Chapter 1

Measurement

Units of Chapter 1: Measurements

- The Physical Quantities, Standards and Units
- The international System of units
  - The standard of time
  - The standard of length
  - The standard of mass
- Dimensional Analysis

Learning goals of this chapter

- **On completing this chapter, the student will be able to :**
- Differentiate between the fundamental quantities and the derivative quantities .
- Express the physical quantities using the international system of units.
- Differentiate between the international system of units and the British system of unit.
- Defined The standard of time
- Defined The standard of length
- Defined The standard of mass
- Convert the units of the physical quantities from system to another .
- Determine the dimensions of the physical quantity.
- Check the physical formula using of Dimensional analysis .

1-1 The Physical Quantities, Standards and Units

- To describe the physical quantities we need to choose a unit that does not differ from a corresponding quantity physically but has a quite definite dimension.
- Every Physical quantity (Y) can be defined as the product of a (unit) multiplied by an abstract number (x):
  - Y = X (unit)
  - For example:
  - Mass = 5 Kg
- Physical Quantities
  - Basic (Length, Mass, Time)
  - Derived (area, speed, density, ...)

1-2 The international System of units

length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Other System of Units

- **Gaussian System of Units**
- **Length in (cm):** 1 cm = 10^{-2} m
- **Mass in (g) :** 1 g = 10^{-3} kg
- **Time in (s)**

- **British System of Units**
- **Length in feet (ft):** 1 foot (ft) = 12 in = 30.48 cm
- **Mass in Pound (lb):** 1 pound (lb) = 453.59 g
- **Time in second (s)**

Prefixes

- The standard prefixes are used to designate common multiples in powers of ten.
- 1 angstrom=10^{-10} m

TABLE 1–4 Common Prefixes

Power	Prefix	Abbreviation
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

1-3 The Standard of Time

- Unit of Time is second (s)
- Before 1960, the second was originally defined as $\left(\frac{1}{60}\right).\left(\frac{1}{60}\right).\left(\frac{1}{24}\right)$ of the mean solar day.
- Now: the second (s) is defined as the time required for Cesium (Cs-133) atom to undergo 9,192,631,770 vibration .

An atomic Clock

Typical Time Intervals

TABLE 1–3 Typical Times

Age of the universe	5×10^{17} s
Age of the Earth	1.3×10^{17} s
Existence of human species	6×10^{13} s
Human lifetime	2×10^{9} s
One year	3×10^{7} s
One day	8.6×10^{4} s
Time between heartbeats	0.8 s
Human reaction time	0.1 s
One cycle of a high-pitched sound wave	5×10^{-5} s
One cycle of an AM radio wave	10^{-6} s
One cycle of a visible light wave	2×10^{-15} s

1-4 The Standard of Length

- SI Unit of Length: the meter (m)
- in October 1983, the meter (m) was redefined as the distance traveled by light in vacuum during a time of 1/299 792 458 second.

Converting Units of length

- 1 inch (in)= 2.54 cm
- 1 foot (ft) = 12 in = 30.48 cm
- 1 yard (yd) = 3 feet = 36 in= 0.9144 m
- 1 miles (mi) =1760 yards = 5280 feet = 1,609.344 m
- 1 m = 3.281 ft

Typical Length

TABLE 1–1 Typical Distances

Distance from Earth to the nearest large galaxy (the Andromeda galaxy, M31)	2×10^{22} m
Diameter of our galaxy (the Milky Way)	8×10^{20} m
Distance from Earth to the nearest star (other than the sun)	4×10^{16} m
One light year	9.46×10^{15} m
Average radius of Pluto's orbit	6×10^{12} m
Distance from Earth to the Sun	1.5×10^{11} m
Radius of Earth	6.37×10^{6} m
Length of a football field	10^{2} m
Height of a person	2 m
Diameter of a CD	0.12 m
Diameter of the aorta	0.018 m
Diameter of a period in a sentence	5×10^{-4} m
Diameter of a red blood cell	8×10^{-6} m
Diameter of the hydrogen atom	10^{-10} m
Diameter of a proton	2×10^{-15} m

Problem 1

Any physical quantity can be multiplied by 1 without changing its value. For example, 1 min = 60 s, so 1 = 60 s/1 min; similarly, 1 ft = 12 in , so 1 = 1 ft/12 in. Using appropriate conversion factors, find

(a) the speed in meters per second equivalent to 55 miles per hour, and

(b) the volume in cubic centimeters of a tank that holds 16 gallons of gasoline.

Solution (*a*) For our conversion factors, we need (see Appendix G) 1 mi = 1609 m (so that 1 = 1609 m/1 mi) and 1 h = 3600 s (so 1 = 1 h/3600 s). Thus

$$\text{speed} = 55\,\frac{\cancel{\text{mi}}}{\cancel{\text{h}}} \times \frac{1609\ \text{m}}{1\ \cancel{\text{mi}}} \times \frac{1\ \cancel{\text{h}}}{3600\ \text{s}} = 25\ \text{m/s}.$$

(*b*) One fluid gallon is 231 cubic inches, and 1 in. = 2.54 cm. Thus

$$\text{volume} = 16\ \cancel{\text{gal}} \times \frac{231\ \cancel{\text{in.}}^3}{1\ \cancel{\text{gal}}} \times \left(\frac{2.54\ \text{cm}}{1\ \cancel{\text{in.}}}\right)^3 = 6.1 \times 10^4\ \text{cm}^3.$$

Problem 2

A light-year is a measure of length (not a measure of time) equal to the distance that light travels in 1 year. Compute the conversion factor between light-years and meters, and find the distance to the star Proxima Centauri (4.0 X 10^{16} m) in light-years.

Solution The conversion factor from years to seconds is

$$1\ \text{y} = 1\ \text{y} \times \frac{365.25\ \text{d}}{1\ \text{y}} \times \frac{24\ \text{h}}{1\ \text{d}} \times \frac{60\ \text{min}}{1\ \text{h}} \times \frac{60\ \text{s}}{1\ \text{min}}$$
$$= 3.16 \times 10^7\ \text{s}\,.$$

The speed of light is, to three significant figures, 3.00×10^8 m/s. Thus in 1 year, light travels a distance of

$$(3.00 \times 10^8\ \text{m/s})\,(3.16 \times 10^7\ \text{s}) = 9.48 \times 10^{15}\ \text{m},$$

so that

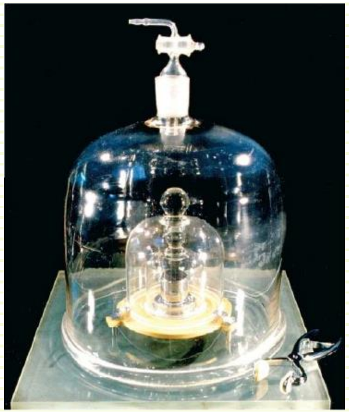
$$1\ \text{light-year} = 9.48 \times 10^{15}\ \text{m}.$$

The distance to Proxima Centauri is

$$(4.0 \times 10^{16}\ \text{m}) \times \frac{1\ \text{light-year}}{9.48 \times 10^{15}\ \text{m}} = 4.2\ \text{light-years}.$$

1-5 Standard Mass

- Unit of Mass: kilogram (kg)
- The kilogram (kg), is defined as the mass of a specific platinum–iridium alloy cylinder kept at the International Bureau of Weights and Measures at Sèvres, France.
- This mass standard was established in 1887 and has not been changed since that time because platinum–iridium is an unusually stable alloy.



- **Converting Unit of Mass**
- The atomic mass unit u is

  $1\ u = 1.661\times10^{-27}$ kg

  1 pound (lb) = 453.59 g

Typical Mass

TABLE 1–2 Typical Masses

Galaxy (Milky Way)	4×10^{41} kg
Sun	2×10^{30} kg
Earth	5.97×10^{24} kg
Space shuttle	2×10^{6} kg
Elephant	5400 kg
Automobile	1200 kg
Human	70 kg
Baseball	0.15 kg
Honeybee	1.5×10^{-4} kg
Red blood cell	10^{-13} kg
Bacterium	10^{-15} kg
Hydrogen atom	1.67×10^{-27} kg
Electron	9.11×10^{-31} kg

1-7 Dimensional Analysis

- **The dimension in physics** refer to the type of quantity in question regardless of the unit used in the measurement.
- The symbols we use to specify length, mass, and time are L, M, and T, respectively.
- We shall often use brackets [ ] to denote the dimensions of a physical quantity. For example, the nature of speed *v*, is length/time, so the dimension of speed $[v] = L/T$, and nature of the area is length $\times$ length, so the dimension of the area $[A] = L^2$.
- Any valid physical formula must be dimensionally consistent- each term of the formula must have the same dimensions.
- This type of calculation with dimensions is (dimensional analysis).

1-7 Dimensional Analysis

Quantity	The type	Dimension
Distance	Length	L
Area	Length $\times$ Length	L^2
Volume	$(\text{Length})^3$	L^3
Velocity	Length/time	L/T
Acceleration	Length/time^2	L/T^2
Force	Mass $\times$ acceleration	ML/T^2
Pressure	Force/area	$ML/T^2L^2 = M/T^2L$
Density	Mass/volume	M/L^3

Problem 4

- To keep an object moving in a circle at constant speed requires a force called the "centripetal force“. Use the dimensional analysis to predict the formula of centripetal force F, if you know that F depends on its mass *m*, its speed *v*, and the radius *r* of its circular path.

Solution:

- Suppose that $F \alpha\, m^a\, v^b\, r^c$
- where the symbol “α” means "is proportional to," and where *a*, *b*, and *c* are numerical exponents to be determined from analyzing the dimensions.
- The dimensions of the left hand side: the force $[F] = MLT^{-2}$

Problem 4

- The dimension of the right hand side $= [m^a]\ [v^b]\ [r^c]$
  $= Ma\ (L/T)^b\ L^c$
- Therefore, $MLT^2 = M^a\ L^{b+c}\ T^{-b}$
- Dimensional consistency means that the fundamental dimensions must be the same on each side. Thus, equating the exponents,

  exponent of M : $a = 1$

  exponent of T : $b = 2$

  exponent of L : $b + c = 1$ so $c = -1$:

  The resulting expression is $F \propto \frac{mv^2}{r}$

Solved problems

- 1- if you know that the acceleration of gravity in SI unit equals g=9.8 ms^{-2}, find the acceleration in British System of Units.
- Solution:
- Since $1\,m = 3.28\,ft$, then
- $g = 9.80665\ ms^{-2} = 9.80665 \times 3.2808\,(ft\,s^{-2}) = 32.174\,ft/s^2$

- 2- if you know that the force is given by Force = Mass $\times$ acceleration , Fined the unit , of the force in SI unit and the British system of unit.
- Solution:
- The force $F = ma$, the dimension of the force is MLT^{-2}.
- The unit of the force in SI unit is kg.m.s^{-2} which is known as Newton (N).
- In Britch system of unit, we use the expression pound-force which is equal to the gravitational force exerted on a mass of one pound, i.e.,
- 1 Pound-force (1 lbf) = 1 lb (pound-mass) $\times$ gravity
- $1\,\mathrm{lbf} = 1\,lb \times 32.174\,(ft/s^2\,) = 32.174\ lb.ft/s^2 = 1\,slug \times ft/s^2$
- $\mathrm{Where}\ 1\,slug = 32.174\,lb$
- $1\,\mathrm{lbf}\ = 0.45359\,kg \times 9.8\,m/s^2 = 4.4443\,N$

Ch.1 Summary

PHYSICS AND THE LAWS OF NATURE

Physics is based on a small number of fundamental laws and principles.

UNITS OF LENGTH, MASS, AND TIME

Length

Was: one ten-millionth of the distance from the North Pole

to the equator

Now: One meter is defined as the distance traveled by the light in vacuum in 1/299,792,458 second.

Mass

One Kilogram is the mass of a metal cylinder kept at the international Bureau of Weights and Standards, Sevres, France.

Time

One second is the time required for a particular type of radiation from Cesium-133 to undergo 9,192,631,770 oscillations.

Ch.1 Summary

DIMENSIONAL ANALYSIS

Dimension:

The dimension of a quantity is the type of quantity it is, for example, Length [L], mass [M], or time [T].

Dimensional Consistency

An equation is dimensionally consistent if each term in it has the same dimensions. All valid physical equations are dimensionally consistent.

Dimensional Analysis:

A calculation based on the dimensional consistency of an equation.

CONVERTING UNITS

Multiply by the ratio of two units to convert from one to another. As an example, to convert 3.5 m t feet, you multiply by the factor (1ft/0.3048 m)

- 1 yard (yd) = 0.9144 m
- 1 miles (mi) = 1,609.344 m
- 1 foot (ft) = 30.48 cm

1 inch (in)= 2.54 cm

1 yard (yd) = 3 feet (ft)

1 m = 3.281 ft

Homework

1. *The earth is approximately a sphere of radius 6.37×10^6 m. (a) What is its circumference in kilometers? (b) what its volume in cubic kilometers?*
2. *A room has dimensions of 21 ft $\times$ 13 ft $\times$ 12 ft. What is the mass of the air it contains? The density of air at room temperature and normal atmospheric pressure is 1.21 Kg/m^3.*
3. *Show that $v=v_o+at$ is dimensionally consistent, where v and v_o are velocities and a is the acceleration and t is the time.*
4. *Show that $x=x_o+v_ot+at^2$ is dimensionally consistent, where x and x_o are distances and v_o is a velocity and a is the acceleration.*