Physics and Measurement

1.1 Standards of Length, Mass, and Time

In mechanics, there are three basic quantities which are length, mass, and time. All other quantities in mechanics can be expressed in terms of these three.

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

Mass: SI unit of mass, 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.

Time: SI unit of time, the *second (s)* is defined as 9,192,631,770 times the period of vibration of radiation from the cesium atom.

In addition to the basic SI units of meter, kilogram, and second, we can also use other units, such as millimeters and nanoseconds, where the prefixes *milli-* and *nano* denote multipliers of the basic units based on various powers of ten. Prefixes for the various powers of ten and their abbreviations are listed in Table 1.4. For example, 10^3 m is equivalent to 1 millimeter (mm), and 10^3 m corresponds to 1 kilometer (km). Likewise, 1 kilogram (kg) is 10^3 grams (g), and 1 megavolt (MV) is 10^6 volts (V).

1 m= 10 dm=100 cm=1000 mm

1 km= 1000 m = 10^3 m

1 m= 0.001 km= 10^{-3} km

Table 1.4

Prefixes for Powers of Ten

Power	Prefix	Abbreviation
10^{-24}	yocto	y
10^{-21}	zepto	z
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zetta	Z
10^{24}	yotta	Y

1.4 Dimensional Analysis

The word *dimension* has a special meaning in physics. It denotes the physical nature of

a quantity. Whether a **distance** is measured in units of feet or meters, it is

still a distance. We say its dimension is *length.*

The symbols we use to specify the dimensions of length, mass, and time are L, M, and T, respectively.

We often use brackets [ ] to denote the dimensions of a physical quantity. For example, the symbol we use for speed is v, and in our notation the dimensions of speed are written $[v] = L/T$. As another example,

the dimensions of area A are $[A] = L^2$.

You may have to derive or check a specific equation. A useful and powerful procedure called *dimensional analysis* can be used to assist in the derivation or to check your final expression.

Quantities can be added or subtracted only if they have the same dimensions. Furthermore, the terms on both sides of an equation must have the same dimensions. By following these simple rules, you can use dimensional analysis to help determine whether an expression has the correct form. The relationship can be correct only if the dimensions on both sides of the equation are the same.

Use dimensional analysis to check the validity of the expression $x = (1/2)\, at^2$.

The quantity x on the left side has the dimension of length. For the equation to be dimensionally correct, the quantity on the right side must also have the dimension of length. We can perform a dimensional check by substituting the dimensions for acceleration, L/T2, and time, T, into the equation. That is, the dimensional form of the equation is

$$L = (L/\cancel{T^2})\, \cancel{T^2} = L$$

The dimensions of time cancel as shown, leaving the dimension of length on the right-hand side.

Example 1. Suppose we are told that the acceleration a of a particle moving with uniform speed v in a circle of radius r is proportional to some power of r, say r^n, and some power of v, say v^m. Determine the values of n and m and write the simplest form of an equation for the acceleration.

$$a = kr^n v^m$$

where k is a dimensionless constant of proportionality.

Dimensional equation,

$$\frac{L}{T^2} = L^n \left(\frac{L}{T}\right)^m = \frac{L^{n+m}}{T^m} \quad ; \quad m=2 \ ; \quad n+m=1 \quad ; \quad n=-1$$

$$a = kr^{-1}v^2 = k\frac{v^2}{r}$$

1.5 Conversion of Units

Sometimes it is necessary to convert units from one measurement system to another, or to convert within a system, for example, from kilometers to meters. Equalities between SI and U.S. customary units of length are as follows:

1 mile= 1609 m = 1.609 km

1 ft = 0.304 8 m = 30.48 cm

1 m = 39.37 in. = 3.281 ft

1 in. = 0.0254 m = 2.54 cm

Conversion Factors

Length

	m	cm	km	in.	ft	mi
1 meter	1	10^2	10^{-3}	39.37	3.281	6.214×10^{-4}
1 centimeter	10^{-2}	1	10^{-5}	0.393 7	3.281×10^{-2}	6.214×10^{-6}
1 kilometer	10^3	10^5	1	3.937×10^4	3.281×10^3	0.621 4
1 inch	2.540×10^{-2}	2.540	2.540×10^{-5}	1	8.333×10^{-2}	1.578×10^{-5}
1 foot	0.304 8	30.48	3.048×10^{-4}	12	1	1.894×10^{-4}
1 mile	1 609	1.609×10^5	1.609	6.336×10^4	5 280	1

Mass

	kg	g	slug	u
1 kilogram	1	10^3	6.852×10^{-2}	6.024×10^{26}
1 gram	10^{-3}	1	6.852×10^{-5}	6.024×10^{23}
1 slug	14.59	1.459×10^4	1	8.789×10^{27}
1 atomic mass unit	1.660×10^{-27}	1.660×10^{-24}	1.137×10^{-28}	1

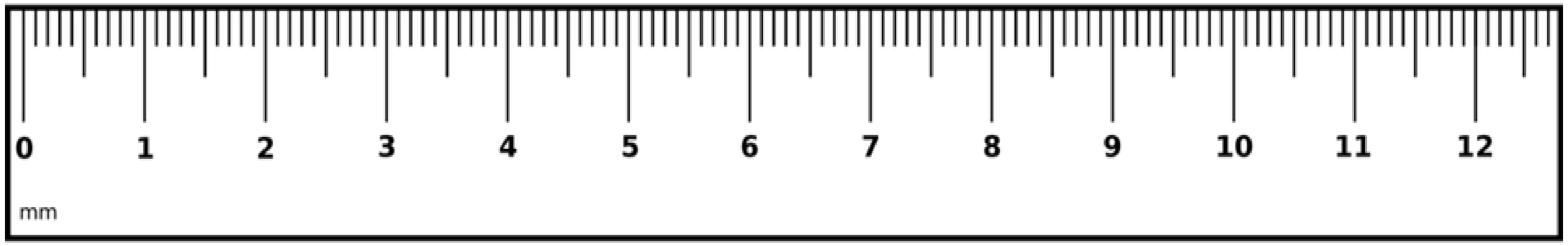
Note: 1 metric ton = 1 000 kg.

Time

	s	min	h	day	yr
1 second	1	1.667×10^{-2}	2.778×10^{-4}	1.157×10^{-5}	3.169×10^{-8}
1 minute	60	1	1.667×10^{-2}	6.994×10^{-4}	1.901×10^{-6}
1 hour	3 600	60	1	4.167×10^{-2}	1.141×10^{-4}
1 day	8.640×10^4	1 440	24	1	2.738×10^{-5}
1 year	3.156×10^7	5.259×10^5	8.766×10^3	365.2	1

1.7 Significant Figures

The number of significant figures in a measurement can be used to express something about the ***uncertainty***.



Assume that the accuracy to which we can measure the length of the label is $\pm$0.1 cm. If the length is measured to be 5.5 cm, we can claim only that its length lies somewhere between 5.4 cm and 5.6 cm. In this case, we say that the measured value has *two significant figures*. Note that the significant figures include the first estimated digit.

Now suppose we want to find the area of the label by multiplying the two measured values. If we were to claim the area is (5.5 cm)(6.4 cm)=35.2 cm^2, our answer would be unjustifiable because it contains three significant figures, which is greater than the number of significant figures in either of the measured quantities.

Rule: When multiplying several quantities, the number of significant figures in the final answer is the same as the number of significant figures in the quantity having the lowest number of significant figures. The same rule applies to division.

Applying this rule to the previous multiplication example, we see that the answer for the area can have only two significant figures because our measured quantities have only two significant figures. Thus, all we can claim is that the area is 35 cm^2, realizing that the value can range between (5.4 cm)(6.3 cm)=34 cm^2 and (5.6 cm)(6.5 cm)=36 cm^2.

Zeros may or may not be significant figures. Those used to position the decimal point in such numbers as 0.03 and 0.0075 are not significant. Thus, there are one and two significant figures, respectively, in these two values. When the zeros come after other digits, however, there is the possibility of misinterpretation. For example, suppose the mass of an object is given as 1500 g. This value is ambiguous because we do not know whether the last two zeros are being used to locate the decimal point or whether they represent significant figures in the measurement. To remove this ambiguity, it is common to use scientific notation to indicate the number of significant figures. In this case, we would express the mass as 1.5×10^3 g if there are two significant figures in the measured value, 1.50×10^3 g if there are three significant figures, and 1.500×10^3 g if there are four. The same rule holds for numbers less than 1, so that 2.3×10^{-4} has two significant figures (and so could be written 0.00023) and 2.30×10^{-4} has three significant figures (also written 0.000230).

In general, a significant figure in a measurement is a reliably known digit (other than a zero used to locate the decimal point) or the first estimated digit.

Rule: When numbers are added or subtracted, the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum.

123 + 5.35= 128 , not 128.35. If we

1.0001 + 0.0003= 1.0004 (the result has five significant figures,

even though one of the terms in the sum, 0.0003, has only one significant figure.)

Likewise,

1.002 - 0.998 = 0.004

the result has only one significant

figure even though one term has four significant figures and the other has

three.