INTRODUCTION TO ENGINEERING CALCULATIONS

1.1 Units and Dimensions

You will need practice to develop your ability to analyze and work engineering problems. To read and understand the principles discussed in this chapter is relatively easy; to apply them to different unfamiliar situations. An engineer becomes competent in his or her profession by mastering the techniques developed by one's predecessors—thereafter comes the time to pioneer new ones.

The chapter begins with a discussion of units, dimensions, and conversion factors, and then goes on to review some terms you should already be acquainted with, such as:
(a) Mole and mole fraction
(b) Density and specific gravity
(c) Measures of concentration
(d) Temperature
(e) Pressure

It then provides some clues on "how to solve problems," which should be of material aid in all the remaining portions of your career. Finally, the principles of stoichiometry are reviewed, and the technique of handling incomplete reactions is illustrated.

1.1 UNITS AND DIMENSIONS

At some time in every student's life comes the exasperating sensation of frustration in problem solving. Somehow, the answers or the calculations do not come out as expected. Often this outcome arises because of inexperience in the handling of units. The use of units or dimensions along with the numbers in your calculations requires more attention than you probably have been giving to your computations in the past, but paying attention will help avoid such annoying experiences. The proper use of dimensions in problem solving is not only sound from a logical viewpoint—it will also be helpful in guiding you along an appropriate path of analysis from what is at hand through what has to be done to the final solution.

1.1-1 Units and Dimensions

Dimensions are our basic concepts of measurement such as length, time, mass, temperature, and so on; units are the means of expressing the dimensions, such as feet or centimeters for length, or hours or seconds for time. Units are associated with some quantities you may have previously considered to be dimensionless. A good example is molecular weight, which is really the mass of one substance per mole of that substance. This method of attaching units to all numbers which are not fundamentally dimensionless has the following very practical benefits:

(a) It diminishes the possibility of inadvertent inversion of any portion of the calculation.
(b) It reduces the calculation in many cases to simple ratios, which can be easily manipulated on a hand-held calculator.
(c) It reduces the intermediate calculations and eliminates considerable time in problem solving.
(d) It enables you to approach the problem logically rather than by remembering a formula and plugging numbers into the formula.
(e) It demonstrates the physical meaning of the numbers you use.

Every freshman knows that what you get from adding apples to oranges is fruit salad! The rule for handling units is essentially quite simple: treat the units as you would algebraic symbols. You can add, subtract, or equate numerical quantities only if the units of the quantities are the same. Thus the operation

\[ 5 \text{ kilograms} + 3 \text{ joules} \]

is meaningless because the dimensions of the two terms are different. The numerical operation

\[ 10 \text{ pounds} + 5 \text{ grams} \]

can be performed (because the dimensions are the same, mass) only after the units are transformed to be the same, either pounds, or grams, or ounces, and so on. In multiplication and division, you can multiply or divide different units, such as (10 centimeters \( \cdot \) 4 seconds) = 2.5 centimeters/second, but you cannot cancel them out unless they are the same. For example, \( 3 \text{ m}^2/60 \text{ cm} \) must first be converted to \( 3 \text{ m}^2/0.6 \text{ m} \) and then to 5 m. The units contain a significant amount of information content that cannot be ignored. They also serve as guides in efficient problem solving, as you will see shortly.

EXAMPLE 1.1 Dimensions and Units

Add the following:
(a) 1 foot + 3 seconds
(b) 1 foot + 3 seconds

Solution
The operation indicated by

\[ 1 \text{ ft} + 3 s \]

has no meaning since the dimensions of the two terms are not the same. One foot has the dimensions of length, whereas 3 seconds has the dimensions of time. In the case of

\[ 1 \text{ hp} + 300 \text{ watts} \]

the dimensions are the same (energy per unit time) but the units are different. You must transform the two quantities into like units, such as horsepower, watts, or something else, before the addition can be carried out. Since 1 hp = 746 watts,
746 watts + 300 watts = 1046 watts

### 1.1-2 Conversion of Units and Conversion Factors

We will make use of what is called the *dimensional equation*. It contains both units and numbers. One quantity is multiplied by a number of ratios termed conversion factors of equivalent values of combinations of time, distance, and so on, to arrive at the final desired answer. The ratios used are simple well-known values and thus the conversion itself should present no great problem. Examine Example 1.2.

**EXAMPLE 1.2 Conversion of Units**

If a plane travels at twice the speed of sound (assume that the speed of sound is 1100 ft/s), how fast is it going in miles per hour?

**Solution**

![Dimensional equation](image)

Of course, it is possible to look up conversion ratios, which will enable the length of the calculation to be reduced; for instance, in Example 1.2 we could have used the conversion factor of 60 mi/hr equals 88 ft/s. However, it usually takes less time to use values you know than to look up shortcut conversion factors in a handbook. Common conversion ratios are listed on the inside front cover.

We have set up the dimensional equation with vertical lines to separate each ratio, and these lines retain the same meaning as an X or multiplication sign placed between each ratio. The dimensional equation will be retained in this form throughout most of this text to enable you to keep clearly problem solving. It is recommended that you always write down the units next to the associated numerical value (unless the calculation is very simple) until you become quite familiar with the use of units and dimensions and can carry them in your head.

At any point in the dimensional equation you can determine the consolidated net units and see what conversions are still required. This may be carried out formally, as shown below by drawing slanted lines below the dimensional equation and writing the consolidated units on these lines, or it may be done by eye, mentally canceling and accumulating the units, or, you can strike out pairs of units as you proceed:
Consistent use of dimensional equations throughout your professional career will assist you in avoiding silly mistakes such as converting 10 centimeters to inches by multiplying by 2.54:

\[
\frac{10 \text{ cm}}{1 \text{ in.}} \times 2.54 = 25.4 \text{ cm} \quad \text{but instead} \quad = 25.4 \text{ cm}^2
\]

Note how easily you discover that a blunder has occurred by including the units in the calculations.

Here is another example of the conversion of units.

EXAMPLE 1.3 Use of Units

Change 400 in./day to cm³/min.

Solution

\[
\frac{400 \text{ in.}^3}{\text{day}} \times \left(\frac{2.54 \text{ cm}}{1 \text{ in.}}\right)^3 \times \frac{1 \text{ day}}{24 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 4.56 \text{ cm}^3 \text{/ min}
\]

In this example note that not only are the numbers raised to a power, but the units also are raised to the same power.