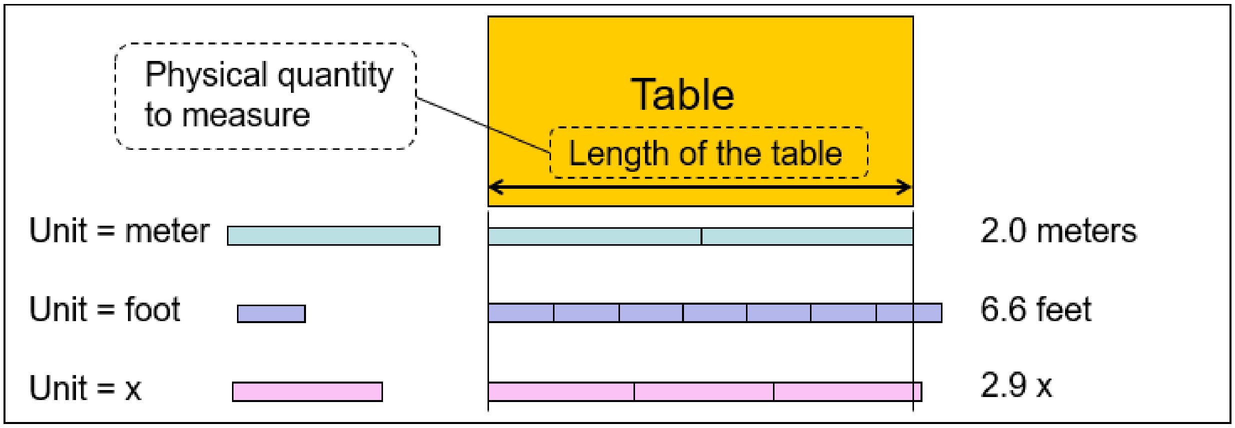
CHAPTER 1: Physics and Measurement

1.1 Standards of Length, Mass, and Time

- To describe natural phenomena, we must make measurements of various aspects of nature.
- Each measurement is associated with a physical quantity, such as the length of an object.
- The laws of physics are expressed as mathematical relationships among some physical quantities.

- Therefore, we need:
  - Rules for measurement and comparison
  - Units for measurement

- **A unit:**
- Is the unique name assigned to the measure of a quantity (mass, time, length, pressure, etc.)
- Corresponds to a standard, a physical quantity with value 1.0 unit (e.g. 1.0 meter = distance traveled by light in a vacuum over a certain fraction of a second)
- For example:



- There are seven fundamental quantities in physics:
    - Length, mass, time, temperature, electric current, luminous intensity, amount of substance.
- In mechanics, the three fundamental quantities are length, mass, and time.
- All other quantities in mechanics can be expressed in terms of these three.

Example 1:

What is the unit of speed?

Derived physical quantity

Base physical quantities

$$\text{speed} = \frac{\text{length}}{\text{time}}$$

$$\text{unit of speed} = \frac{\text{unit of length}}{\text{unit of time}} = \frac{\text{meter}}{\text{second}}$$

The International System of Units (Systéme International (SI)):

The SI system of units was established in 1960

Quantity	Unit name	Unit symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

For example, the SI unit of energy is the joule which can be written in terms of SI base units as follows

SI derived unit   SI base units

$$\text{joule} = \boxed{\frac{\text{kg m}^2}{\text{s}^2}}$$

One joule is one kilogram-meter squared per second squared.

Meter, Second, and Kilogram:

- Length: The meter is defined as the distance traveled by light during a precisely specified time interval (1/299 792 458 of a second).

- Time: The second is defined in terms of the oscillations of light emitted by an atomic (cesium-133) source. Accurate time signals are sent worldwide by radio signals keyed to atomic clocks in standardizing laboratories.

- Mass: The kilogram is defined in terms of a platinum–iridium standard mass kept near Paris. For measurements on an atomic scale, the atomic mass unit, defined in terms of the atom carbon-12, is usually used.

- **Density:** The density of a substance (ρ) is the amount of mass contained in a unit volume

$$\rho = \frac{m}{V}$$

1.3 Dimensional Analysis

- Dimension has a specific meaning – it denotes the physical nature of a quantity.
- Dimensions are often denoted with square brackets [--].
  - Length [L]
  - Mass [M]
  - Time [T]

Table 1.5 Dimensions and Units of Four Derived Quantities

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

[3]The *dimensions* of a quantity will be symbolized by a capitalized, nonitalic letter such as L or T. The *algebraic symbol* for the quantity itself will be an italicized letter such as L for the length of an object or t for time.

Dimensional Analysis

- Technique to check the correctness of an equation or to assist in deriving an equation
- Dimensions (length, mass, time, combinations) can be treated as algebraic quantities.
  - Add, subtract, multiply, divide

- Both sides of equation must have the same dimensions.
- Any relationship can be correct only if the dimensions on both sides of the equation are the same.
- Cannot give numerical factors: this is its limitation

Example 2:

- Given the equation: $x = ½ at^2$ Check dimensions on each side:

$$L = \frac{L}{\cancel{T^2}} \cdot \cancel{T^2} = L$$

- The T^2's cancel, leaving L for the dimensions of each side.
- The equation is dimensionally correct.
- There are no dimensions for the constant.

Example 3 (power law):

Suppose the distance x is given in terms of acceleration a and time t as in the following expression $x = k\, a^n\, t^m$,

where k is a dimensionless constant. Find m and n.

Solution

Both sides of the equation should have the same dimensions.

$[x] = L$

$[k\, a^n\, t^m] = (1)\left(\frac{L}{T^2}\right)^n T^m = L^n\, T^{m-2n}$

$L = L^n\, T^{m-2n}$

$L = L^1\, T^0$

$n = 1$

$m - 2n = 0 \rightarrow m = 2n = 2$

$x = k\, a\, t^2$

Example 4:

The position of a particle is given by $x = At^3 + (B/A)t^2$, where x is in meters and t is in seconds. The dimension of B is:

A) L^2T^{-5}
B) LT^{-4}
C) L^2T^2
D) LT^{-3}
E) T^{-3}

Solution

$$x = At^3 + \left(\frac{B}{A}\right) t^2$$

In order for the equation to be dimensionally correct, each term on the right side must also have the dimension of length.

$$[At^3] = \mathrm{L} \Rightarrow [\mathrm{A}] = LT^{-3}$$

$$\left[\frac{B}{A}\right] T^2 = L$$

$$\Longrightarrow \quad [B] = \frac{L\,[A]}{T^2} = \frac{L\, LT^{-3}}{T^2} = L^2\, T^{-5}$$

1.4 Conversion of Units:

Sometimes it is necessary to convert units from one measurement system to another or convert within a system (for example, from minute to second).

Example 5:

$$3 \text{ min} = (3 \text{ min})(1) = (3\ \cancel{\text{min}})\left(\boxed{\frac{60 \text{ s}}{1\ \cancel{\text{min}}}}\right) = 180 \text{ s}$$

conversion factor

$$180 \text{ s} = (180 \text{ s})(1) = (180\ \cancel{\text{s}})\left(\boxed{\frac{1 \text{ min}}{60\ \cancel{\text{s}}}}\right) = 3 \text{ min}$$

A conversion factor is a ratio of units that is equal to one. Multiplying any quantity by unity leaves the quantity unchanged.

Example 6:

How many centimeters are there in 5.30 inches?

1 inch = 2.540 cm

$$5.30 \text{ in} = (5.30 \cancel{\text{in}})\underbrace{\left(\frac{2.540 \text{ cm}}{1 \cancel{\text{in}}}\right)}_{\text{conversion factor}} = 13.5 \text{ cm}$$

Important:

Always Include Units When performing calculations with numerical values, include the units for every quantity and carry the units through the entire calculation.

Example 7:

A car moves at speed of 1.14 miles per minute. Use the following conversion factors to find its speed in kilometers per hour (km/h)

1 mile = 5280 feet

1 foot = 0.3048 meter

Solution

$$1.14 \frac{\text{miles}}{\text{min}} = \left(1.14 \frac{\cancel{\text{miles}}}{\cancel{\text{min}}}\right)\left(\frac{5280 \cancel{\text{feet}}}{1 \cancel{\text{mile}}}\right)\left(\frac{0.3048 \cancel{\text{m}}}{1 \cancel{\text{foot}}}\right)\left(\frac{1 \text{ km}}{1000 \cancel{\text{m}}}\right)\left(\frac{60 \cancel{\text{min}}}{1 \text{ h}}\right)$$

$$= 110 \text{ km/h}$$

Example 8:

How many liters are there in one US fluid gallon, if

1 US fluid gallon = 231 in^3

1 in = 2.540 cm

1 L = 1000 cm^3?

Solution

$$1\ \text{gallon} = (1\ \cancel{\text{gallon}})\left(\frac{231\ \cancel{\text{in}^3}}{1\ \cancel{\text{gallon}}}\right)\left(\frac{2.54\ \cancel{\text{cm}}}{1\ \cancel{\text{in}}}\right)^3\left(\frac{1\ \text{L}}{1000\ \cancel{\text{cm}^3}}\right)$$

$$= 3.79\ \text{L}.$$

Example 9:

Express the speed of sound, 330 m/s in miles/h .(Take 1 mile = 1609 m)

Solution

$$330\frac{\text{m}}{\text{s}} = 330\frac{1\text{m}\dfrac{1\text{mile}}{1609\text{m}}}{1\text{s}\dfrac{1\text{hour}}{3600\text{s}}} = 330\times\frac{3600}{1609}\frac{\text{mile}}{\text{h}} = 738\frac{\text{mile}}{\text{h}}$$