Chapter 4

Temperature

- **Temperature** is a measure of the energy (mostly kinetic) of the molecules in a system. This definition tells us about the amount of energy.
- Other scientists prefer to say that **Temperature** is a property of the state of thermal

equilibrium of the system with respect to other systems because temperature tells us about the capability of a system to transfer energy (as heat).

☒ Four types of temperature:

Two based on a **relative scale**, **degrees Fahrenheit (°F)** and **Celsius (°C)**, and two based on an **absolute scale**, **degree Rankine (°R)** and **Kelvin (K)**.

☒ Temperature Conversion

$$\Delta°F = \Delta°R$$

$$\Delta°C = \Delta K$$

Also, the Δ°C is larger than the Δ°F

$$\frac{\Delta°C}{\Delta°F} = 1.8 \quad \text{or} \quad \Delta°C = 1.8\ \Delta°F$$

$$\frac{\Delta K}{\Delta°R} = 1.8 \quad \text{or} \quad \Delta K = 1.8\ \Delta°R$$

Also, because of the temperature difference between boiling water and ice (Celsius: 100°C – 0°C =100°C; Fahrenheit: 212°F – 32°F = 180°F), the following relationships hold:

Δ°C = 1.8000 Δ°F and Δ K = 1.8000 Δ°F

The proper meaning of the symbols **°C, °F, K,** and **°R,** as either the temperature or the unit temperature difference, must be interpreted from the context of the equation or sentence being examined.

Suppose you have the relation:

$$T_{°F} = a + bT_{°C}$$

What are the units of **a** and **b**? The units of **a** must be **°F** for consistency. The correct units for **b** must involve the conversion factor **(1.8 Δ°F\Δ°C)**, the factor that converts the size of an interval on one temperature scale

$$T_{°F} = a_{°F} + \underbrace{\left(\frac{1.8\ \Delta°F}{\Delta°C}\right)}_{b} T_{°C}$$

Unfortunately, the units for b are usually ignored; just the value of b (1.8) is employed.

✶ The relations between **°C, °F, K,** and **°R** are:

$$T_{°R} = T_{°F}\left(\frac{1\ \Delta°R}{1\ \Delta°F}\right) + 460°R$$

Or **$T_{°R} = T_{°F} + 460$**

$$T_K = T_{°C}\left(\frac{1\ \Delta K}{1\ \Delta°C}\right) + 273\ K$$

$$T_{°F} - 32°F = T_{°C}\left(\frac{1.8\ \Delta°F}{1\ \Delta°C}\right)$$

$$T_{°C} = (T_{°F} - 32°F)\left(\frac{1\ \Delta°C}{1.8\ \Delta°F}\right)$$

Or **$T_K = T_{°C} + 273$**

Or **$T_{°F} = 1.8\ T_{°C} + 32$**

Example 4.1

Convert 100 °C to (a) K, (b) °F, and (c) °R.

Solution

(a) $(100 + 273)°C \frac{1\ \Delta K}{1\ \Delta°C} = 373\ K$

or with suppression of the Δ symbol,

$$(100 + 273)°C \frac{1\ K}{1°C} = 373\ K$$

(b) $(100°C)\frac{1.8\ \Delta°F}{1\ \Delta°C} + 32°F = 212°F$

(c) $(212 + 460)°F \frac{1\ \Delta°R}{1\ \Delta°F} = 672°R$

or

$$(373\ K)\frac{1.8\ \Delta°R}{1\ \Delta K} = 672°R$$

Example 4.2

The heat capacity of sulfuric acid has the units J/(g mol)(°C), and is given by the relation

$$\text{Heat capacity} = 139.1 + 1.56 * 10^{-1}\ T$$

where T is expressed in °C. Modify the formula so that the resulting expression has the associated units of Btu/(lb mol) (°R) and T is in °R.

Solution

$T_{°F} = 1.8\ T_{°C} + 32 \Longrightarrow T_{°C} = (T_{°F} - 32)/1.8$

$T_{°R} = T_{°F} + 460 \Longrightarrow T_{°F} = T_{°R} - 460$

$\therefore\ T_{°C} = [T_{°R} - 460 - 32]/1.8$

$$\text{heat capacity} = \left\{139.1 + 1.56 \times 10^{-1}\overbrace{\left[(T_{°R} - 460 - 32)\frac{1}{1.8}\right]}^{T_{°C}}\right\} \times \frac{1\ J}{(g\ mol)(°C)}\underbrace{\left|\frac{1\ Btu}{1055\ J}\right|\frac{454\ g\ mol}{1\ lb\ mol}\left|\frac{1°C}{1.8°R}\right.}_{\text{conversion factors}} =$$

$$= 23.06 + 2.07 \times 10^{-2} T_{°R}$$

Note the suppression of the Δ symbol in the conversion between °C and °R.

Problems

1. Complete the following table with the proper equivalent temperatures:

°C	°F	K	°R
–40	____	____	____
____	77.0	____	____
____	____	698	____
____	____	____	69.8

2. The heat capacity of sulfur is $C_p = 15.2 + 2.68T$, where C_p is in J/(g mol)(K) and T is in K. Convert this expression so that C_p is in cal/(g mol)(°F) with T in °F.

Answers:

1.

°C	°F	K	°R
−40.0	−40.0	233	420
25.0	77.0	298	537
425	796	698	1256
−234	−390	38.8	69.8

2. $C_p = 93.2 + 0.186\, T_{°F}$

Supplementary Problems (Chapter Four):

Problem 1

Complete the table below with the proper equivalent temperatures.

°C	°F	K	°R
- 40.0	----------	------------	-----------
----------	77.0	------------	-----------
----------	----------	698	-----------
----------	----------	------------	69.8

Solution

The conversion relations to use are:

$$°F = 1.8\,°C + 32$$
$$K = °C + 273$$
$$°R = °F + 460$$
$$°R = 1.8\,K$$

°C	°F	K	°R
- 40.0	**- 40.0**	**233**	**420**
25.0	77.0	**298**	**437**
425	**797**	698	**1257**
- 235	**-390**	**38.4**	69.8

Problem 2

The specific heat capacity of toluene is given by following equation

$$C_p = 20.869 + 5.293 \times 10^{-2}\,T$$ where C_p is in Btu/(LB mol) (° F) and T is in ° F

Express the equation in cal/(g mol) (K) with T in K.

Solution

First, conversion of the units for the overall equation is required.

$$C_p = \frac{[20.869 + 5.293 \times 10^{-2}(T_{°F})] \quad \text{Btu}}{1\ (\text{lb mol})\ (°F)} \left| \frac{252\ \text{cal}}{1\ \text{Btu}} \right| \frac{1\ \text{lb mol}}{454\ \text{g mol}} \left| \frac{1.8\ °F}{1\ K} \right.$$

$$= [\,20.869 + 5.293 \times 10^{-2}(T_{°F})]\,\frac{\text{cal}}{(\text{g mol})\ (K)}$$

Note that the coefficients of the equation remain unchanged in the new units for this particular conversion. The T of the equation is still in °F, and must be converted to kelvin.

$$T_{°F} = (T_K - 273)\,1.8 + 32$$

$$C_p = 20.69 + 5.293 \times 10^{-2}\,[(T_K - 273)\,1.8 + 32]$$

Simplifying $C_p = -3.447 + 9.527 \times 10^{-2}\ T_K$