Chapter 1

Measurement

We measure each quantity by its own "unit" or by comparison with a standard.

A unit is a measure of a quantity that scientists around the world can refer to.

This has to be both accessible and invariable.

For example

- 1 meter (m) is a unit of length. Any other length can be expressed in terms of 1 meter. A variable length, such as the length of a person's nose is not appropriate.

1.3 International System of Units

The SI system, or the International System of Units, is also called the metric system.

Three basic quantities are the length, time, and mass.

Many units are derived from this set, as in speed, which is distance divided by time.

Table 1-1

Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

1.3 International System of Units

Table 1-2

Prefixes for SI Units

Factor	Prefix[a]	Symbol	Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y	10^{-1}	deci-	d
10^{21}	zetta-	Z	$\mathbf{10^{-2}}$	**centi-**	**c**
10^{18}	exa-	E	$\mathbf{10^{-3}}$	**milli-**	**m**
10^{15}	peta-	P	$\mathbf{10^{-6}}$	**micro-**	$\boldsymbol{\mu}$
10^{12}	tera-	T	$\mathbf{10^{-9}}$	**nano-**	**n**
$\mathbf{10^{9}}$	**giga-**	**G**	$\mathbf{10^{-12}}$	**pico-**	**p**
$\mathbf{10^{6}}$	**mega-**	**M**	10^{-15}	femto-	f
$\mathbf{10^{3}}$	**kilo-**	**k**	10^{-18}	atto-	a
10^{2}	hecto-	h	10^{-21}	zepto-	z
10^{1}	deka-	da	10^{-24}	yocto-	y

[a]The most frequently used prefixes are shown in bold type.

Scientific notation uses the power of 10.

Example:

3 560 000 000 m = 3.56 x 10^{9}m.

Sometimes special names are used to describe very large or very small quantities (as shown in Table 1-2).

For example,

2.35 x 10^{-9} = 2.35 nanoseconds (ns)

1.4 Changing units

Based of the base units, we may need to change the units of a given quantity using the chain-link conversion.

For example, since there are 60 seconds in one minute,

$$\frac{1\,\text{min}}{60\,s} = 1 = \frac{60\,s}{1\,\text{min}},\ \textit{and}$$

$$2\,\text{min} = (2\,\text{min})x(1) = (2\,\text{min})x\left(\frac{60\,s}{1\,\text{min}}\right) = 120\,s$$

Conversion between one system of units and another can therefore be easily figured out as shown.

The first equation above is often called the “Conversion Factor”.

1.5 Length

Redefining the meter:

In 1792 , the newborn Republic of France established a new system of weights and measures. Its cornerstone was the meter, defined as one ten-millionth of the distance from the north pole to the equator.

Later, the meter was defined as the distance between two finely engraved lines near the ends of a standard platinum-iridium bar, the standard meter bar. This bar is placed in the International Bureau of Weights and Measures near Paris, France.

In 1960, a new standard for the meter, based on the wavelength was adopted. The standard for the meter was redefined to be 1 650 763.73 wavelengths of a particular orange-red light emitted by krypton-86 in a gas discharge tube that can be set anywhere in the world.

In 1983, the meter was defined as the length of the path traveled by light in a vacuum during the time interval of 1/299 792 458 of a second. The speed of light is then exactly 299 792 458 m/s.

Some examples of lengths

Table 1-3

Some Approximate Lengths

Measurement	Length in Meters
Distance to the first galaxies formed	2×10^{26}
Distance to the Andromeda galaxy	2×10^{22}
Distance to the nearby star Proxima Centauri	4×10^{16}
Distance to Pluto	6×10^{12}
Radius of Earth	6×10^{6}
Height of Mt. Everest	9×10^{3}
Thickness of this page	1×10^{-4}
Length of a typical virus	1×10^{-8}
Radius of a hydrogen atom	5×10^{-11}
Radius of a proton	1×10^{-15}

1.5 Length: Estimation

PROBLEM: The world's largest ball of string is about 2 m in radius. To the nearest order of magnitude, what is the total length, L, of the string of the ball?

SETUP: Assume that the ball is a sphere of radius 2 m. In order to get a simple estimate, assume that the cross section of the string is a square with a side edge of 4 mm. This overestimate will account for the loosely packed string with air gaps.

CALCULATE: The total volume of the string is roughly the volume of the sphere. Therefore, V = (cross-sectional area)(length)= $d^2L = 4/3\pi R^3$

$d^2L = 4R^3$, because π is about 3. $d^2L=4R^3$

$$V = (4x10^{-3})^2 x L = \frac{4}{3}\pi R^3 \approx 4R^3$$

$$\Rightarrow L = \frac{4(2m)^3}{(4x10^{-3}m)^2} = 2x10^6 m = 3km$$

1.5 Time

Time has two aspects. For civil and some scientific purposes, we want to know the time of day so that we can order events in sequence.

Atomic clocks give very precise time measurements.

An atomic clock at the National Institute of Standards and Technology in Boulder, CO, is the standard, and signals are available by shortwave radio stations.

In 1967 the standard second was defined to be the time taken by

9 192 631 770 oscillations of the light (of a specified wavelength) emitted by cesium-133 atom.

Table 1-4

Some Approximate Time Intervals

Measurement	Time Interval in Seconds
Lifetime of the proton (predicted)	3×10^{40}
Age of the universe	5×10^{17}
Age of the pyramid of Cheops	1×10^{11}
Human life expectancy	2×10^{9}
Length of a day	9×10^{4}
Time between human heartbeats	8×10^{-1}
Lifetime of the muon	2×10^{-6}
Shortest lab light pulse	1×10^{-16}
Lifetime of the most unstable particle	1×10^{-23}
The Planck time[a]	1×10^{-43}

[a]This is the earliest time after the big bang at which the laws of physics as we know them can be applied.

1.5 Mass

A platinum-iridium cylinder, kept at the International Bureau of Weights and Measures near Paris, France, has the standard mass of 1 kg.

Another unit of mass is used for atomic mass measurements. Carbon-12 atom has a mass of 12 atomic mass units (u), defined as

$$1u = 1.66053886 x 10^{-27} kg$$

Table 1-5

Some Approximate Masses

Object	Mass in Kilograms
Known universe	1×10^{53}
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Small mountain	1×10^{12}
Ocean liner	7×10^{7}
Elephant	5×10^{3}
Grape	3×10^{-3}
Speck of dust	7×10^{-10}
Penicillin molecule	5×10^{-17}
Uranium atom	4×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}

1.5 Density

Density is typically expressed in kg/m^3, and is often expressed as the Greek letter, rho (ρ)= m/V.

Example, Density and Liquefaction:

A heavy object can sink into the ground during an earthquake if the shaking causes the ground to undergo *liquefaction,* in which the soil grains experience little friction as they slide over one another. The ground is then effectively quicksand. The possibility of liquefaction in sandy ground can be predicted in terms of the *void ratio e* for a sample of the ground:

$$e = \frac{V_{\text{voids}}}{V_{\text{grains}}}. \qquad (1\text{-}9)$$

Here, V_{grains} is the total volume of the sand grains in the sample and V_{voids} is the total volume between the grains (in the *voids*). If e exceeds a critical value of 0.80, liquefaction can occur during an earthquake. What is the corresponding sand density ρ_{sand}? Solid silicon dioxide (the primary component of sand) has a density of $\rho_{SiO_2} = 2.600 \times 10^3$ kg/m^3.

KEY IDEA

The density of the sand ρ_{sand} in a sample is the mass per unit volume—that is, the ratio of the total mass m_{sand} of the sand grains to the total volume V_{total} of the sample:

$$\rho_{\text{sand}} = \frac{m_{\text{sand}}}{V_{\text{total}}}. \qquad (1\text{-}10)$$

Calculations: The total volume V_{total} of a sample is

$$V_{\text{total}} = V_{\text{grains}} + V_{\text{voids}}.$$

Substituting for V_{voids} from Eq. 1-9 and solving for V_{grains} lead to

$$V_{\text{grains}} = \frac{V_{\text{total}}}{1+e}. \qquad (1\text{-}11)$$

From Eq. 1-8, the total mass m_{sand} of the sand grains is the product of the density of silicon dioxide and the total volume of the sand grains:

$$m_{\text{sand}} = \rho_{SiO_2} V_{\text{grains}}. \qquad (1\text{-}12)$$

Substituting this expression into Eq. 1-10 and then substituting for V_{grains} from Eq. 1-11 lead to

$$\rho_{\text{sand}} = \frac{\rho_{SiO_2}}{V_{\text{total}}} \frac{V_{\text{total}}}{1+e} = \frac{\rho_{SiO_2}}{1+e}. \qquad (1\text{-}13)$$

Substituting $\rho_{SiO_2} = 2.600 \times 10^3$ kg/m^3 and the critical value of $e = 0.80$, we find that liquefaction occurs when the sand density is less than

$$\rho_{\text{sand}} = \frac{2.600 \times 10^3 \text{ kg/m}^3}{1.80} = 1.4 \times 10^3 \text{ kg/m}^3.$$

(Answer)

A building can sink several meters in such liquefaction.