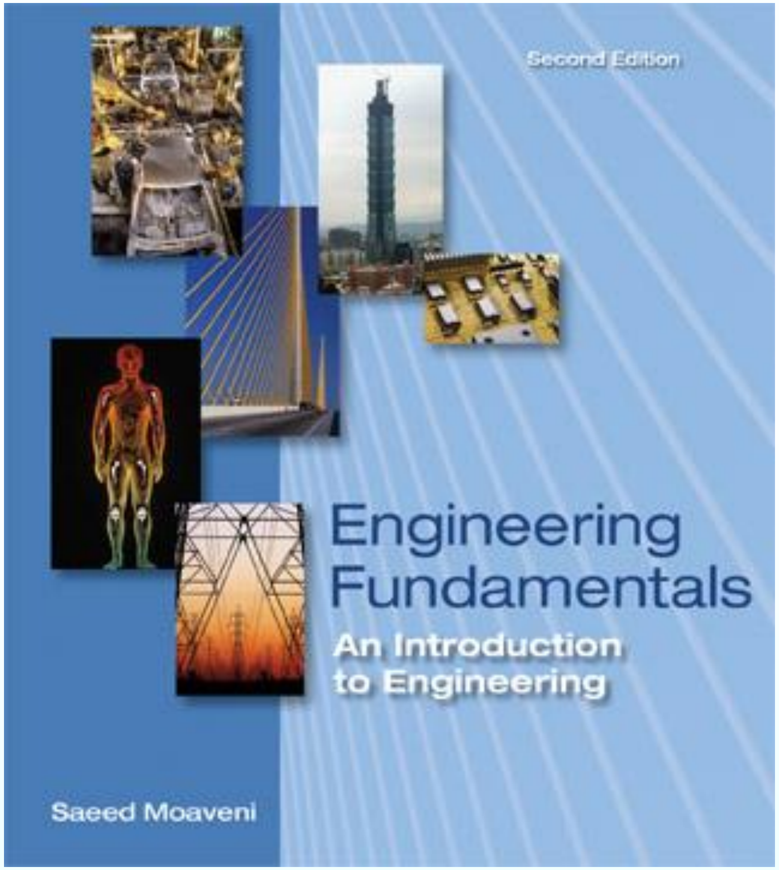
CHAPTER 6

Fundamental Dimensions and Units



Engineering system, made of several components

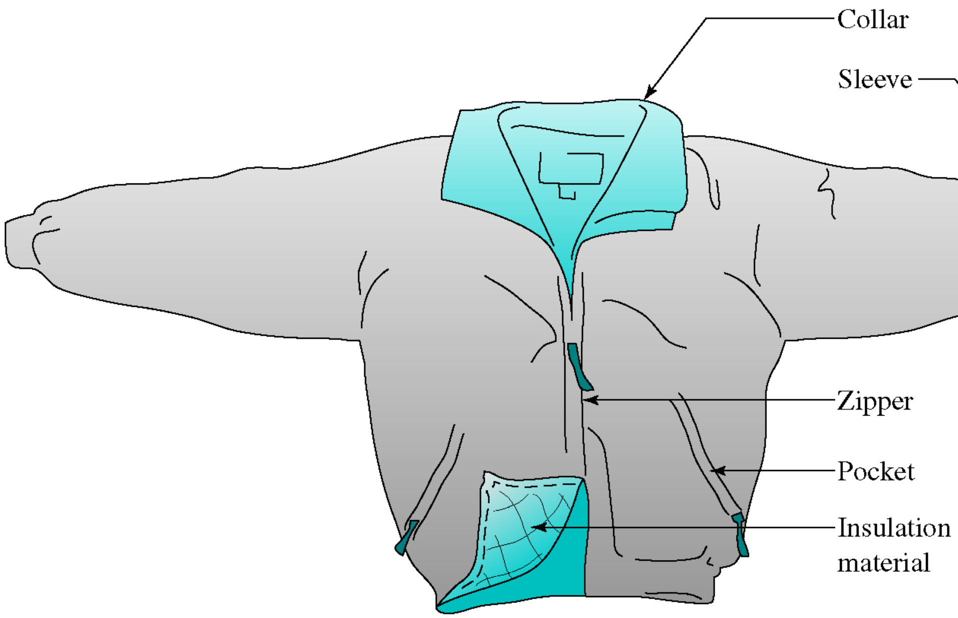


Figure 6.5
A simple system and its components.

Another engineering system, made of several components

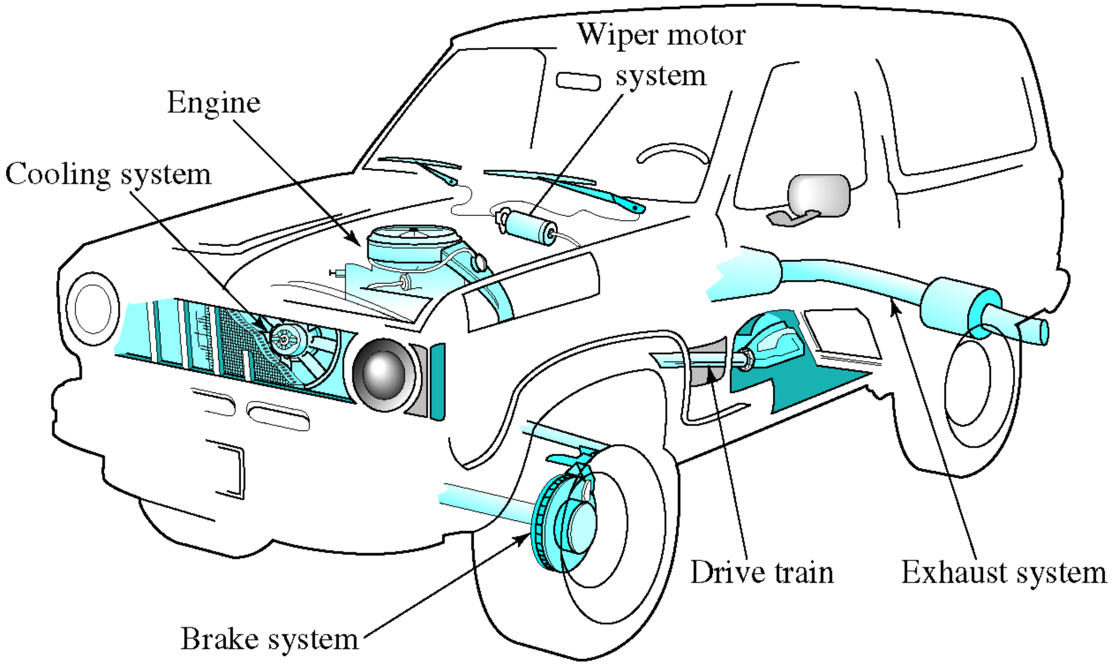


Figure 6.6
An engineering system and its main components.

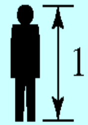
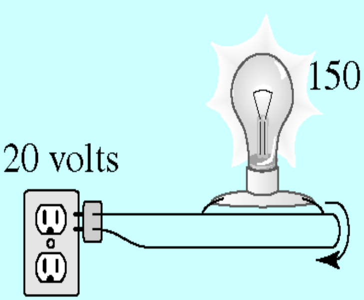
International System (SI) of units

- SI is the most common system of units in use in the world today

Definitions of base units

- The ***meter*** is the length of the path traveled by light in a vacuum during a time interval of 1/299,792,458 of a second.
- The ***kilogram*** is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
- The ***second*** is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
- The ***ampere*** is that constant current which, if maintained in two 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 2 X 10^7 Newtons per meter of length.
- The ***kelvin,*** The unit of Kelvin is related to the degree celsius, according to K = °C + 273.16.
- The **mole** is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012Kg of carbon 12
- The **candela** is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hz and that has a radiant intensity in that direction of 1/683 W/steradian

TABLE 6.1 A List of SI Base (Fundamental) 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
Electric current	 150 watts 120 volts 1.25 amps	Ampere	A

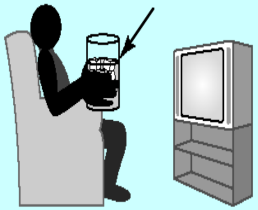
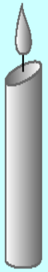
Thermodynamic temperature	Ice water: 273 kelvin  Comfortable room temperature: 295 kelvin	Kelvin	K
Amount of substance	Uranium 238 ← One of the Gold 197 heaviest Silver 108 atoms known Copper 64 Calcium 40 Aluminum 27 Carbon 12 ← Common Carbon is Helium 4 used as a standard Hydrogen 1 ← Lightest atom	Mole	mol
Luminous intensity	 A candle has luminous intensity of approximately 1 candela	Candela	cd

TABLE 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

British gravitational (BG) system

- Unit of length = foot, 1 **ft** = 0.3048 m
- Unit of time = second, **s**
- Unit of mass = slug, 1 **slug** = 14.63 Kg
- Unit of force = pound, 1 **lb** (or **lbf**) = 4.448N
- Unit of temperature = fahrenheit (or Rankine, in absolute), T(**^{o}F**) = 9/5 T(^{o}C) + 32

and T(**^{o}R**) = 9/5 T(^{o}K)

US customary units

- Unit of length = foot, **ft**
- Unit of time = second, **s**
- Unit of mass = pound, 1 **lbm** = 0.4536 Kg
- Unit of force = pound, 1 **lb** (or **lbf**) = 4.448N
- Unit of temperature = fahrenheit (or Rankine, in absolute), T(^{o}**F**) = 9/5 T(^{o}C) + 32

and T(^{o}**R**) = 9/5 T(^{o}K)

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

Note: unit of electric potential: kg m^2/s^3A

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
Radio broadcasting signal frequencies	88–108 MHz (FM broadcast band) 0.54–1.6 MHz (AM broadcast band)
Police, fire	153–159 MHz
Global positioning system signals	1575.42 MHz and 1227.60 MHz

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)

Unit conversion

- Units are the reference of the measurement. Several errors have occurred where units were not clearly indicated.
- …*By the way, this is why whenever you forget putting the units at the answer of a problem you end up missing grades!*

Unit conversion

Example 6.1:

- A person who is 6 feet and 1 inch tall and weighs 185 pound force (Lbf) is driving a car at a speed of 65 miles per hour over a distance of 25 miles. The outside air temperature is 80°F and has a density of 0.0735 pound mass per cubic foot (lbm/ft3). Convert all of the values given in this example from U.S. Customary Units to SI units.

Note: use tables given in the book (1ft=12in; 1ft=0.3048m; 1lbf=4.448N; 1mile=5280ft; 1lbm=0.453Kg)

Example 6.1 - solution

Height:

$$H=\left(6ft+1in\left(1\,\frac{ft}{12\,in}\right)\right)\left(\frac{0.3048m}{1\,ft}\right)=1.854\,m$$

$$or,\ in\ cm:\ H=1.854m\left(\frac{100\ cm}{1\ m}\right)=185.4\ cm$$

weight:

$$W=185\,lbf\left(\frac{4.448\,N}{1\,lbf}\right)=822.88\,N$$

speed of the car:

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

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

Example 6.1 – solution – cont.

Distsance travelled:

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

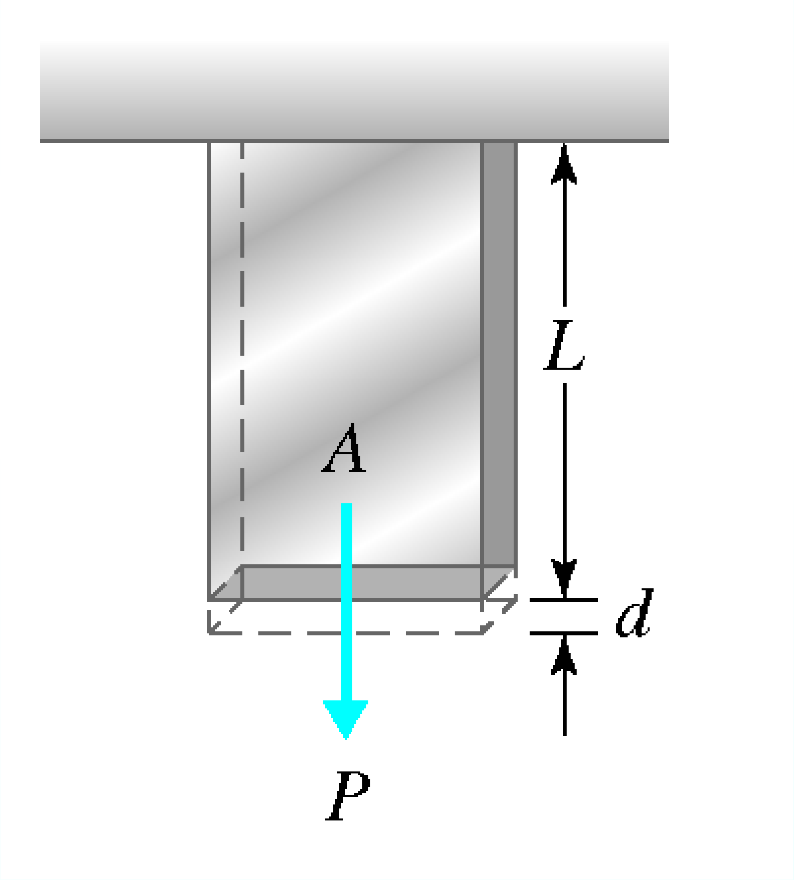
Temperature of air, T

$$T^{o}\ C = \frac{5}{9}\left(T^{o}\ F - 32\right) = \frac{5}{9}(80 - 32) = 26.7^{o}\ C$$

density of air, ρ

$$\rho = \left(0.0735\ \frac{lbm}{ft^{3}}\right)\left(\frac{0.453Kg}{1\ lbm}\right)\left(\frac{1\ ft}{0.3048\ m}\right)^{3} = 1.176\ Kg/m^{3}$$

Dimensional homogeneity



When a constant load is applied to a bar of constant cross section, as shown in the figure, the amount by which the end of the bar will deflect can be determined from the following relationship:

$$d = PL/(AE)$$

Where :

d = end deflection of the bar in meter (m)

P = applied load in newton (N)

A = cross-sectional area of the bar in m^2

E = modulus of elasticity of the material

- What are the units for modulus of elasticity?

Dimensional homogeneity – another example

The heat transfer rate through a solid material is governed by Fourier ' s law:

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

where q = heat transfer rate

k = thermal conductivity in $W/m\cdot{}^\circ C$

A = area in m^2

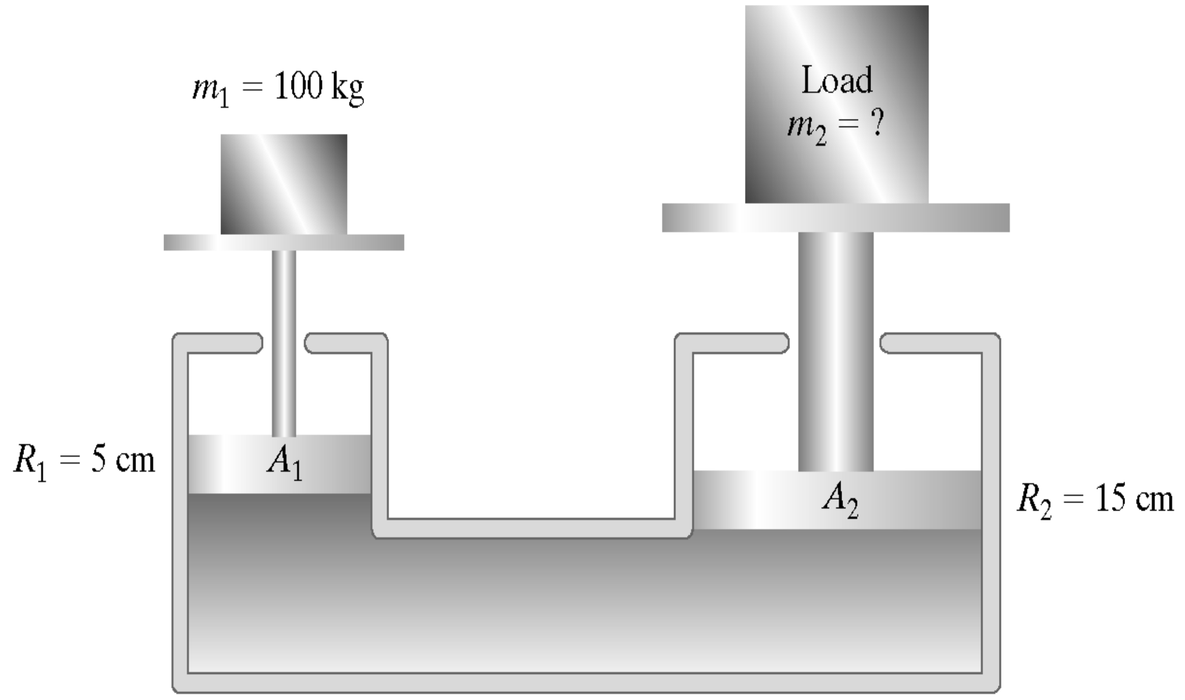
$(T_1 - T_2)$ temperature difference in ${}^\circ C$

L = thickness of material in m

what is the unit of q?

Numeric Vs Symbolic solutions

- Determine the load (m_2=?) that can be lifted by the hydraulic system shown. All of the necessary information is shown in the figure



Numeric Vs Symbolic solutions

- *Numeric solution:*
  - $F_1 = m_1 g$ = (100 kg) (9.81 m/s^2) = 981 N
  - $F_2 = (A_2/A_1)F_1$

    $$= \frac{\pi\,(0.15\,m)^2}{\pi\,(0.05\,m)^2}(981\,N)$$

    = 8829N
  - $F2$ = 8829 N = m_2 (9.81 m/s^2)
  - m_2 = 900 kg

- Symbolic solution:

$$P_1 = P_2$$

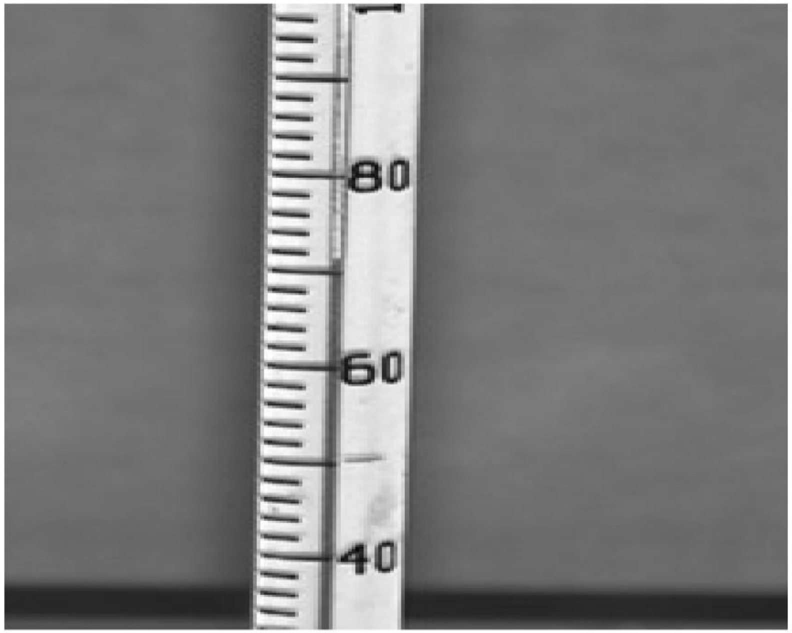
$$\Rightarrow F_2 = \frac{A_2}{A_1} F_1$$

$$\Rightarrow m_2\, g = \frac{\pi R_2^2}{\pi R_1^2} m_1\, g$$

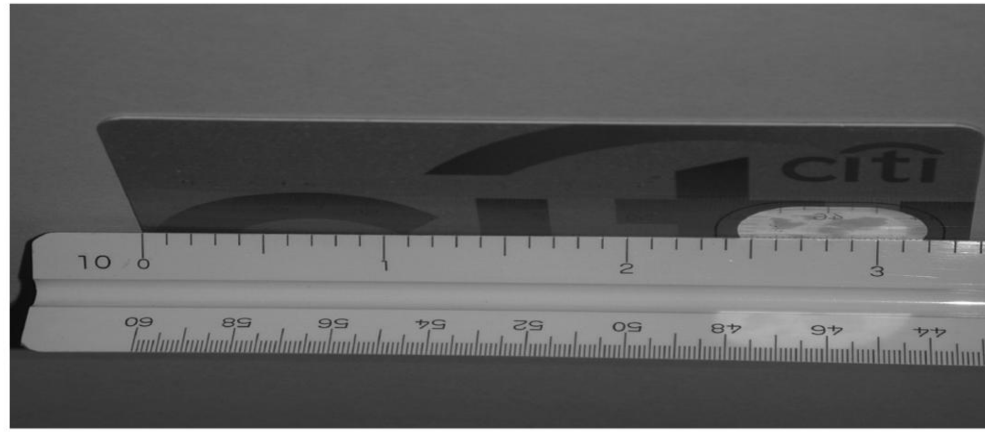
$$\Rightarrow m_2 = \frac{R_2^2}{R_1^2} m_1$$

$$= \frac{(15\,cm)^2}{(5\,cm)^2}(100\,kg) = 900kg$$

Significant Figures



a) 71 ± 1 °F



b) 3.35 ± 0.05 inches

c) 7.5 ± 0.5 inches of water

Significant Figures (or digits)

- Numbers with 3 significant figures: 175, 25.5, 1.85, 0.00125
- 1.5×10^3, 0.015×10^5 have 2 sig.fig.
- 1500.0 has 4
- 1500 has an undefined number of sig.fig.

Calculations with Significant Figures

Addition and subtraction:

The precision of the result is equal to the lowest of all numbers.

Multiplication and division:

The number of significant figures is equal to the lowest of all numbers.

Examples

152.47 +
3.9
____
156.37
156.3

Answer has 4 significant digits

132.853 -
5
____
127.853
127

Answer has 3 significant digits

Examples

152.47 x
3.9

594.633
5.9×10^2

Answer has 2 significant digits

152.47 ÷
3.9

39.0948717949
39

Answer has 2 significant digits

Physical laws

- Based on observation
- Proven by experiment
- Examples include: conservation of mass, of energy, newton’s laws of motion