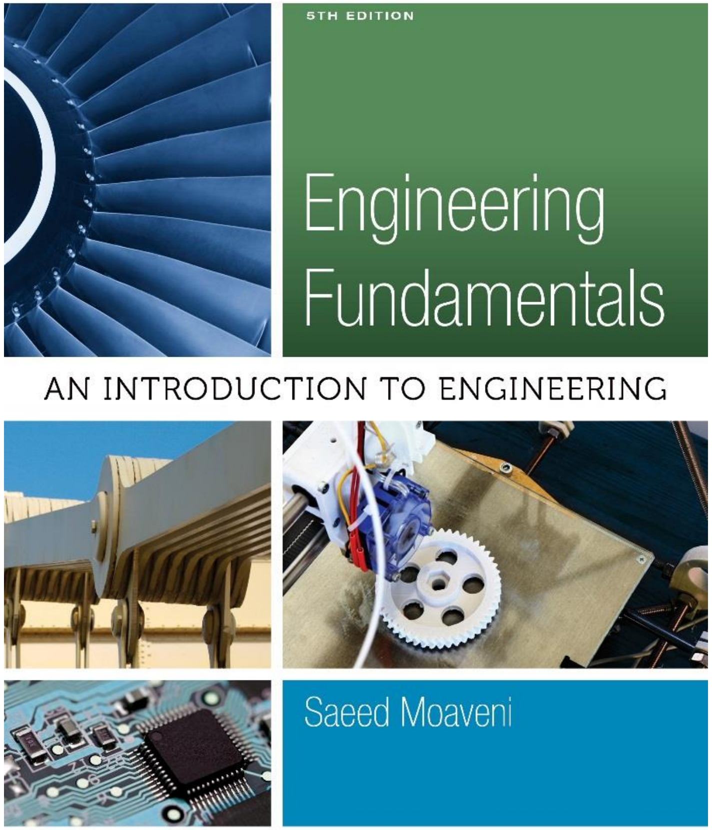


Engineering Fundamentals

An Introduction to Engineering

Chapter 6

Fundamental Dimensions and Units

Learning Objectives

1. **Fundamental Dimensions and Units**

   Explain what they mean and give examples

2. **Systems of Units**

   Describe what systems of units represent and give examples of SI (metric), British, and U.S. Customary units for length, time, mass, force, and temperature

3. **Unit Conversion and Dimensional Homogeneity**

   Know how to convert data from the SI units to British and U.S. Customary units (and vice versa) and check for dimensional homogeneity in formulas

Learning Objectives

4. Significant Digits (Figures)

Explain what they mean and give examples

5. Components and Systems

Describe what they mean and give examples

6. Physical Laws and Observations

State what they mean and give examples

Discussion Starter

Read the discussion starter for Chapter 6 on page 147 (10 minutes). You may discuss your thoughts with the student sitting next to you.

- As you can see, not much has changed since 1996. What are your thoughts?
- Do you think we should switch to metric units, and if so, what are the benefits?

Engineering Fundamentals – Concepts Every Engineer Should Know

- Fundamental dimensions and units
- Length
- Time
- Mass
- Force
- Temperature
- Electric current
- Energy and power

Fundamental Dimensions and Units

Fundamental Dimensions

The physical quantities used to fully describe natural events and our surroundings

- Length
- Time
- Mass
- Temperature
- Electric current
- Amount of substance
- Luminous intensity

Fundamental Dimensions and Units

Units

- Used to measure physical dimensions
- Appropriate divisions of physical dimensions to keep numbers manageable

(e.g.) 19 years old vs. 612,000,000 seconds old

Before You Go On

Answer the following questions to test your understanding of the preceding section.

1. Name at least four fundamental dimensions.
2. What is the difference between a dimension and a unit?
3. Name at least two units that you use every day.
4. What is the difference between mass and weight?

Before You Go On

Vocabulary—State the meaning of the following terms:

- Dimension ___
- Unit ___
- Mass ___
- Temperature ___

Systems of Units

Common systems of units

- International System (SI) of Units
- British Gravitational (BG) System of Units
- U.S. Customary Units

International System (SI) of Units

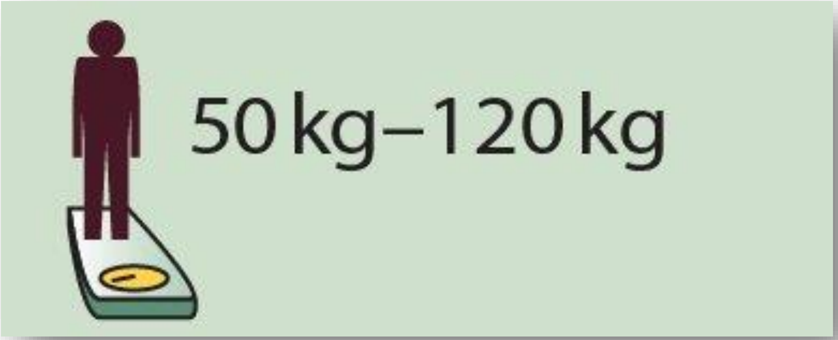
- Most common system of units used in the world
- Examples of SI units: m, kg, ampere
- Approved by the General Conference on Weights and Measures (CGPM)
- Series of prefixes & symbols of decimal multiples (adapted by CGPM, 1960)

Fundamental Unit of Length

Meter (m)

Length of the path traveled by light in a vacuum during a time interval of 1/299,792,458 of a second

Fundamental Unit of Mass



Kilogram (kg)

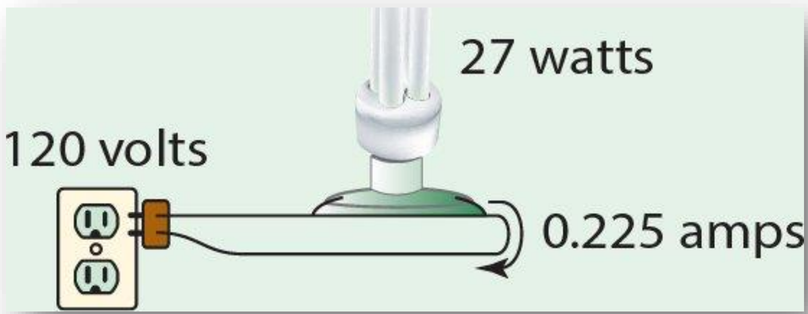
A unit of mass; it is equal to the mass of the international prototype of the kilogram

Fundamental Unit of Time

Second (s)

Duration of 9,192,631,770 periods of the radiation corresponding to the transition between the 2 hyperfine levels of the ground state of cesium 133 atom

Fundamental Unit of Electric Current



Ampere (A)

Constant current that, if maintained in 2 straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in a vacuum, would produce between these conductors a force equal to $2x10^{-7}$N/m length

Fundamental Unit of Temperature

Kelvin (K)

Unit of thermodynamic temperature, is the fraction 1/273.16 of thermodynamic temperature of the triple point of water

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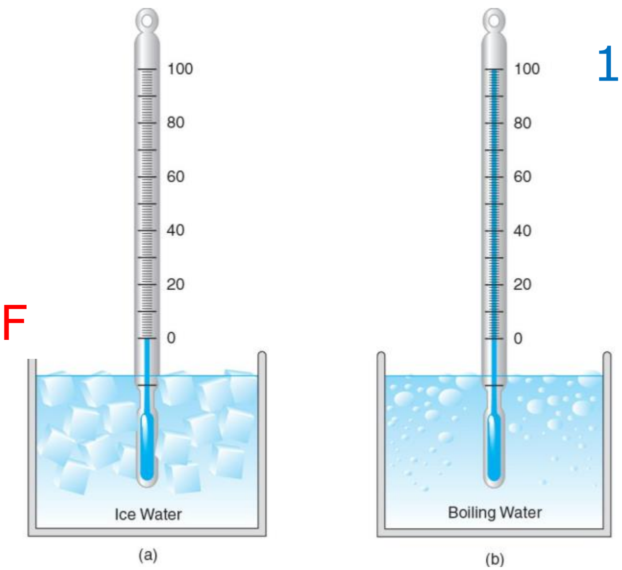
Units of Temperature

100°C = 212°F

0°C = 32°F



- Both the Celsius and the Fahrenheit scales are arbitrarily defined
- The Kelvin and Rankine scales are absolute scales

$$\text{temperature (K)} = \text{temperature (°C)} + 273$$

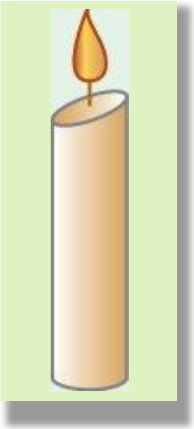
Fundamental Unit of Amount of Substance

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)

The amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilograms of carbon 12

Fundamental Unit of Luminous Intensity



Candela (cd)

In a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian

SI – Prefix & Symbol

TABLE 6.2 The List of Decimal Multiples and Prefixes Used with SI Base Units

Multiplication Factors	Prefix	SI Symbol
1,000,000,000,000,000,000,000,000 = 10^{24}	yotta	Y
1,000,000,000,000,000,000,000 = 10^{21}	zetta	Z
1,000,000,000,000,000,000 = 10^{18}	exa	E
1,000,000,000,000,000 = 10^{15}	peta	P
1,000,000,000,000 = 10^{12}	tera	T
1,000,000,000 = 10^{9}	giga	G
1,000,000 = 10^{6}	mega	M
1000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deka	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000,001 = 10^{-6}	micro	μ
0.000,000,001 = 10^{-9}	nano	n
0.000,000,000,001 = 10^{-12}	pico	p
0.000,000,000,000,001 = 10^{-15}	femto	f
0.000,000,000,000,000,001 = 10^{-18}	atto	a
0.000,000,000,000,000,000,001 = 10^{-21}	zepto	z
0.000,000,000,000,000,000,000,001 = 10^{-24}	yocto	y

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Examples of Derived Units in Engineering

TABLE 6.3 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	$V \cdot s/A$
Absorbed dose of radiation	gray	Gy	J/kg or m^2/s^2

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British Gravitation (BG) System of Units

- Primary units
  - Length : foot (ft), 1 ft = 0.3048 m
  - Time : second
  - Mass : slug, 1lb = (1 slug)(1 ft/s2)

    Derived from Newton's second law
  - Force : pound (lb), 1 lb = 4.448 N
  - Temperature: Fahrenheit (°F), Rankine (°R)

$$T(^\circ F) = \frac{9}{5}T(^\circ C) + 32 \qquad T(^\circ R) = \frac{9}{5}T(K)$$

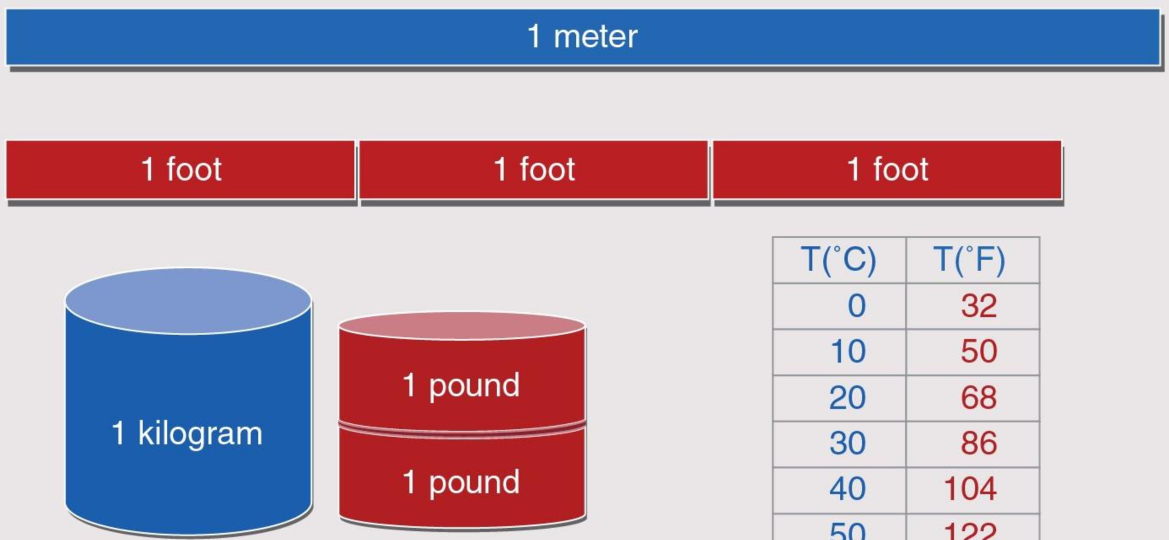
U.S. Customary System of Units

- Primary units
  - Length : foot (ft), 1 ft = 0.3048 m
  - Time : second
  - Mass : pound mass (lbm)

    1 lbm = 0.453592 kg, 1 slug = 32.2 lbm
  - Force : pound force (lbf)

    Defined as the weight of an object having a mass of 1 lbm at sea level and at a latitude of 45^{o}, where acceleration due to gravity is 32.2 ft/s^{2} , 1 lbf = 4.448 N
  - Temperature: Fahrenheit (°F), Rankine (°R)

SI vs. U.S. Customary Units



T(˚C)	T(˚F)
0	32
10	50
20	68
30	86
40	104
50	122
60	140
70	158
80	176
90	194
100	212

Examples of SI Units in Everyday Use

TABLE 6.4 Examples of SI Units in Everyday use

Examples of SI Unit Usage	SI Units Used
Camera film	35 mm
Medication dose such as pills	100 mg, 250 mg, or 500 mg
Sports:	
Swimming	100 m breaststroke or butterfly stroke
Running	100 m, 200 m, 400 m, 5000 m, and so on
Automobile engine capacity	2.2 L (liter), 3.8 L, and so on
Light bulbs	60 W, 100 W, or 150 W
Electric consumption	kWh (kilowatt-hour)
Radio broadcasting signal frequencies	88–108 MHz (FM broadcast band)
	0.54–1.6 MHz (AM broadcast band)
Police, fire signal frequencies	153–159 MHz
Global positioning system signals	1575.42 MHz and 1227.60 MHz

Examples of U.S. Customary Units in Everyday Use

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)

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Before You Go On

Answer the following questions to test your understanding of the preceding section.

1. What are the two most common systems of units?
2. What are the base SI units?
3. Name at least three prefixes and symbols of decimal multiples of SI units.
4. What are the units of mass and weight in U.S.?
5. What do we mean by absolute zero temperature?
6. What are the units of mass and weight in BGS?

Before You Go On

Vocabulary—State the meaning of the following terms:

- Absolute Zero Temperature ___
- Rankine Temperature Scale ___
- Kelvin Temperature Scale ___
- One Slug ___

Unit Conversion

- Important to learn to convert information from one system of units to another *correctly*
- Always show the appropriate units that go with your calculations
- See the conversion tables given in the book

Example 6.3 – Unit Conversion

Given: A person who is 6′-3″ tall and weighs 185 pound force (lbf)

Find: Height and weight in SI units

Solution:

The person's height, H

$$H = \left(6\ \text{ft} + 3\ \text{in}\left(\frac{1\ \text{ft}}{12\ \text{in}}\right)\right)\left(\frac{0.3048\ \text{m}}{1\ \text{ft}}\right) = 1.905\ \text{m}$$

The person's weight, W

$$W = (185\ \text{lb}_f)\left(\frac{4.448\ \text{N}}{1\ \text{lb}_f}\right) = 822.88\ \text{N}$$

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Example 6.3 – Unit Conversion

(Cont.)

Given: A person is driving a car at a speed of 65 miles per hour (mph) over a distance of 25 miles

Find: Speed and distance in SI units

Solution: Speed of car, S

$$S = \left(65\,\frac{\text{miles}}{\text{h}}\right)\left(\frac{5280\text{ ft}}{1\text{ mile}}\right)\left(\frac{0.3048\text{ m}}{1\text{ ft}}\right) = 104{,}607\text{ m/h} = 104.607\text{ km/h}$$

$$\text{or}\quad S = \left(104{,}607\,\frac{\text{m}}{\text{h}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 29.057\text{ m/s}$$

Distance traveled, D

$$D = (25\text{ miles})\left(\frac{5280\text{ ft}}{1\text{ mile}}\right)\left(\frac{0.3048\text{ m}}{1\text{ ft}}\right)\left(\frac{1\text{ km}}{1000\text{ m}}\right) = 40.233\text{ km}$$

Example 6.1 – Unit Conversion

(Cont.)

Given: Outside temperature is 80°F and has a density of 0.0735 pound mass per cubic foot (lbm/ft³)

Find: Temperature in SI units

Solution:

Temperatur e of air, T

$$T(°\mathrm{C}) = \frac{5}{9}\left[T(°\mathrm{F}) - 32\right] = \frac{5}{9}(80 - 32) = 26.7°\mathrm{C}$$

Example 6.5 – Unit Conversion

Given: Area A = 100 cm^2

Find: A in m^2

Solution:

$$A = \left(100\,\text{cm}^2\right)\left(\frac{1\,\text{m}}{100\,\text{cm}}\right)^2 = 0.01\,\text{m}^2$$

Example 6.5 – Unit Conversion

(Cont.)

Given: Volume V = 1000 mm^3

Find: V in m^3

Solution:

$$V = \left(1000\ \text{mm}^3\right)\left(\frac{1\ \text{m}}{1000\ \text{mm}}\right)^3 = 10^{-6}\ \text{m}^3$$

Example 6.5 – Unit Conversion

(Cont.)

Given: Atmosphere pressure $P = 10^5\ \mathrm{N/m^2}$

Find: P in $\mathrm{lbf/in^2}$

Solution:

$$P = \left(10^5\ \frac{\mathrm{N}}{\mathrm{m}^2}\right)\left(\frac{1\ \mathrm{lb}}{4.448\ \mathrm{N}}\right)\left(\frac{0.0254\ \mathrm{m}}{1\ \mathrm{in}}\right)^2 = 14.5\ \mathrm{lb/in}^2$$

Example 6.2 – Unit Conversion

(Cont.)

Given: Density of water = 1000 kg/m^3

Find: Density in lbm/ft^3

Solution:

$$\rho = \left(1000\,\frac{\text{kg}}{\text{m}^3}\right)\left(\frac{1\,\text{lbm}}{0.4536\,\text{kg}}\right)\left(\frac{1\,\text{m}}{3.28\,\text{ft}}\right)^3 = 62.5\,\text{lbm/ft}^3$$

Dimensional Homogeneity

- All formulas used in engineering analysis must be dimensionally homogeneous

(e.g.) *Given*: $\underbrace{L}_{\text{length}} = \underbrace{a + b + c}_{\text{length}}$

Left hand side of equation should have the same dimension as right hand side of equation

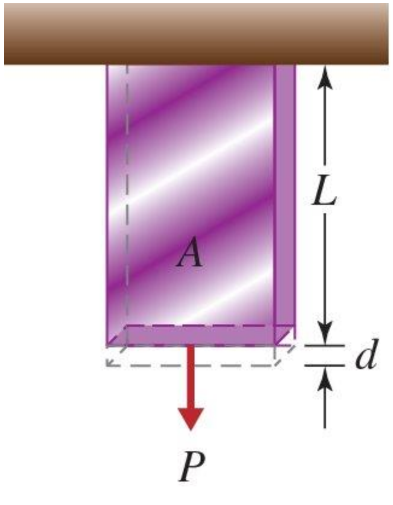
FIGURE 6.4 Example of elements that are not homogeneous.

Example 6.6 – Dimensional Homogeneity

Given: $$d = \frac{PL}{AE}$$

where

d = end deflection, in m
P = applied load, in N
L = length of bar, in m
A = cross-sectional area of bar, in m^2
E = modulus of elasticity



Find: The units for modulus of elasticity

Example 6.6 – Dimensional Homogeneity

(Cont.)

Solution:

$$d = \frac{PL}{AE} \quad \Rightarrow \quad \mathrm{m} = \frac{(\mathrm{N})(\mathrm{m})}{\mathrm{m}^2 E}$$

$$E = \frac{(\mathrm{N})(\mathrm{m})}{\mathrm{m}(\mathrm{m}^2)} = \frac{\mathrm{N}}{\mathrm{m}^2}$$

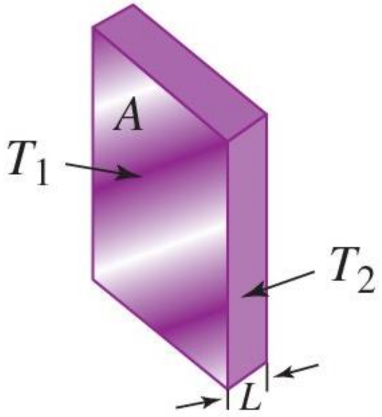
Example 6.6 – Dimensional Homogeneity

(Cont.)

Given: The heat transfer rate through a solid material

Fourier's law:

$$q = kA\frac{T_1 - T_2}{L}$$



where

q = heat transfer rate
k = thermal conductivity of the solid material in W/m·°C
A = area in m^2
$T_1 - T_2$ = temperature difference, °C
L = thickness of the material, m

Find: The units for *q*

Example 6.6 – Dimension Homogeneity

(Cont.)

Solution:

$$q = kA\frac{T_1 - T_2}{L} = \left(\frac{\mathrm{W}}{\mathrm{m}\cdot{}^\circ\mathrm{C}}\right)\left(\mathrm{m}^2\right)\left(\frac{{}^\circ\mathrm{C}}{\mathrm{m}}\right) = \mathrm{W}$$

Numerical versus Symbolic Solutions

Numerical solution

Data is given for problems to be solved

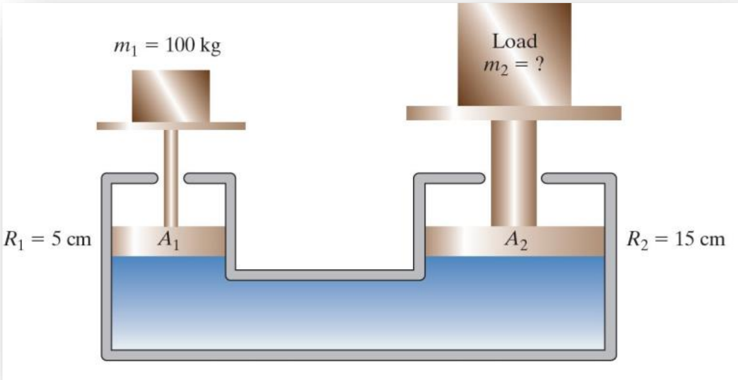
Symbolic solution

The steps and the final answer are presented with variables that could be substituted with data–if necessary

Example 6.7 – Numerical Versus Symbolic Solutions

Given: The hydraulic system shown

Find: The load that can be lifted: m_2



Numerical solution:

$$F_1 = m_1 g = 100\text{ kg}\left(9.81\text{ m/s}^2\right) = 981\text{ N}$$

$$F_2 = \frac{A_2}{A_1} F_1 = \frac{\pi(0.15\text{ m})^2}{\pi(0.05\text{ m})^2}(981\text{ N}) = 8829\text{ N}$$

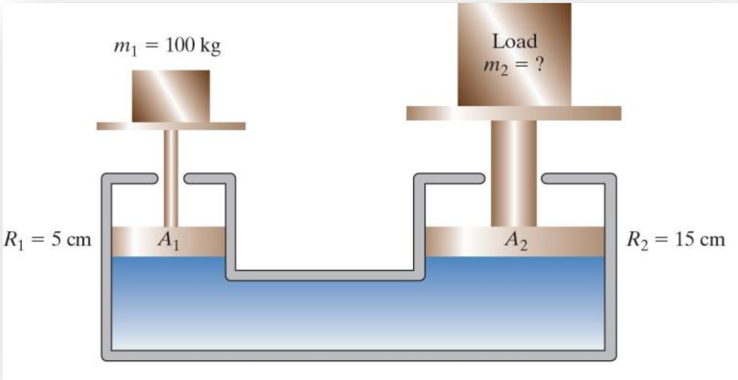
$$F_2 = m_2\left(9.81\text{ m/s}^2\right) = 8829\text{N} \quad \Rightarrow \quad m_2 = 900\text{ kg}$$

Example 6.7 – Numerical Versus Symbolic Solutions

(Cont.)

Given: The hydraulic system shown

Find: The load that can be lifted: m_2



Symbolic solution:

$$F_2 = \frac{A_2}{A_1} F_1 \quad \Leftrightarrow \quad m_2 \cancel{g} = \frac{\cancel{\pi}(R_2)^2}{\cancel{\pi}(R_1)^2}(m_1 \cancel{g})$$

$$\boxed{m_2 = \frac{R_2^2}{R_1^2} m_1} = \frac{(0.15\,\mathrm{m})^2}{(0.05\,\mathrm{m})^2}(100\,\mathrm{kg}) = 900\,\mathrm{kg}$$

Before You Go On

Answer the following questions to test your understanding of the preceding section.

1. Why is it important to know how to convert from one system of units to another?
2. What do we mean by dimensional homogeneity? Give an example.
3. Show the steps that you would take to convert your height from feet and inches to meters and centimeters.
4. Show the steps that you would take to convert your weight from pound-force to Newtons.

Before You Go On

Vocabulary—State the meaning of the following terms:

- Dimensional Homogeneity ___
- Unit Conversion ___

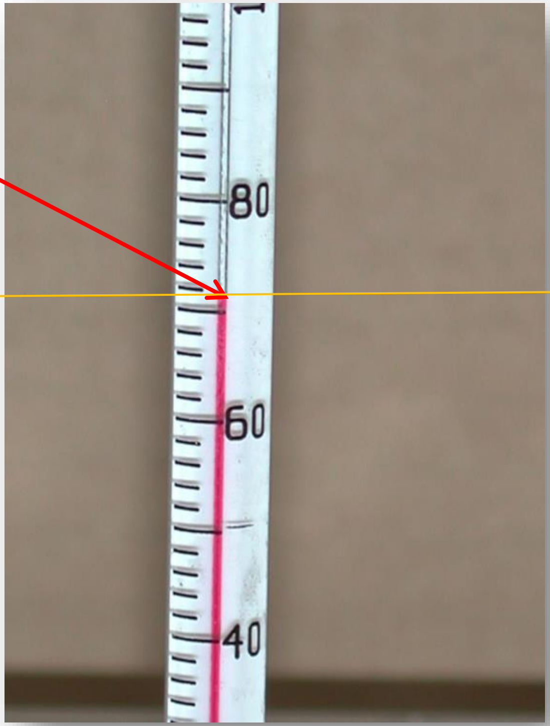
Significant Digits (Figures)

- Engineers make measurements and carry out calculations
- Engineers record the results of measurements and calculations using numbers
- Significant digits (figures) represent and convey the extent to which recorded or computed data is dependable

Significant Digits – How to Record a Measurement

What should we record for this temperature measurement?

Between the smallest scale division



Least count
One half of the smallest scale division

The least count is 1°F
(the smallest division is 2°F)

71 ± 1°F

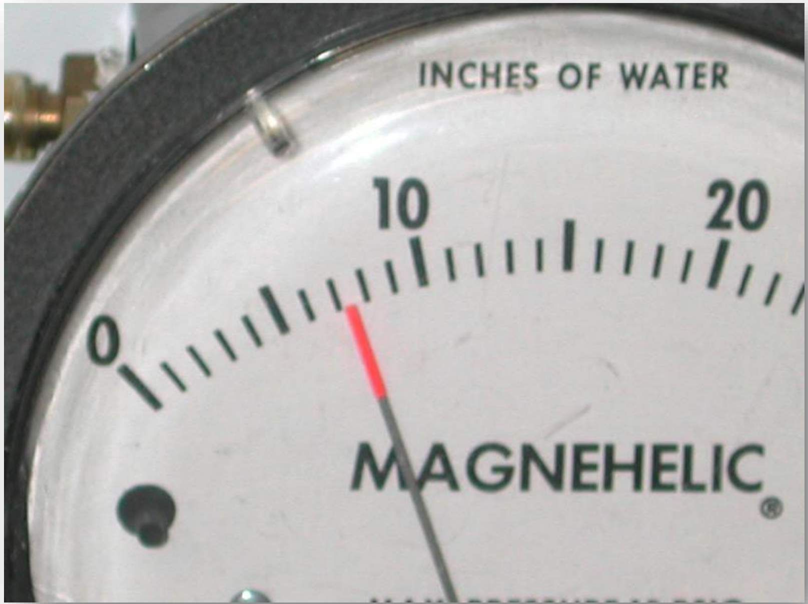
Significant Digits – How to Record a Measurement

What should we record for the length?

The least count is 0.05 in.
(the smallest division is 0.1 in.)

Significant Digits – How to Record a Measurement

What should we record for this pressure?



The least count is 0.5 in.
(the smallest division is 1 in.)

Significant Digits

- 175, 25.5, 1.85, and 0.00125 each have three significant digits
- The number of significant digits for the number 1500 is not clear
  - It could be 2, 3, or 4
  - If recorded as 1.5×10^3 or 15×10^2, then 2 significant digits

Significant Digits – Addition and Subtraction Rules

The result of the calculation should be recorded with the last significant digit in the result determined by the position of the last column of digits common to all of the numbers being added or subtracted.

For example,

152.47	or		132.853
+ 3.9		-	5
156.37			127.853
156.3			127

The result should be recorded this way

Significant Digits – Multiplication and Division Rules

The result of the calculation should be recorded with the least number of significant digits given by any of the numbers used in the calculation

For example,

$$\begin{array}{r} 152.47 \\ \times \quad 3.9 \\ \hline 594.633 \end{array} \quad \text{or} \quad \begin{array}{r} 152.47 \\ \div \quad 3.9 \\ \hline 39.0948717949 \end{array}$$

← 5 significant digits

← 2

5.9×10^2

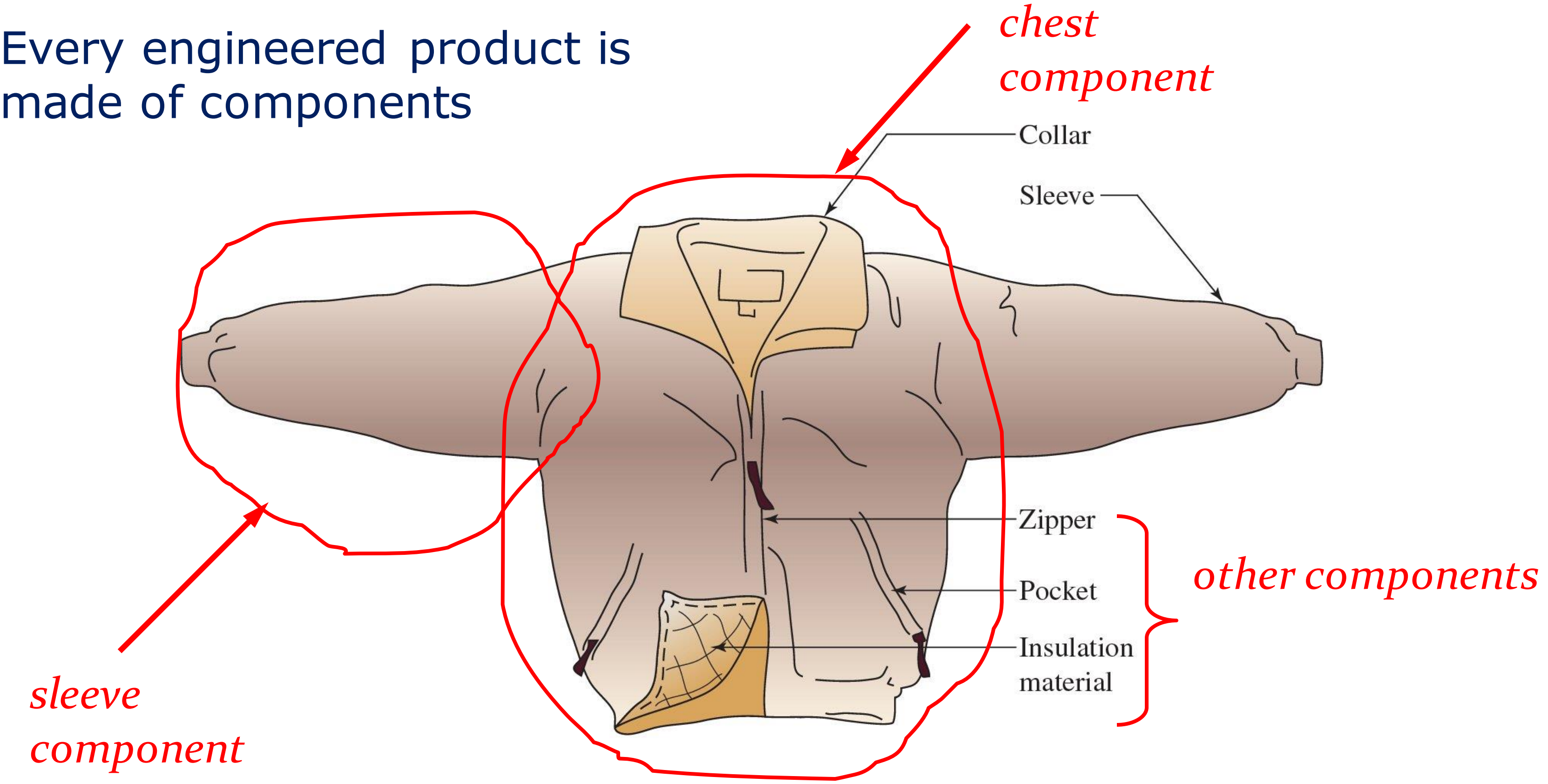
39 ← The result should be recorded with 2 significant digits

Components and Systems

- Every product is considered a system that serves a purpose
- Any given engineered product or engineering system is made up of smaller parts called components
- The components of a well-designed engineering system should function and fit well together

Components and Systems

Every engineered product is made of components



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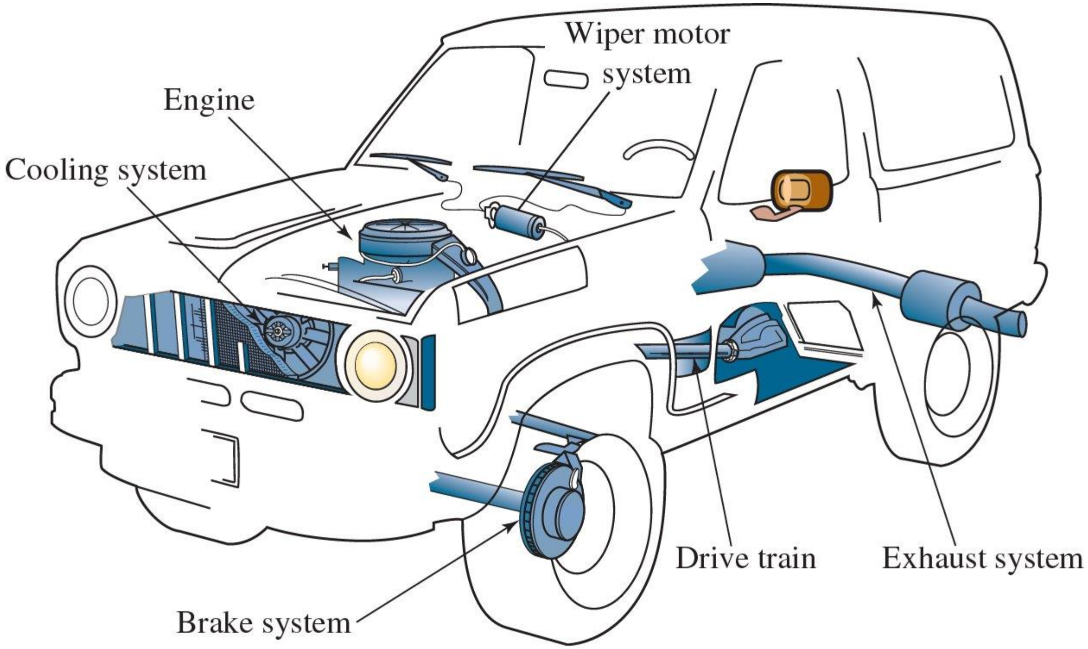
Components and Systems



Components:
- Cooling system
- Engine
- Wiper motor system
- Exhaust system
- Drive train
- Brake system

System:
- Vehicle

Before You Go On

Answer the following questions to test your understanding of the preceding section.

1. What is the difference between a component and a system?
2. What are the major components of a building?
3. How would you define the major components for a supermarket?
4. What are the major components of a bicycle?

Before You Go On

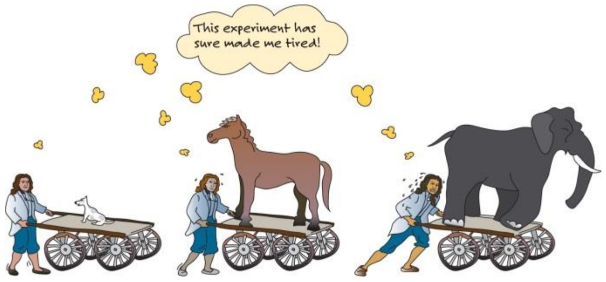
Vocabulary—State the meaning of the following terms:

- A component ___
- A system ___

Physical Laws and Observations

- Physical laws are based on observation and experimentation and are expressed using mathematical formulas

- Engineers apply physical and chemical laws and principles along with mathematics to design, develop, test, and produce products and services that we use in our everyday lives



Physical Laws and Observations

For example,

- Second law of thermodynamics
  - Heat flows spontaneously from a high-temperature region to a low-temperature region
  - When a hot object is placed next to a cold object, the hot object gets cooler and the cold object gets warmer; the cold object does not get colder

Physical Laws and Observations

- Conservation of mass

  The rate by which mass enters a system minus the rate by which it leaves the system should equal the rate of increase or decrease of mass within the system

- Conservation of energy
- Newton's second law of motion

  Direct relationship between the push, the mass of the object being pushed, and the acceleration of mass

Physical Laws and Observations

- Physical laws are based on observations
- Some physical laws may not fully describe all possible situations
- Some laws are stated in a particular way to keep the mathematical expression simple
- Engineering correlations are based on experimental results and have limited applications

Before You Go On

Answer the following questions to test your understanding of the preceding section.

1. What do we mean by a physical law and what are they based on?
2. Give two examples of physical laws.
3. In your own words, describe the conservation of mass.

Before You Go On

Vocabulary—State the meaning of the following terms:

- Physical Law ___
- Correlation ___

Learning Engineering Fundamental Concepts and Design Variables from Fundamental Dimensions

- Chapters 7–12: Engineering Fundamentals
- Understand fundamental concepts
- We only need a few physical quantities (fundamental dimensions) to describe events and our surroundings
- With the help of these fundamental dimensions, we can define or derive engineering variables that are commonly used in analysis and design