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1.4 BASIS

Your objectives in studying this section are to be able to:

1. State the three questions useful in selecting a basis.
2. Apply the three questions to problems and select a suitable basis or sequences of bases.

Have you noted in previous examples that the word **basis** has appeared at the top of the computations? This concept of basis is vitally important both to your understanding of how to solve a problem and also to your solving it in the most expeditious manner. The basis is the reference chosen by you for the calculations you plan to make in any particular problem, and a proper choice of basis frequently makes the problem much easier to solve. The basis may be a period of time—for example, hours, or a given mass of material—such as 5 kg of CO_2 or some other convenient quantity. In selecting a sound basis (which in many problems is predetermined for you but in some problems is not so clear), you should ask yourself the following questions:

(a) What do I have to start with?
(b) What do I want to find out?
(c) What is the most convenient basis to use?

These questions and their answers will suggest suitable bases. Sometimes, when a number of bases seem appropriate, you may find it is best to use a unit basis of 1 or 100 of something, as, for example, kilograms, hours, moles, cubic feet. For liquids and solids when a weight analysis is used, a convenient basis is often 1 or 100 lb or kg; similarly, 1 or 100 moles is often a good choice for a gas. The reason for these choices is that the fraction or percent automatically equals the number of pounds, kilograms, or moles, respectively, and one step in the calculations is saved.

EXAMPLE 1.15 Choosing a Basis

Aromatic hydrocarbons form 15 to 30% of the components of leaded fuels and as much as 40% of nonleaded gasoline. The carbon/hydrogen ratio helps to characterize the fuel components. If a fuel is 80% C and 20% H by weight, what is the C/H ratio in moles?

Solution

If a basis of 100 lb or kg of oil is selected, percent = pounds or kilograms.

Basis: 100 kg of oil (or 100 lb of oil)

Component	kg = percent or lb = percent	Mol. wt.	kg mol or lb mol
C	80	12.0	6.67
H	20	1.008	19.84
Total	100		

Consequently, the C/H ratio in moles is

$$C/H = \frac{6.67}{19.84} = 0.336$$

EXAMPLE 1.16 Choosing a Basis

Most processes for producing high-energy-content gas or gasoline from coal include some type of gasification step to make hydrogen or synthesis gas. Pressure gasification is preferred because of its greater yield of methane and higher rate of gasification.

Given that a 50.0-kg test run of gas averages 10.0% H_2, 40.0% CH_4, 30.0% CO, and 20.0% CO_2, what is the average molecular weight of the gas?

Solution

The obvious basis is 50.0 kg of gas ("what I have to start with"), but a little reflection will show that such a basis is of no use. You cannot multiply *mole percent* of this gas times kg and expect the answer to mean anything. Thus the next step is to choose a "convenient basis," which is 100 kg mol or lb mol of gas, and proceed as follows:

Basis: 100 kg mol or lb mol of gas

Component	percent = kg mol or lb mol	Mol. wt.	kg or lb
CO_2	20.0	44.0	880
CO	30.0	28.0	840
CH_4	40.0	16.04	642
H_2	10.0	2.02	20
Total	100.0		2382

$$\text{average molecular weight} = \frac{2382 \text{ kg}}{100 \text{ kg mol}} = 23.8 \text{ kg/kg mol}$$

It is important that your basis be indicated near the beginning of the problem so that you will keep clearly in mind the real nature of your calculations and so that anyone checking your problem will be able to understand on what basis they are performed. If you change bases in the middle of the problem, a new basis should be indicated at that time. Many of the problems that we shall encounter will be solved on one basis and then at the end will be shifted to another basis to give the desired answer. The significance of this type of manipulation will become considerably clearer as you accumulate more experience.

EXAMPLE 1.17 Changing Bases

A sample of medium-grade bituminous coal analysis is as follows:

Component	Percent
S	2
N	1
O	6
Ash	11
Water	3

The residuum is C and H in the mole ratio H/C = 9. Calculate the weight fraction composition of the coal with the ash and the moisture omitted.

Solution

Take as a basis 100 kg of coal, for then percent = kilograms.

Basis: 100 kg of coal

The sum of the S + N + O + ash + water is

$$2 + 1 + 6 + 11 + 3 = 23 \text{ kg}$$

Hence the C + H must be 100 − 23 = 77 kg.

To determine the kilograms of C and H, we have to select a new basis. Is 77 kg satisfactory? No. Why? Because the H/C ratio is in terms of moles, not weight (mass). Pick instead:

Basis: 100 kg mol of C + H

Component	Mole fraction	kg mol	Mol. wt.	kg
H	$\frac{9}{1+9} = 0.90$	90	1.008	90.7
C	$\frac{1}{1+9} = 0.10$	10	12	120
Total	1.00	100		210.7

Finally, to return to the original basis, we have

$$\text{H: } \frac{77 \text{kg}}{} \left| \frac{90.7 \text{ kg H}}{210.7 \text{ kg total}} \right. = 33.15 \text{ kg H}$$

$$\text{C: } \frac{77 \text{ kg}}{} \Bigg| \frac{120 \text{ kg C}}{210.7 \text{ kg total}} = 43.85 \text{ kg C}$$

and we can prepare a table summarizing the results.

Component	kg	Wt. fraction
C	43.85	0.51
H	33.15	0.39
S	2	0.02
N	1	0.01
O	6	0.07
Total	86.0	1.00

The ability to choose the basis that requires the fewest steps in solving a problem can only come with practice. You can quickly accumulate the necessary experience if, as you look at each problem illustrated in this text, you determine first in your own mind what the basis should be and then compare your choice with the selected basis. By this procedure you will quickly obtain the knack of choosing a sound basis.

Self-Assessment Test

1. What are the three questions you should ask yourself in selecting a basis?
2. What would be good initial bases to select in solving Problems 1.13, 1.18, 1.30, and 1.47?

1.5 TEMPERATURE

Your objectives in studying this section are to be able to:

1. Define temperature.
2. Explain the difference between absolute temperature and relative temperature.
3. Convert a temperature in any of the four scales (°C, K, °F, °R) to any of the others.
4. Convert an expression involving units of temperature and temperature difference to other units of temperature and temperature difference.
5. Know the reference points for the four temperature scales.

Our concept of temperature no doubt originated with our physical sense of hot and cold. Temperature can be rigorously defined once you have an acquaintence with thermodynamics, but here we simply paraphrase Maxwell's definition:

The temperature of a body is a measure of its thermal state considered in reference to its power to transfer heat to other bodies.

Measurement of the thermal state can be accomplished through a wide variety of instruments, including

(a) A thermometer containing a liquid such as mercury or alcohol.
(b) The voltage produced by a junction of two dissimilar conductors that changes with temperature and is used as a measure of temperature (the *thermocouple*).
(c) The property of changing electrical resistance with temperatures gives us a device known as the *thermistor*.
(d) Two thin strips of metal bonded together at one end expand at different rates with change of temperature. These strips assist in the control of the flow of water in the radiator of an automobile and in the operation of air conditioners and heating systems.
(e) High temperatures can be measured by devices called *pyrometers*, which note the radiant energy leaving a hot body.

Figure 1.3 illustrates the appropriate ranges for various temperature-measuring devices.

Temperature is normally measured in degrees **Fahrenheit** or **Celsius** (centigrade). The common scientific scale is the *Celsius* scale,[5] where 0° is the ice point of water and 100° is the normal boiling point of water. In the early 1700s, Gabriel D. Fahrenheit (1686–1736), a glassblower by trade, was able to build mercury thermometers that gave temperature measurements in reasonable agreement with each other. The *Fahrenheit* scale is the one commonly used in everyday life in the United States. Its reference points are of more mysterious origin, but it is reported that the fixed starting point, or 0° on Fahrenheit's scale, was that produced by surrounding the bulb of the thermometer with a mixture of snow or ice and sal ammoniac; the highest temperature was that at which mercury began to boil. The distance between these two points was divided into 600 parts or degrees. By trial Fahrenheit found that the mercury stood at 32 of these divisions when water just began to freeze, the temperature of human blood was at 96 divisions, and the mercury was at 212 divisions when the thermometer was immersed in boiling water. In the SI system, temperature is measured in kelvin, a unit named after the famous Lord Kelvin (1824–1907). Note that in the SI system the degree symbol is suppressed (e.g., the boiling point of water is 373 K).

The Fahrenheit and Celsius scales are *relative* scales; that is, their zero points were arbitrarily fixed by their inventors. Quite often it is necessary to use *absolute*

[5] As originally devised by Anders Celsius a Swedish astronomer (1701–1744) in 1742, the freezing point was designated as 100°. Officially, °C now stands for *degrees Celsius*.

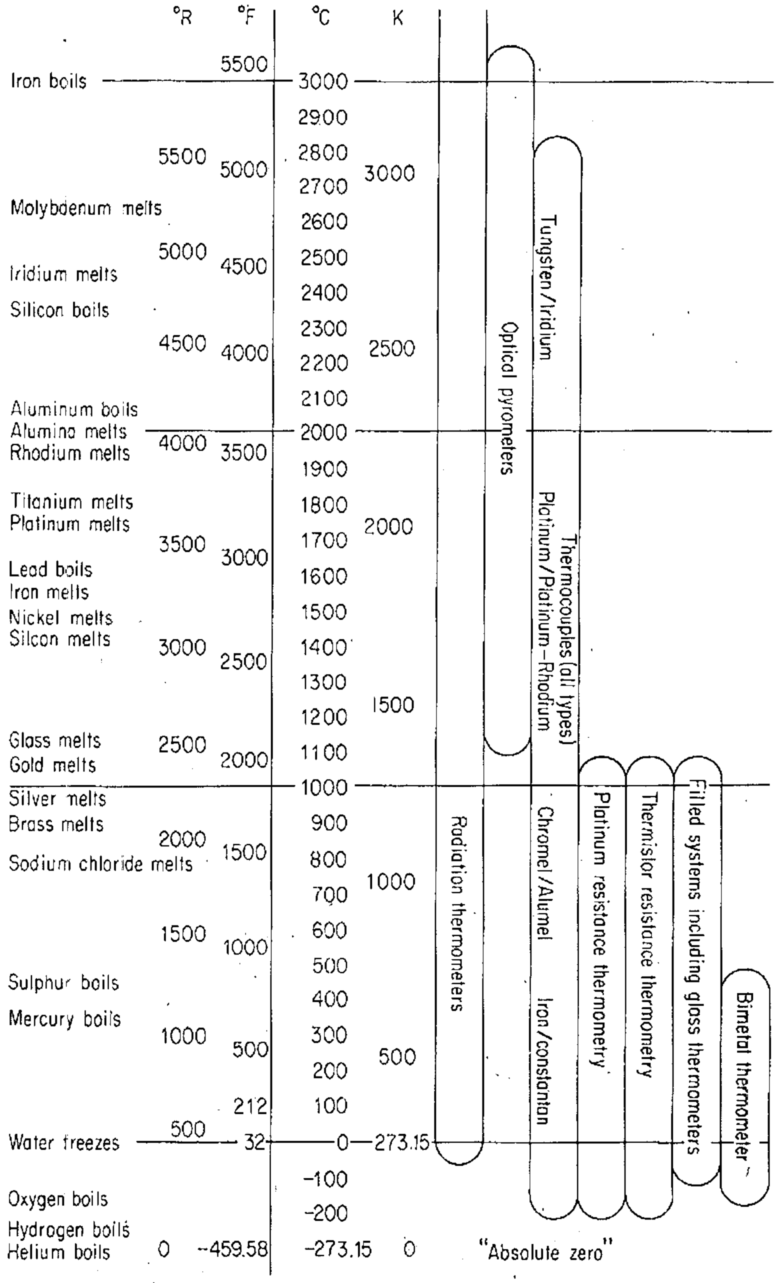

Figure 1.3 Temperature measuring instruments span the range from near absolute zero to beyond 3000 K. The chart indicates the preferred methods of thermal instrumentation for various temperature regions.

temperatures instead of relative temperatures. Absolute temperature scales have their zero point at the lowest possible temperature which we believe can exist. As you may know, this lowest temperature is related both to the ideal gas laws and to the laws of thermodynamics. The absolute scale which is based on degree units the size of those in the Celsius (centigrade) scale is called the *kelvin* scale; the absolute scale which corresponds to the Fahrenheit degree scale is called the *Rankine* scale in honor of W. J. M. Rankine (1820–1872), a Scottish engineer. The relations between relative temperature and absolute temperature are illustrated in Fig. 1.4. We shall round off absolute zero on the Rankine scale of −459.67° to −460°F; similarly, −273.15°C will be rounded off to −273°C. In Fig. 1.4 all the values of the temperatures have been rounded off, but more significant figures can be used. 0°C and its equivalents are known as *standard conditions of temperature*.

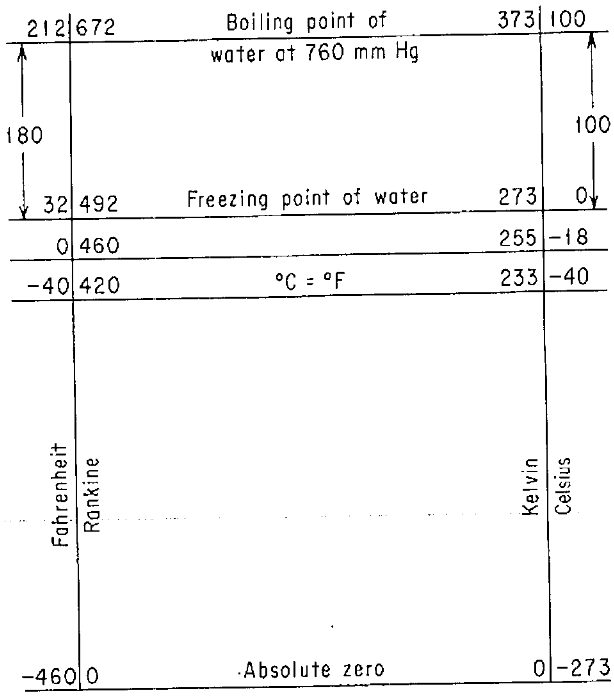

Figure 1.4 Temperature scales.

You should recognize that the unit degree (i.e., the unit temperature difference) on the kelvin–Celsius scale is not the same size as that on the Rankine-Fahrenheit scale. If we let Δ°F represent the unit temperature difference in the Fahrenheit scale, Δ°R be the unit temperature difference in the Rankine scale, and Δ°C and ΔK be the analogous units in the other two scales, you should be aware that

$$\Delta°\text{F} = \Delta°\text{R} \tag{1.13}$$

$$\Delta°\text{C} = \Delta\text{K} \tag{1.14}$$

Also, if you keep in mind that the Δ°C is larger than the Δ°F,

$$\frac{\Delta°C}{\Delta°F} = 1.8 \qquad \text{or} \qquad \Delta°C = 1.8\Delta°F \tag{1.15}$$

$$\frac{\Delta K}{\Delta°R} = 1.8 \qquad \text{or} \qquad \Delta K = 1.8\Delta°R \tag{1.16}$$

Unfortunately, the symbols Δ°C, Δ°F, ΔK, and Δ°R are not in standard usage because the Δ symbol becomes inconvenient, especially in typing. A few books try to maintain the difference between degrees of temperature (°C, °F, etc.) and the unit degree by assigning the unit degree the symbol C°, F°, and so on. But most journals and texts use the same symbol for the two different quantities. Consequently, **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.**

You should learn how to convert one temperature to another with ease. The relations between °R and °F and between K and °C are, respectively,

$$T_{°R} = T_{°F}\left(\frac{1\ \Delta°R}{1\ \Delta°F}\right) + 460 \tag{1.17}$$

$$T_K = T_{°C}\left(\frac{1\ \Delta K}{1\ \Delta°C}\right) + 273 \tag{1.18}$$

Because the relative temperature scales do not have a common zero at the same temperature, as can be seen from Fig. 1.4, the relation between °F and °C is

$$T_{°F} - 32 = T_{°C}\left(\frac{1.8\ \Delta°F}{1\ \Delta°C}\right) \tag{1.19}$$

After you have used Eqs. (1.17)–(1.19) a bit, they will become so familiar that temperature conversion will become an automatic reflex. During your "learning period," in case you forget them, just think of the appropriate scales side by side as in Fig. 1.4, and put down the values for the freezing and boiling points of water. Or, you can recover Eq. (1.19) by recognizing that the equation is linear (see Appendix M)

$$T_{°F} = b_0 + b_1 T_{°C} \tag{1.20}$$

Insert two known pairs of values of $T_{°F}$ and $T_{°C}$ in Eq. (1.20) and solve the resulting two equations together. For example, 0°C corresponds to 32°F, and 100°C corresponds to 212°F:

$$32 = b_0 + b_1(0) \tag{1.21a}$$

$$212 = b_0 + b_1(100) \tag{1.21b}$$

Solution of Eqs. (1.21a) and (1.21b) together yields

$$b_0 = 32.00 \qquad b_1 = 1.800$$

so that $T_{°F} = 32 + 1.8T_{°C}$.

EXAMPLE 1.18 Temperature Conversion

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

Solution

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

or with suppression of the Δ symbol,

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

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

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

or

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

The suppression of the Δ symbol perhaps makes the temperature relations more familiar looking.

EXAMPLE 1.19 Temperature Conversion

The thermal conductivity of aluminum at 32°F is 117 Btu/(hr)(ft^2)(°F/ft). Find the equivalent value at 0°C in terms of Btu/(hr)(ft^2)(K/ft).

Solution

Since 32°F is identical to 0°C, the value is already at the proper temperature. The "°F" in the denominator of the thermal conductivity actually stands for Δ°F, so that the equivalent value is

$$\frac{117\ (\text{Btu})(\text{ft})}{(\text{hr})(\text{ft}^2)(\Delta°\text{F})}\left|\frac{1.8\ \Delta°\text{F}}{1\ \Delta°\text{C}}\right|\frac{1\ \Delta°\text{C}}{1\ \Delta\text{K}} = 211\ (\text{Btu})/(\text{hr})(\text{ft}^2)(\text{K/ft})$$

or with the Δ symbol suppressed,

$$\frac{117\ (\text{Btu})(\text{ft})}{(\text{hr})(\text{ft}^2)(°\text{F})}\left|\frac{1.8°\text{F}}{1°\text{C}}\right|\frac{1°\text{C}}{1\ \text{K}} = 211\ (\text{Btu})/(\text{hr})(\text{ft}^2)(\text{K/ft})$$

EXAMPLE 1.20 Temperature Conversion

The heat capacity of sulfuric acid in a handbook has the units cal/(g mol)(°C) and is given by the relation

$$\text{heat capacity} = 33.25 + 3.727 \times 10^{-2}T$$

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

Solution

The units of °C in the denominator of the heat capacity are Δ°C, whereas the units of T are °C. First, substitute the proper relation in the formula to convert T in °C to T in °R, and then convert the units in the resulting expression to those requested.

$$\text{heat capacity} = \left\{33.25 + 3.727 \times 10^{-2}\left[(T_{°R} - 460 - 32)\frac{1}{1.8}\right]\right\}\frac{\text{cal}}{(\text{g mol})(°\text{C})}$$

$$\times \frac{1\ \text{Btu}}{252\ \text{cal}}\,\frac{454\ \text{g mol}}{1\ \text{lb mol}}\,\frac{1°\text{C}}{1.8°\text{R}} = 23.06 + 2.071 \times 10^{-2}T_{°R}$$

Self-Assessment Test

1. What are the reference points of (a) the Celsius and (b) Fahrenheit scales?
2. How do you convert a *temperature difference*, Δ, from Fahrenheit to Celsius?
3. Is the unit temperature difference Δ°C a larger interval than Δ°F? Is 10°C higher than 10°F?
4. In Appendix E, 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 so that C_p is in cal/(g mol)(°F) with T in °F.
5. Complete the following table with the proper equivalent temperatures:

°C	°F	K	°R
−40.0	____	____	____
____	77.0	____	____
____	____	698	____
____	____	____	69.8

6. Suppose that you are given a tube partly filled with an unknown liquid and are asked to calibrate a scale on the tube in °C. How would you proceed?
7. Answer the following questions:
   (a) In relation to absolute zero, which is higher, 1°C, or 1°F?
   (b) In relation to 0°C, which is higher, 1°C, or 1°F?
   (c) Which is larger, 1Δ°C or 1Δ°F?

Thought Problem

1. In reading a report on the space shuttle you find the statement that "the maximum temperature on reentry is 1482.2°C. How many significant figures do you think are represented by this temperature?