# Introduction

Throughout your career as a chemical engineer you will be presented with quantities or measurements in a particular set of units, for example, 55 miles per hour, but in order to solve a problem you will need to convert that quantity or measurement to an equivalent magnitude in a different system of units. Thus, in this appendix you will review the concepts and skills involved in converting a magnitude with a particular set of units to an equivalent magnitude in a second system of units. First, the three major systems of units, the **cgs**, **mks**, and **fps** will be discussed. Next, you will be introduced to the concept of an **equivalence relationship** and how to form a **units conversion factor** from the appropriate equivalence relationship. Then, the procedures for using the unit conversion factors as part of a **dimensional equation** will be presented.

## B.1 Systems of Units

Three systems of units are of importance to you as a chemical engineer. They are the **cgs**, **mks**, and **fps** systems. As you will see below, the respective names for each of these systems indicate the units used for the primary quantities of length, mass, and time in each of them.

### B.1.1 The cgs System of Units

The **cgs system** of units, also known as the **common scientific system**, derives its name from the units for length, mass, and time in the system: the centimeter, the gram, and the second respectively.

| Primary Quantity | Unit |
|---|---|
| length | **c**entimeter (cm) |
| mass | **g**ram (g) |
| time | **s**econd (s) |

### B.1.2 The mks System of Units

The **mks system** of units, which is known as the **SI system**, also derives its name from the units for length, mass, and time used in the system: the meter, the kilogram, and the second respectively.

| Primary Quantity | Unit |
|---|---|
| length | **m**eter (m) |
| mass | **k**ilogram (kg) |
| time | **s**econd (s) |

### B.1.3 The fps System of Units

The **fps system** or **American Engineering system** of units, used commonly in the United States, again derives its name from the units for length, mass, and time in the system: the foot, the pound mass, and the second respectively.

| Primary Quantity | Unit |
|---|---|
| length | **f**oot (ft) |
| mass | **p**ound mass ($lb_m$) |
| time | **s**econds (s) |

## B.2 Equivalence Relations

When taken in the context of units conversion, an equivalence relation is an expression which relates equal magnitudes of a quantity in different systems of units. For instance, a well-established fact is that there are 100 centimeters in 1 meter. Therefore, 100 cm is an equivalent length to 1 m, and it can be expressed by the following equivalence relation:

$$100 \text{ cm} \equiv 1 \text{ m},$$

which is read, "one hundred centimeters is equivalent to one meter." The "≡" symbol is used rather than an "=" symbol in an equivalence relation since an equivalence relation does not assign the value on the right to the value on the left, as is the case when the "=" symbol is used in equations like:

$$y = 3$$
$$a^2 = b^2 + c^2.$$

Other examples of equivalence relations include the following:

$$
\begin{aligned}
60 \text{ min} &\equiv 1 \text{ h} \\
3 \text{ ft} &\equiv 1 \text{ yard} \\
1 \text{ kg} &\equiv 1000 \text{ g} \\
1 \text{ mL} &\equiv 1 \text{ cm}^3 \\
1 \text{ ft} &\equiv 12 \text{ in.}
\end{aligned}
$$

Can you think of others?

### B.2.1 Fundamental Equivalence Relations

The fundamental equivalence relations between the **cgs**, **mks**, and **fps** systems of units are listed in Table “**gotche**” for the basic quantities in chemical engineering at the beginning of Chapter 3 of the *CinChE* manual. The bad news is that you will need to memorize the equivalence relationships in Table “**gotche**”. At first this may seem overwhelming, but many of these you should already know. Since you will be using the rest of them on such a regular basis, you should have little trouble remembering them. The good news is that, with a few exceptions, any additional equivalence relations, that you will need, can be derive from those in Table “**gotche**” or be looked up in reference sources, such as the website www.onlineconversion.com for over 5,000 units and 50,000 equivalence relations.

**Note:** A vast majority of the equivalence relations of important use to you can be found in the textbook by Felder and Rousseau (see inside of front cover). Felder and Rousseau improperly used the symbol "=" for equivalence. You should mentally replace this symbol of "=" with the correct symbol "≡".

  

## B.3 Generating Unit Conversion Factors

In order to perform a units conversion, an entity known as a conversion factor must be generated from the appropriate equivalence relation. In order to generate the required conversion factor, the following steps are employed:

1. Determine the **current state** of the units of the given engineering quantity, i.e. what are the given units?

2. Determine the **goal state** of the units of the given engineering quantity, i.e. to what units do you desire to convert the given quantity?

3. Select an **equivalence relation** which relates the units in the current state and the goal state.

4. Transform the equivalence relation selected in Step 3 into a **conversion factor** (CF) according to the following rule:

$$\text{CF} \implies \frac{\text{side of equivalence relation containing the } \textbf{goal} \text{ state units}}{\text{side of equivalence relation containing the } \textbf{current} \text{ state units}}$$

5. Enclose the CF in triangular brackets "<CF>" to distinguish it as a conversion factor

**Example B-1**: Convert $m' = 1500$ g to $lb_m$.

Current state units: grams
Goal state units: pounds-mass

Equivalence relation: $453.592 \text{ g} \equiv 1 \text{ lb}_m$

$$\text{CF} \implies \frac{1 \text{ lb}_m}{453.592 \text{ g}}$$

$$\text{CF} \implies \left\langle \frac{1\, lb_m}{453.592\, g} \right\rangle$$

**Example B-2**: Convert $L' = 12$ m to ft.

Current state units: meters
Goal state units: feet

Equivalence relation: $3.2808 \text{ ft} \equiv 1 \text{m}$

$$\text{CF} \implies \frac{3.2808 \text{ ft}}{1 \text{m}}$$

$$\text{CF} \implies \left\langle \frac{3.2808\ ft}{1\, m} \right\rangle$$

## Practice for Section B.3

Click here for the answers.

Below you will find a series of magnitudes whose units need to be converted in the indicated fashion. Please generate as many of the conversion factors as you need to master the formations of CF's.

**PB.3.1:** Convert m' = 575 g to $lb_m$.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.2:** Convert m' = 1000 $lb_m$ to kg.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.3:** Convert L' = 6048 cm to ft.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.4:** Convert L' = 6096 m to ft.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.5:** Convert t' = 21.75 h to min.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.6:** Convert n' = 220 g-mol to lb-mol.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.7:** Convert n' = 523.5 g-mol to kg-mol.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.8:** Convert P' = 33 atm to bar.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.9:** Convert P' = 6.06 x$10^6$ dynes/$cm^2$ to atm.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

**PB.3.10:** Convert V' = 25 $ft^3$ to gal.

Current state units: ____________________
Goal state units: ____________________
Equivalence relation: ____________________

CF ==> ____________________________

## B.4 Using Conversion Factors

Once the units conversion factor has been formed, to complete the units conversions process you must form a dimensional equation (DE). A dimensional equation states the equality between the desired units and the original units using the necessary units conversion factor(s). Continuing with Example B-1 should help clarify this process.

**Example B-1a**: Convert m' = 1500 g to $lb_m$.

Current state units: grams
Goal state units: pounds-mass

Equivalence relation: 453.592 g ≡ 1 $lb_m$

CF ==> $$\left\langle \frac{1\,lb_m}{453.592\,g} \right\rangle$$

DE ==> $$m = 1500\text{ g} \left\langle \frac{1\,lb_m}{453.592\,g} \right\rangle$$

$$m = 3.307\ lb_m.$$

In completing Example B-1a, the original magnitude, m', which was measured in grams was converted to a second new magnitude, m, whose units are $lb_m$. The symbols m' and m are different variables because they have different units. If you examine Example B-1a, you will find the dimensional equation (DE) has the following characteristics:

1) the **left-hand side is a symbol** which represents the new magnitude that is to be created by the units conversion process;

2) the **right-hand side** consists of two components:

   a) the **given magnitude** which is to be converted and its associated units;
   b) the appropriate conversion factor.

Once that the dimensional equation has been formed, it is evaluated just as you would evaluate any other algebraic expression, performing all the necessary multiplications and divisions and appropriate cancellations of units. As a check on your work, if you have formed the dimensional equation with the correct conversion factors, the units which result on the right-hand side of the dimensional equation should be the goal state units for the problem. See if you can identify the characteristic parts of the dimensional equation in Example B-2a.

**Example B-2a**: Convert L' = 12.00 m to ft.

Current state units: meters
Goal state units: feet

Equivalence relation: 3.2808 ft ≡ 1 m

CF==> $$\left\langle \frac{3.2808\ ft}{1\,m} \right\rangle$$

  

DE==> $L = 12.00\ m \left\langle \dfrac{3.2808\ ft}{1\ m} \right\rangle$

$L = 39.7$ ft.

**Practice for Section B.4**

Click here for the answers.

Using the conversions factors you found in practice Exercises B4.3.1 to B4.3.10, complete the units conversion process by forming and evaluating a dimensional equation for each of the unit conversion problems below.

**PB.4.1:** Convert m' = 575 g to $lb_m$.

DE ==> ______________________________

______________________________

**PB.4.2:** Convert m' = 1000 $lb_m$ to kg.

DE ==> ______________________________

______________________________

**PB.4.3:** Convert L' = 6048 cm to ft.

DE ==> ______________________________

______________________________

**PB.4.4:** Convert L' = 6096 m to ft.

DE ==> ______________________________

______________________________

**PB.4.5:** Convert t' = 21.75 h to min.

DE ==> ______________________________

______________________________

**PB.4.6:** Convert n' = 220 g-mol to lb-mol.

DE ==> ______________________________

______________________________

**PB.4.7:** Convert n' = 523.5 g-mol to kg-mol.

DE ==> ______________________________

______________________________

**PB.4.8:** Convert P' = 33 atm to bar.

DE ==> ______________________________

______________________________

**PB.4.9:** Convert P' = 6.06 x$10^6$ dynes/$cm^2$ to atm.

DE ==> ______________________________

______________________________

**PB.4.10:** Convert V' = 25 $ft^3$ to gal.

DE ==> ______________________________

______________________________

  

## B.5 Temperature Conversions

You may have noticed that up to this point the conversion of temperature units has not been discussed, nor have you been asked to work any examples involving temperature. This anomaly results from the fact that two types of temperature measurement exist. Therefore, two types of units conversions equations must be built.

Regardless of the temperature scale used (i.e., either Fahrenheit, Rankine, Centigrade, or Kelvin) your work in this course will involve two classes of temperature measurements. The first class contains those temperature measurements most commonly used in specific heat capacity, thermal conductivity, and heat transfer calculations. These temperature measurements reflect a change in temperature or the difference between two temperature readings. For instance, if water at 10$^o$C is heated to 50$^o$C, the **change in the temperature** of the water is 40 $\Delta^o$C. Notice the $\Delta$ symbol is included in the units to indicate that the measurement reflects a **change or difference** in two temperatures. Appropriately enough, temperature measurements which fall into this class are referred to as delta temperature measurements. Correspondingly, if the same water is then cooled to 20$^o$C, the temperature change for the cooling process would be 30 $\Delta^o$C.

**Note:** $\Delta^o$F, $\Delta^o$C, $\Delta^o$R and $\Delta$K may also be written F$^o$, C$^o$, R$^o$, and K$^o$, respectively.

The second class of temperature measurements are measurements which indicate a **particular temperature** on a given scale such as a thermometer. For instance, 32$^o$F, 491.67$^o$R, 0$^o$C, and 273.15 K are the particular temperatures in each of the respective temperature scales at which water freezes. The particular temperatures in each of the respective temperature scales at which water boils are 212$^o$F, 671.67$^o$R, 100$^o$C, and 373.15 K. Each of the four temperature scales has a reference point at which a particular temperature on that scale has been assigned the value of zero degrees. In the centigrade scale, the zero-degree reference point has been assigned at the freezing point of water. In both the Kelvin and Rankine scales this reference point has been placed at the temperature at which all matter ceases motion, commonly known as absolute zero. In the Fahrenheit scale the zero-degree reference point has been assigned so the freezing point of water will be at 32$^o$F on the scale.

## B.6 Units Conversion for Delta Temperatures

Converting between temperature units for delta temperature measurements involves the same process as described in Sections B.3 to B.4 which you have used for other types of units conversion. Consequently, a few examples and exercises, that use the equivalence relations in Table B.1, should crystallize this process for you.

**Table B.1.** Delta Temperature Equivalences

| | |
|---|---|
| 1 $\Delta^o$C $\equiv$ 1.8 $\Delta^o$F | $\Delta^o$F $\equiv$ $\Delta^o$R |
| 1 $\Delta$K $\equiv$ 1.8 $\Delta^o$R | $\Delta^o$C $\equiv$ $\Delta$K |

  

**Example B-3**: Convert $\Delta T' = 10\ \Delta^oC$ to $\Delta^oF$.

Equivalence relation: $1\ \Delta^oC \equiv 1.8\ \Delta^oF$

Current state units: $\Delta^oC$
Goal state units: $\Delta^oF$

CF ==> $\left\langle \frac{1.8\ \Delta^\circ F}{1\ \Delta^\circ C} \right\rangle$

DE ==> $\Delta T = 10\ \Delta^oC \left\langle \frac{1.8\ \Delta^\circ F}{1\ \Delta^\circ C} \right\rangle$

$\Delta T = 18\ \Delta^oF$

**Example B-4**: Convert $\Delta T' = 18\ \Delta^oR$ to $\Delta K$.

Equivalence relation: $1\ \Delta K \equiv 1.8\ \Delta^oR$

Current state units: $\Delta^oR$
Goal state units: $\Delta K$

CF ==> $\left\langle \frac{1\ \Delta K}{1.8\ \Delta^\circ R} \right\rangle$

DE ==> $\Delta T = 18\ \Delta^oR \left\langle \frac{1\ \Delta K}{1.8\ \Delta^\circ R} \right\rangle$

$\Delta T = 10\ \Delta K$

## Practice for Section B.6

Click here for the answers.

Perform the delta temperature unit conversions in the problems below using the equivalence relations in Table B.1 to form the required conversion factors.

**PB.6.1:** Convert $\Delta T' = 82\ \Delta^oF$ to $\Delta^oR$.
Equivalence relation: ____________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

**PB.6.4:** Convert $\Delta T' = 127\ \Delta K$ to $\Delta^oR$.
Equivalence relation: ____________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

**PB.6.2:** Convert $\Delta T' = 22\ \Delta^oC$ to $\Delta^oF$.
Equivalence relation: ___________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

**PB.6.3:** Convert $\Delta T' = 98.6\ \Delta^oF$ to $\Delta^oC$.
Equivalence relation: ___________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

**PB.6.5:** Convert $\Delta T' = 67\ \Delta^oC$ to $\Delta K$.
Equivalence relation: ___________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

**PB.6.6:** Convert $\Delta T' = 250\ \Delta^oR$ to $\Delta K$.
Equivalence relation: ___________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

## B.7 Units Conversion for Particular Temperatures

Since, with particular temperatures, an individual temperature reading is referenced against the respective temperature scale's zero point which is, in turn, referenced against a physical phenomenon (either the freezing point of water or absolute zero), the difference in these reference points must be compensated for in the units conversion equation when converting a particular temperature between two temperature scales.

Thus, when converting, say $104^oF$ to $^oC$, the dimensional process must accomplish three tasks. First, the process must compensate for the difference in the location of the zero points in the temperature scales. This is accomplished by finding the delta temperature between the given particular temperature and the particular temperature in the scale being used to indicate some known physical phenomenon. In our example this can be accomplished by subtracting $32^oF$ from $104^oF$, so that the temperature is referenced against the freezing point of water. In the second phase of the units conversion process, the resulting delta temperature of $72\ \Delta^oF$ must then be converted to a delta Centigrade temperature using the methods discussed in Section B.6. Doing so yields a delta Centigrade temperature of $40\ \Delta^oC$. The third phase of the particular temperature units conversion process requires this second delta temperature to be referenced against the particular temperature of the reference phenomenon in the second temperature scale to produce the final particular temperature. Since in our example the reference phenomenon is the freezing point of water, which is $0^oC$, a delta temperature of $40\ \Delta^oC$ with a lower reference point of $0\ ^oC$ means the desired particular temperature is $40^oC$.

  

Mathematically, the above process can be expressed through the following general derivation, if the original Fahrenheit temperature is given by **TF** and the desired Centigrade temperature is given by **TC**.

1) $\mathbf{\Delta TF}\ \Delta^{o}F = [\mathbf{TF} - 32\ ^{o}F]\ \Delta^{o}F$ -- this operation has units of $\Delta^{o}F$.

2) $\mathbf{\Delta TC}\ \Delta^{o}C = \mathbf{\Delta TF}\ \Delta^{o}F \left\langle \frac{1\ \Delta^{\circ} C}{1.8\ \Delta^{\circ} F} \right\rangle$ -- **ΔTC** has units of $\Delta^{o}C$.

3) $\mathbf{\Delta TC}\ \Delta^{o}C = [\mathbf{TC} - 0\ ^{o}C]\ \Delta^{o}C$ -- the right-hand side of this equation has units of $\Delta^{o}C$.

If Equation 1 and 3 above are substituted into Equation 2 above, the following dimensional equation results:

$$[\mathbf{TC} - 0\ ^{o}C]\ \Delta^{o}C = [\mathbf{TF} - 32\ ^{o}F]\ \Delta^{o}F \left\langle \frac{1\ \Delta^{\circ} C}{1.8\ \Delta^{\circ} F} \right\rangle .$$

By cancelling units and simplifying this expression you come up with this familiar dimensional equation:

$$\mathbf{TC} = (\mathbf{TF} - 32\ ^{o}F)\ \frac{1}{1.8} \ ,$$

which can be rearranged to the even more familiar form of

$$\mathbf{TF} = 1.8\ \mathbf{TC} + 32$$

or

$$\mathbf{TF} - 32 = \frac{9}{5}\ \mathbf{TC} .$$

If we substitute 104$^{o}$F in the above equation and solve for TC, then TC is equal to 40.0$^{o}$C.

Following similar reasoning and mathematics, the following dimensional equations can also be derived:

$$\mathbf{TR} = \mathbf{TF} + 459.67$$

$$\mathbf{TK} = \mathbf{TC} + 273.15$$

$$\mathbf{TR} = 1.8\ \mathbf{TK}$$

where **TF** is a particular temperature in $^{o}$F, **TR** is a particular temperature in $^{o}$R, **TC** is a particular temperature in $^{o}$C, and **TK** is a particular temperature in K. Though the actual derivations for these three dimensional equations are not going to be provided here, you should perform them as a check on your understanding of the principles underlying the dimensional equations for particular temperatures.

**Practice for Section B.7** Click here for the answers.

  

Perform the particular temperature unit conversions in the problems below using the proper dimensional equation listed above for temperature.

**PB.7.1:** Convert T' = 202$^o$F to $^o$R.
DE ==> ______________________________

______________________________

**PB.7.2:** Convert T' = -13$^o$C to $^o$F.
DE ==> ______________________________

______________________________

**PB.7.3:** Convert T' = 67$^o$F to $^o$C.
DE ==> ______________________________

______________________________

**PB.7.4:** Convert T' = 535.65 K to $^o$C.
DE ==> ______________________________

______________________________

**PB.7.5:** Convert T' = 223$^o$C to $^o$F.
DE ==> ______________________________

______________________________

**PB.7.6:** Convert T' = 18$^o$F to $^o$C.
DE ==> ______________________________

______________________________

## B.8 Generating Unit Conversion Factors When the Unit to be Converted is in the Denominator

So far, you have learned how to create conversion factors from equivalence relations, how to form and evaluate unit conversion equations, and how to perform units conversion on both delta and particular temperatures. However, in all of these tasks it has been assumed that only a single unit has been involved. In the sections which follow, you will learn how to form unit conversion factors for (1) magnitudes that have a unit to be converted in the denominator of a fraction of units and (2) magnitudes that have compound units, that is, units that are made up of several sub-units multiplied together.

One common quantity whose units consist of a fraction of units is velocity. For instance, the velocity of a certain chemical process stream might be given to you as **u** = 60 feet per minute, and you might need to know what this velocity is in feet per second. In order to perform this units conversion, you will need to form a conversion factor which effects only the units in the denominator of the units fraction. In order to generate the need conversion factor in this situation, the following steps are employed:

1. Determine the **current state** of the units of the given quantity, i.e. what are the given units?

2. Determine the **goal state** of the units of the given quantity, i.e. to what units do you desire to convert the given quantity?

3. Select an **equivalence relation** which relates the units in the current state and the goal state.

4. Transform the equivalence relation selected in Step 3 into a **conversion factor** (CF) according to the following rule:

$$\text{CF} \implies \frac{\text{side of equivalence relation containing the } \textbf{current} \text{ state units}}{\text{side of equivalence relation containing the } \textbf{goal} \text{ state units}}$$

5. Enclose the CF in triangular brackets "<CF>" to distinguish it as a conversion factor.

  

Notice that the steps given above are the same steps given in Section B.3 when you were first introduced to forming conversion factors, except the current state side of the equivalence relation now goes into the numerator of the conversion factor and the goal state side of the equivalence relation now goes into the denominator.

**Example B-5**: Convert $u' = 60 \frac{ft}{min}$ to $\frac{ft}{s}$.

Current state units: minutes
Goal state units: seconds

Equivalence relation: 60 seconds ≡ 1 minute

CF ==> $\frac{1 \text{ min}}{60 \text{ s}}$

$$\left\langle \frac{1 \text{ min}}{60\ s} \right\rangle$$

With the conversion factor formed, you can proceed to form the dimensional equation just as you did in Section B.4.

**Example B-5a**: Convert $u' = 60 \frac{ft}{min}$ to $\frac{ft}{sec}$.

Current state units: minutes
Goal state units: seconds

Equivalence relation: 60 seconds ≡ 1 minute

CF ==> $\left\langle \frac{1 \text{ min}}{60\ s} \right\rangle$

DE ==> $u = 60 \frac{ft}{\text{min}} \left\langle \frac{1 \text{ min}}{60\ s} \right\rangle$

$$u = 1.0 \frac{\text{ft}}{\text{s}}$$

Perform the units conversion process on the two magnitudes below. Each of the magnitudes has a unit in the denominator which needs to be converted. You will need to form a conversion factor, and form and solve a dimensional equation for each magnitude.

**Practice for Section B.8**

Click here for the answers.

  

**PB.8.1:** Convert v' = 5280 $\frac{\text{miles}}{\text{h}}$ to $\frac{\text{miles}}{\text{s}}$.

Equivalence relation: ____________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

**PB.8.2:** Convert v' = 3.600 $\frac{\text{m}}{\text{s}}$ to $\frac{\text{m}}{\text{h}}$.

Equivalence relation: ____________________

CF ==> ______________________________

DE ==> ______________________________

______________________________

## B.9 Generating Unit Conversion Equations When More Than One Unit Must Be Converted

You are now equipped to create unit conversion factors and to form and solve dimensional equations when the unit to be converted is either in the numerator or the denominator of a unit which is a fraction of units. You will now put those skills together to allow you to properly perform the units conversion when you need to transform the units of both the numerator and denominator of a unit fraction. For instance, what if you need to convert the velocity of u = 60.00 feet per minute (given to you in Example B-5) to meters per second? This problem requires two unit conversions. Consequently, two conversion factors must be generated. The first conversion factor must convert feet in the numerator of the fraction of units to meters. This can be done using the procedure outlined in Section B-3 (see Example B-6 below). The second conversion factor must convert minutes, which is in the denominator of the fraction of units, to seconds. This conversion factor is produced by the method outlined in Section B.8.

**Example B-6**: Convert v' = 60 $\frac{\text{ft}}{\text{min}}$ to $\frac{\text{m}}{\text{s}}$.

Current state 1 units: ft
Goal state 1 units: m

Equivalence relation 1: 3.2808 ft ≡ 1 m

$CF_1$ ==> $\left\langle \frac{1\, m}{3.2808\ ft} \right\rangle$

Current state 2 units: minutes
Goal state 2 units: seconds

Equivalence relation 2: 60 seconds ≡ 1 minute

$CF_2$ ==> $\left\langle \frac{1\ \text{min}}{60\ s} \right\rangle$

Having generated the two required conversion factors, the dimensional equation must now be generated. This equation will be generated in the same fashion as the dimensional equations you generated earlier. The left-hand side will still be a symbol which represents the new magnitude to be created by the units conversion process. The right-hand side will still consist of two components: 1) the given magnitude and its associated units, and 2) the appropriate conversion factors. The only difference is that the right-hand side of the dimensional equation will contain more than one conversion factor. In fact, if the units of a given magnitude are made of more than one sub-unit and “n” of those sub-units must be converted in the units conversion process, the right-hand side of the dimensional equation will contain at least “n” conversion factors. Finishing the conversion process for Example B-6 should help clarify these points for you.

**Example B-6a**: Convert $v' = 60.00 \frac{\text{ft}}{\text{min}}$ to $\frac{\text{m}}{\text{s}}$.

Current state 1 units: ft
Goal state 1 units: m

Equivalence relation 1: 3.2808 ft ≡ 1 m

$CF_1$ ==> $\left\langle \frac{1\,m}{3.2808\;ft} \right\rangle$

Current state 2 units: minutes
Goal state 2 units: seconds

Equivalence relation 2: 60 seconds ≡ 1 minute

$CF_2$ ==> $\left\langle \frac{1\text{ min}}{60\;s} \right\rangle$

DE ==> $$v = 60.00\ \frac{ft}{\text{min}} \left\langle \frac{1\,m}{3.2802\;ft} \cdot \frac{1\text{ min}}{60\;s} \right\rangle$$

$$v = \frac{1}{3.2808}\ \frac{\text{m}}{\text{s}}$$

$$v = 0.3049 \frac{\text{m}}{\text{s}}$$

A special case of generating a dimensional equation when more than one unit must be converted occurs when the unit to be converted is raised to a power. For instance, how would you go about converting 35.3134 $\text{ft}^3$ to cubic meters? The trick here is to realize the following:

$$\text{ft}^3 = \text{ft} \cdot \text{ft} \cdot \text{ft} \qquad \text{and}$$

$$\text{m}^3 = \text{m} \cdot \text{m} \cdot \text{m}.$$

Consequently, the reality of the problem indicates that you are required to convert feet to meters three times. Thus, to perform this units conversion you will simply need to construct a dimensional equation which uses the feet to meters conversion factor three times on the right-hand side of the equation (see Example B-7).

**Example B-7**: Convert $V' = 35.3134\ \text{ft}^3$ to $\text{m}^3$.

Current state units: ft

  

Goal state units: m

Equivalence relation: 3.2808 ft ≡ 1 m

$CF_1$ ==> $\left\langle \dfrac{1\,m}{3.2808\,ft} \right\rangle$

DE ==> $V = 35.3134\ ft^3 \left\langle \dfrac{1\,m}{3.2808\,ft} \cdot \dfrac{1\,m}{3.2808\,ft} \cdot \dfrac{1\,m}{3.2808\,ft} \right\rangle$

$$V = 35.3134\ ft^3 \left\langle \dfrac{1\,m^3}{3.2808^3\ ft^3} \right\rangle$$

$$V = 1.00000\ m^3.$$

Thus, in general, once the appropriate conversion factor has been generated from an appropriate equivalence relation, if the unit to be converted is raised to the $n^{th}$ power, the dimensional equation will contain the appropriate conversion factor raised to the $n^{th}$ power.

It should also be noted that in the process of performing complicated unit conversions an equivalence relation which directly relates the two different units may not be known. For example, there isn't a standard equivalence relation which relates dyne/cm$^2$ to bars. However, Table ‘gotche” in Chapter 3 of the *CinChE* manual gives an equivalence relation which relates dyne/cm$^2$ to atmospheres and atmospheres to bars. In this situation you will need to derive your own equivalence relationship. Example B-8 illustrates this process well.

**Example B-8**: Convert $P' = 1.01325 \dfrac{\text{dynes}}{\text{cm}^2}$ to bar.

Current state units: $\dfrac{\text{dynes}}{\text{cm}^2}$

Goal state units: bars

Equivalence relation 1: $1.01325 \times 10^6 \dfrac{\text{dynes}}{\text{cm}^2} \equiv 1$ atm

Equivalence relation 2: 1 atm ≡ 1.01325 bar

If $1.01325 \times 10^6$ dyne/cm$^2$ is equivalent to one atmosphere and one atmosphere is equivalent to 1.01325 bar, then $1.01325 \times 10^6$ dyne/cm$^2$ is equivalent to 1.01325 bar. Thus the following equivalence relation can be formed:

$$1.01325 \times 10^6 \dfrac{\text{dynes}}{\text{cm}^2} \equiv 1.01325 \text{ bar.}$$

  

CF ==> $\left\langle \dfrac{1.01325\ bar}{1.01325 \times 10^{6}\ \dfrac{dyne}{cm^{2}}} \right\rangle$

DE ==> $P = 1.01325\ \dfrac{dyne}{cm^{2}} \left\langle \dfrac{1.01325\ bar}{1.01325 \times 10^{6}\ \dfrac{dyne}{cm^{2}}} \right\rangle$

$P = 1.01325 \times 10^{-6}$ bar

## Practice for Section B.9

Click here for the answers.

The practice exercises which follow all require you to perform units conversion on magnitudes whose units are either in the denominator or are compound units or some combination of the two. Because there are so many variations on how these problems can be solved, the exercises themselves will not attempt to structure your solutions as was the case with previous exercises. However, you should decide on a structure for solving each problem and work them in a neat organized fashion.

**PB.9.1:** Convert 10 000 dyne to $lb_f$.

**PB.9.2:** Convert $0.7861\ \dfrac{g}{cm^3}$ to $\dfrac{lb_m}{ft^3}$.

**PB.9.3:** Convert $115\ \dfrac{dyne}{cm^2}$ to $\dfrac{N}{m^2}$.

**PB.9.4:** Convert $1800\ \dfrac{m}{s^2}$ to $\dfrac{cm}{h^2}$.

**PB.9.5:** Convert $32.56\ \dfrac{g}{h}$ to $\dfrac{lb_m}{s}$.

**PB.9.6:** Convert 35 $m^3$ to $ft^3$.

**PB.9.7:** Convert $62.43\ \dfrac{lb_m}{ft^3}$ to $\dfrac{kg}{m^3}$.

**PB.9.8:** Convert $44.1\ \dfrac{lb_f}{in^2}$ to atm.

**PB.9.9:** Convert 0.055 kPa to $\dfrac{dyne}{cm^2}$.

**PB.9.10:** Convert 124 $lb_f$ to newton and $kg_f$.

  