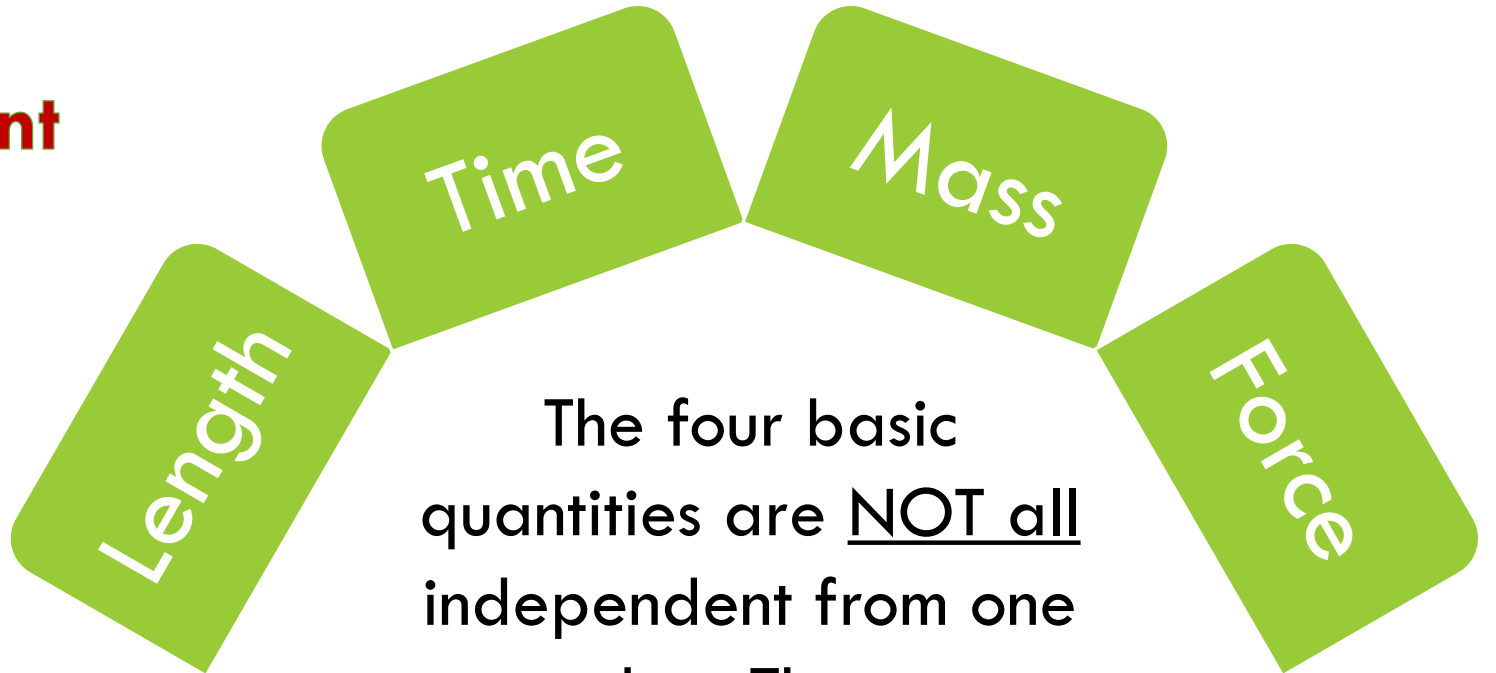
We will use Newton's first and third law extensively in statics!



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

Length
in meters (m)

Time
in seconds (s)

Mass
in kilograms (kg)

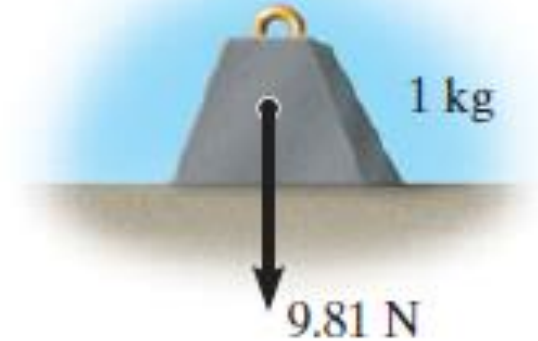
The SI unit

Derived unit

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

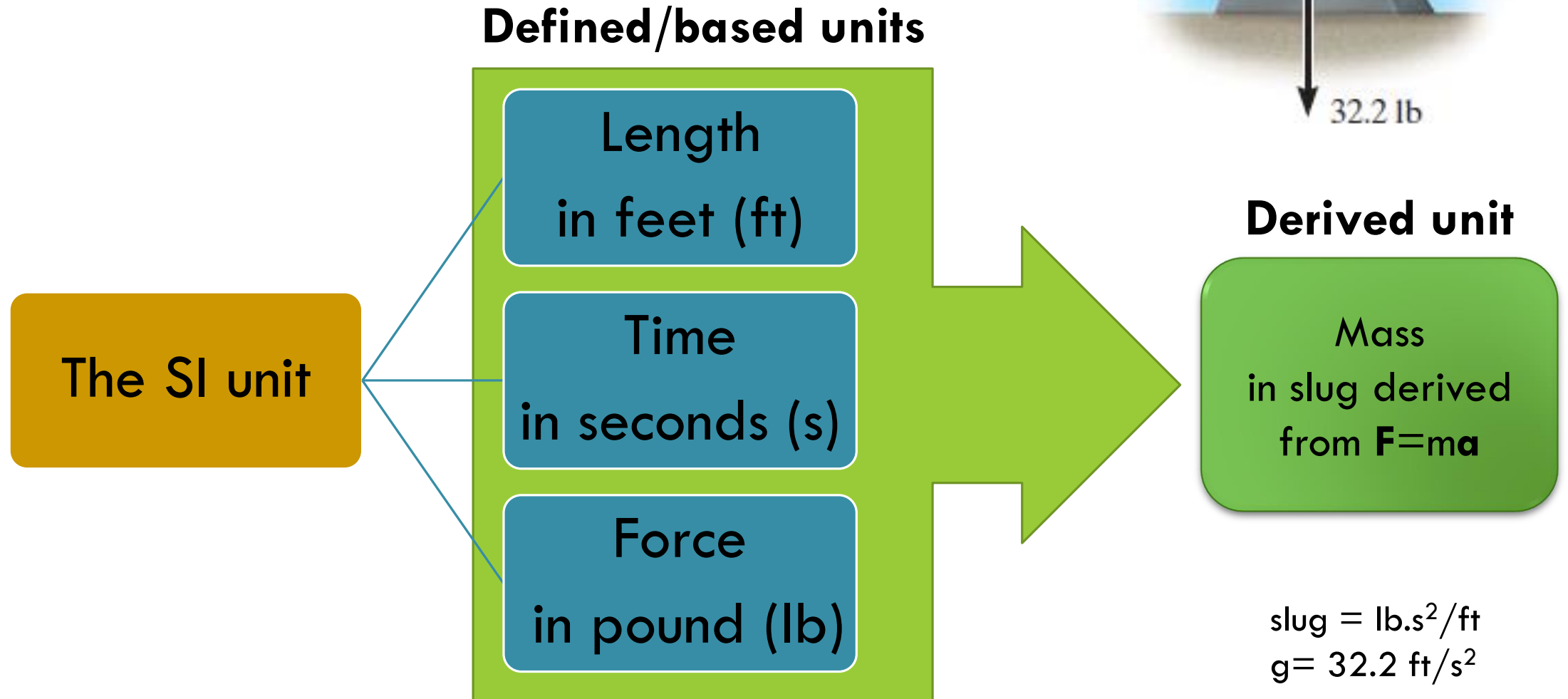
$$N = \text{kg}\cdot\text{m}/\text{s}^2$$

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



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	meter	second	kilogram	newton*
SI	m	s	kg	N $\left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2}\right)$
U.S. Customary	foot	second	slug*	pound
FPS	ft	s	$\left(\frac{\text{lb} \cdot \text{s}^2}{\text{ft}}\right)$	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	μ
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:

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

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

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

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) μMN , (b) $\text{N}/\mu\text{m}$, (c) MN/ks^2 , and (d) kN/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 lb/ft^2 . Atmospheric pressure at sea level is 14.7 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 kN/m^3 , and (c) $15 \text{ ft}/\text{h}$ to mm/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”