Chapter One: Measurements and Units

1.1 Measuring Things.

Physics is an experimental science. Physicists observe the phenomena of nature and try to find patterns and principles that relate these phenomena.

1.2 Standards and Units

The physics is an experimental science. Experiments require measurements, and we generally use numbers to describe the results of measurements. Any number that is used to describe a physical phenomenon quantitatively is called a physical quantity. For example, two physical quantities that describe you are your weight and your height. Some physical quantities are so fundamental that we can define them only by describing how to measure them. Such a definition is called an operational definition. Two examples are measuring a distance by using a ruler and measuring a time interval by using a stopwatch. In other cases we define a physical quantity by describing how to calculate it from other quantities that we can measure. When we measure a quantity, we always compare it with some reference standard. The system of units used by scientists and engineers around the world is commonly called "the metric system," but since 1960 it has been known officially as the International System, or SI.

Time

The present standard is based on an atomic clock, which uses the energy difference between the two lowest energy states of the cesium atom. When bombarded by microwaves of precisely the proper frequency, cesium atoms undergo a transition from one of these states to the other.

Length

The speed of light in a vacuum was measured to be 299,792,458 m/s. The meter is defined to be consistent with the 299,792,458 m/s and with the above definition of the second. Hence the new definition of the meter (abbreviated m) is the distance that light travels in a vacuum in 1/299,792,45 8 second. This provides a much more precise standard of length than the one based on a wavelength of light.

Mass

The standard of mass, the kilogram (abbreviated kg), is defined to be the mass of a particular cylinder of platinum-iridium alloy kept at the International Bureau of Weights and Measures at Sevres, near Paris.

Unit Prefixes

Once we have defined the fundamental units, it is easy to introduce larger and smaller units for the same physical quantities. In the metric system these other units are related to the fundamental units (or, in the case of mass, to the gram) by multiples of 10 or 1/10. With this notation, 1 km = 10^3m and 1 cm = 10^{-2} m. For example, the prefix "kilo-," abbreviated k, always means a unit larger by a factor of 1000; thus

$$1 \text{ kilometer} = 1 \text{ km} = 10^3 \text{ meters} = 10^3 \text{ m}$$
$$1 \text{ kilogram} = 1 \text{ kg} = 10^3 \text{ grams} = 10^3 \text{ g}$$
$$1 \text{ kilowatt} = 1 \text{ kW} = 10^3 \text{ watts} = 10^3 \text{ W}$$

Here are several examples of the use of multiples of 10 and their prefixes with the units.

Length

$1 \text{ nanometer} = 1 \text{ nm} = 10^{-9} \text{ m}$ (a few times the size of the largest atom)
$1 \text{ micrometer} = 1\ \mu\text{m} = 10^{-6} \text{ m}$ (size of some bacteria and living cells)
$1 \text{ millimeter} = 1 \text{ mm} = 10^{-3} \text{ m}$ (diameter of the point of a ballpoint pen)
$1 \text{ centimeter} = 1 \text{ cm} = 10^{-2} \text{ m}$ (diameter of your little finger)
$1 \text{ kilometer} = 1 \text{ km} = 10^{3} \text{ m}$ (a 10-minute walk)

Mass

$1 \text{ microgram} = 1\ \mu\text{g} = 10^{-6} \text{ g} = 10^{-9} \text{ kg}$ (mass of a very small dust particle)
$1 \text{ milligram} = 1 \text{ mg} = 10^{-3} \text{ g} = 10^{-6} \text{ kg}$ (mass of a grain of salt)
$1 \text{ gram} = 1 \text{ g} = 10^{-3} \text{ kg}$ (mass of a paper clip)

Time

1 nanosecond = 1 ns = 10^{-9} s (time for light to travel 0.3 m)
1 microsecond = 1 μs = 10^{-6} s (time for an orbiting space shuttle to travel 8 mm)
1 millisecond = 1 ms = 10^{-3} s (time for sound to travel 0.35 m)

The three fundamental quantities in physics are shown in the table below:

Length	Time	Mass
Meter (m)	second (s)	kilogram (kg)
L	T	M

All other quantities in physics can be derived from these fundamental quantities.

For example: [Speed] = [L] / [T], [Volume] = $[L]^3$, [Density] = [M] / $[L]^3$, [Acceleration] = [L] / $[T]^2$

1.3 Unit Consistency and Conversions

Each algebraic symbol always denotes both a number and a unit. For example, d might represent a distance of 10 m, t a time of 5 s, and v a speed of 2 m/s. For example, if a body moving with constant speed □ travels a distance d in a time t, these quantities are related by the equation

$$d = vt$$

If d is measured in meters, then the product □t must also be expressed in meters. Using the above numbers as an example, we may write

$$10\ \text{m} = \left(2\frac{\text{m}}{\cancel{\text{s}}}\right)(5\ \cancel{\text{s}})$$

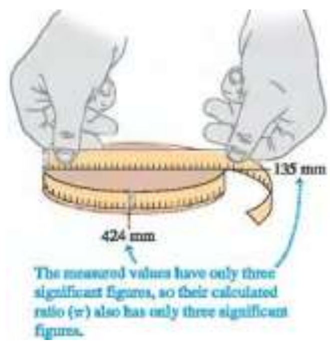
Example

Convert 1228.0 km/h in meters per second.

$$1228.0\ \text{km/h} = \left(1228.0 \times 10^3 \frac{\text{m}}{\cancel{\text{h}}}\right)\left(\frac{1\ \cancel{\text{h}}}{3600\ \text{s}}\right) = 341.11\ \text{m/s}$$

1.4 Uncertainty and Significant Figures

Measurements always have uncertainties. If you measure the thickness of the cover of this book using an ordinary ruler, your measurement is reliable only to the nearest millimeter, and your result will be 3 mm. If you use a micrometer caliper, a device that measures distances reliably to the nearest 0.01 mm, the result will be 2.91 mm. The distinction between these two measurements is in their uncertainty. The measurement using the micrometer caliper has a smaller uncertainty; it's a more accurate measurement. The uncertainty is also called the error because it indicates the maximum difference there is likely to be between the measured value and the true value. The uncertainty or error of a measured value depends on the measurement technique used. We often indicate the accuracy of a measured value by writing the number, the symbol ±, and a second number indicating the uncertainty of the measurement. If the diameter of a steel rod is given as 56.47±0.02 mm, this means that the true value is unlikely to be less than 56.45 mm or greater than 56.49 mm. As an application of these ideas, suppose you want to verify the value of π, the ratio of the circumference of a circle to its diameter.



Example

The rest energy E of an object with rest mass m is given by Einstein's equation

$$E = mc^2$$

where **c** is the speed of light in a vacuum. Find E for an object with m=9.1 1 x 10^{-31} kg (the mass of an electron).The SI unit for E is the joule (1); 1J = 1kg.m^2/s^2.

We are given the equation to use and the value of the mass m; the exact value of the speed of light is c = 299,792,458 m/s = 2.99792458 X 10^8 m/s.

$$
\begin{aligned}
E &= (9.11 \times 10^{-31}\,\mathrm{kg})(2.99792458 \times 10^{8}\,\mathrm{m/s})^2 \\
&= (9.11)(2.99792458)^2(10^{-31})(10^{8})^2\,\mathrm{kg \cdot m^2/s^2} \\
&= (81.87659678)(10^{[-31+(2\times 8)]})\,\mathrm{kg \cdot m^2/s^2} \\
&= 8.187659678 \times 10^{-14}\,\mathrm{kg \cdot m^2/s^2}
\end{aligned}
$$

So;

$$E = 8.19 \times 10^{-14}\,\mathrm{kg \cdot m^2/s^2} = 8.19 \times 10^{-14}\,\mathrm{J}$$

<u>Home Works</u>

1-The micrometer (1 μm) is often called the micron. (a) How many microns make up 1.0 km? (b) What fraction of a centimeter equals 1.0 mm? (c) How many microns are in 1.0 yd?

2-Earth is approximately a sphere of radius 6.37×10^6 m. What are (a) its circumference in kilometers, (b) its surface area in square kilometers, and (c) its volume in cubic kilometers?

3-(a) Assuming that each cubic centimeter of water has a mass of exactly 1 g, find the mass of one cubic meter of water in kilograms. (b) Suppose that it takes 10.0 h to drain a container of 5700 m^3 of water. What is the "mass flow rate," in kilograms per second, of water from the container?

4-Iron has a mass of 7.87 g per cubic centimeter of volume, and the mass of an iron atom is 9.27 x 10^{-26} kg. If the atoms are spherical and tightly packed, (a) what is the volume of an iron atom and (b) what is the distance between the centers of adjacent atoms?