A.1 PRECISION

The accuracy of a measured or calculated quantity is the degree to which it agrees with the true value, while the precision of a measurement is the degree to which the measurement is reproducible. A reported measurement must contain units and should indicate both the numerical value of the measurement and the precision with which it was made. The units indicate the scale that was used to make the measurement. A measurement is useless without units. Reporting that the magnitude of a measurement is 3.618 reveals nothing to the reader because it does not indicate the scale used. The precision of the measurement is given by the number of digits to which the numerical value is reported. It is normally dictated by the measuring device. The last digit of a reported measurement should be assumed to be an estimate, and, unless stated otherwise, it is generally assumed good to ±1. Thus, if a mass is reported to be 3 g, the reader will assume that the mass is somewhere between 2 and 4 g. A reported mass of 3.0 g tells the reader that the measurement was made more precisely, and that the mass is between 2.9 and 3.1 g.

As an example of the use of precision in reporting numbers, consider the measurement of the blue bar in Figure A.1 with a ruler marked in centimeters. The ruler in Figure A.1a is a low precision ruler and the first digit is an estimate. The length appears to be slightly over $\frac{3}{4}$ of the ruler length, which makes the length about 6 cm ($\frac{3}{4} \times 8 = 6$). The reported length would be expressed as 6 cm, and a reader would imply that the 6 is an estimate. In Figure A.1b, a more precise ruler is used. The length is not quite halfway between 6 and 7 cm, and would be reported as 6.4 cm, which tells the reader that the length is between 6.3 and 6.5 cm. Again, the implication is that the last digit is an estimate. In Figure A.1c, the most precise ruler is used. The bar is between 6.4 and 6.5 cm, but it is clearly closer to 6.4 cm. The reported length would be 6.42 cm. Someone else might make the measurement and report a length of 6.43 cm, which is consistent with the fact that the last digit is an estimate.

![Figure A.1 Rulers with different precisions](image)

A.2 SIGNIFICANT FIGURES

Significant figures are the digits that are obtained in a measurement. Thus, the precision of a measurement is indicated by the number of significant figures it contains. A measurement of 6.43 cm, which contains three significant figures, is more precise than a measurement of 6.4 cm, which contains only two significant figures. Reporting the number of significant figures correctly is an important part of any measurement because the number of significant figures indicates the
precision of the measurement. The most common mistake made in reporting a measurement is not reporting trailing zeros to the right of the decimal. However, in a science laboratory, there is a big difference between a measurement reported to be 3 g and one reported as 3.0000 A. It is important that your number show both the magnitude and precision correctly. Consider the case where you are trying to prove or disprove a prediction that the mass of the product of a reaction should be 2.8 A. A measurement of 3.0000 g indicates that the prediction is wrong, but a measurement of 3 g supports the prediction.

There are some simple rules that allow us to determine which digits in a number are significant.

1. All nonzero numbers in a reported measurement are significant.
2. Zeroes to the left of the decimal but to the right of all nonzero digits cannot be assumed significant. In this text, we use the practice of placing a decimal at the end of a number to indicate that the zeroes are significant. Thus, the number of significant figures in the number ‘300’ is unclear while the number ‘300.’ has three significant figures. The best way to indicate the number of significant figures is use scientific notation. The numbers $3 \times 10^2$, $3.0 \times 10^2$ and $3.00 \times 10^2$ show a measurement of 300 to one, two and three significant figures, respectively.
3. Leading zeroes for numbers less than one are not significant, but other zeros in the number are significant. The number 0.00012 contains only two significant figures. This becomes apparent when the number is expressed in scientific notation, $1.2 \times 10^{-4}$.
4. All zeroes to the right of the decimal of numbers greater than one are significant. The number 1.00012 contains six significant figures.

If you are uncertain about the number of significant figures in a number, rewrite the number in scientific notation. All digits of a number expressed in scientific notation are significant.

**EXAMPLE A.1**

Indicate the number of significant figures in each of the following numbers.

a) 3.000

The number is greater than one so all zeroes to the right of the decimal are significant (Rule 4). This number contains four significant figures.

b) 320

The zero cannot be assumed to be significant, so the number would be assumed to have only two significant figures. To indicate that the zero is significant, write the number in scientific notation, $3.20 \times 10^2$. In this text, we would write the number as ‘320.’ to indicate that the zero was significant.

c) 0.0005606

Rule 3 indicates that leading zeroes in numbers less than one are not significant but the other zero is. This number has four significant figures. This becomes clear when the number is expressed in scientific notation, $5.606 \times 10^{-4}$.

**A.3 REPORTING ANSWERS TO CALCULATIONS**

It is frequently the case that the number to be reported is not the measurement itself, but a number obtained after a calculation involving several measurements. As with individual measurements, it is important to report the result of a calculation to the correct number of significant figures so that the reader understands the precision to which the result is known. A common mistake in reporting results of a calculation is to include all of the digits shown on the calculator. For example, consider a 5.2-mL sample that has a mass of 3.7 A. The density of the material would be determined to be $\frac{3.7 \text{ g}}{5.2 \text{ mL}} = 0.711538 \text{ g mL}^{-1}$, but if you report the density with that many significant figures, you would imply far more precision in your measurements than is warranted by the experiment. Thus, the answer must be rounded to the correct number of significant figures. The following two rules should help you report the result of a calculation correctly.
• **Multiplications and Divisions**: The number of significant figures in the result of a calculation involving multiplication or division is equal to the number of significant figures in the least precise number used in the calculation. Thus, the density discussed in the preceding paragraph should be rounded to 0.71 g·mL\(^{-1}\) because both the mass and the volume were measured to two significant figures.

• **Additions and Subtractions**: The number of decimal places in the result of an addition or subtraction is equal to the number of decimal places in the number used in the addition or subtraction that has the fewest decimal places. A good way to remember this rule is to realize that the result of the addition of a significant number and an insignificant number is insignificant. If you had $3.25 and someone gave you change worth about $2, you would have a total of about $5, not $5.25. However, if you were given $2.00 in change, you would have $5.25.

**EXAMPLE A.2**

Write the answer to the following operations to the correct number of significant figures.

a) \(2.7 \times 6.345\)

The calculator indicates that the answer is 17.1315. However, the correct number of significant figures must equal to the number of significant figures in the least precise number used in the calculation. Thus, the answer should be rounded to 17 because 2.7 has only two significant figures, which means that the answer can have only two significant figures.

b) \(1.0 - 0.0003\)

The calculator indicates that the answer is 0.9997, but the number with the fewest decimal places is good to only a tenth so the answer cannot be reported to better than a tenth. Consequently, the answer should be reported as 1.0. This is true because the number 1.0 implies an error of ±0.1, which is greater than the number being subtracted.

c) \(12.3 - 11.2634\)

The calculator answer is 1.0366. However, the number with the fewest decimal places is reported to only a tenth. Therefore, the answer should be reported as 1.0. Note, that the answer is good to only two significant figures, less than either of the original numbers. It is not unusual to lose significant figures in a subtraction, so you should avoid determining results that are small differences between large numbers.

d) \(8.76 + 7.13\)

The calculator answer is 15.89, and all of the figures are significant because both numbers in the calculation are good to two decimal places. Note that we have gained a significant figure in this addition.

e) \(8.5128/3.20\)

The result is 2.660250.0, but the least significant number contains three significant figures, so the result must be rounded to 2.66.

f) \(12.3425 - 12.3417\)

The calculator result is 3.444297 x \(10^{-5}\). At first glance, it might appear that the answer should be reported to six significant figures because all of the numbers have six significant figures. However, the first step in the calculation is the subtraction, and the result of that is 0.0008, which has only one significant figure. Consequently, the result of the division is good only to one significant figure and should be reported as 3 x \(10^{-5}\). Significant figures are lost again because of a subtraction.
A.4 Rounding Errors

It is often the case that intermediate values in a calculation involving several steps must also be reported, and they should be reported to the correct number of significant figures. However, the use of the rounded values in subsequent calculations can lead to rounding errors. Two calculations, done in the same way except for rounding differences can lead to two different answers. Example A.3 is an example of rounding differences.

Example A.3

a) A mixture contains 4.0 g of $N_2$ ($M_m = 28.0$ g·mol$^{-1}$) and 4.0 g of $O_2$ ($M_m = 32.0$ g·mol$^{-1}$). How many moles of each gas are present in the mixture?

We divide the mass by the molar mass to obtain the number of moles of each gas. The results of the calculation as shown on a calculator are:

moles of $N_2 = \frac{4.0}{28.0} = 0.14286$ and moles of $O_2 = \frac{4.0}{32.0} = 0.125$

However each answer is good to only two significant figures, so the number of moles of each gas would be rounded to 0.14 mol $N_2$ and 0.13 mol $O_2$

b) What is the (moles of $O_2$) to (moles of $N_2$) ratio in the mixture?

Using the answers to part A as our starting point, we obtain the following:

$0.13$ mol $O_2/0.14$ mol $N_2 = 0.93$ mol $O_2$/mol $N_2$

However, if the calculation for the ratio is done in one step, the following is obtained:

$(4.0/32.0)/(4.0/28.0) = 0.88$ mol $O_2$/mol $N_2$

The calculation using the rounded values is about 6% higher than the true value due to rounding errors!

As demonstrated in Example A.3, rounding errors can be substantial, and they can get worse in calculations involving several steps. Consequently, calculations with rounded numbers should be avoided whenever possible. If rounded numbers must be used, they should be used with more digits than can be expected for the final answer. In this text, we show many intermediate answers, which have been rounded to the correct number of significant figures, but the final answer that is given is always calculated without the use of the rounded numbers. You should always keep that in mind when you compare your answers with those given in the text.
## Appendix B
### Selected Values of Thermodynamic Properties at 298.15K

<table>
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<th>Substance</th>
<th>$\Delta H^\circ_f$ kJ.mol$^{-1}$</th>
<th>$\Delta G^\circ_f$ kJ.mol$^{-1}$</th>
<th>$S^\circ$ J.mol$^{-1}$.K$^{-1}$</th>
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<th>$\Delta H^\circ_f$ kJ.mol$^{-1}$</th>
<th>$\Delta G^\circ_f$ kJ.mol$^{-1}$</th>
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# Appendix C

## $K_a$’s and $pK_a$’s of Selected Acids at 25 °C by Acid Name

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<th>Name</th>
<th>Formula</th>
<th>$K_a$</th>
<th>$pK_a$</th>
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<td>Acetic</td>
<td>$\text{HC}_2\text{H}_3\text{O}_2$</td>
<td>$1.8 \times 10^{-5}$</td>
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<tr>
<td>Ascorbic</td>
<td>$\text{C}_6\text{H}_8\text{O}_6$</td>
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<td>$\text{C}_6\text{H}_7\text{O}_6\text{O}^{1-}$</td>
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<td>Ammonium</td>
<td>$\text{NH}_4^{1+}$</td>
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<td>Benzoic</td>
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<td>$\text{HCO}_3^{1-}$</td>
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## $pK_a$’s at 25 °C by $pK_a$

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# Appendix E

## Selected Standard Reduction Potentials in Aqueous Solutions at 298 K

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* These half-cell potentials for O₂/H₂O and H₂O/H₂ couples are for neutral (pH = 7) water and are not standard reduction potentials where [OH⁻] or [H⁺] = 1.0 M.
Appendix F
Balancing Redox Reactions

F.1 THE HALF-REACTION METHOD

We used this method in Section 10.5, CAMS, where redox reactions were written as the sum of tabulated half-reactions. In this process, each half-reaction must be multiplied by an integer that makes the number of electrons gained in the reduction half-reaction equal to the number of electrons lost in the oxidation process. In this section, we discuss how those half-reactions are constructed.

Charge and mass balance of redox reactions by the half-reaction method are accomplished by following the steps outlined below:

Step 1 **Divide the reaction into an oxidation half-reaction and a reduction half-reaction.** The half-reactions should show only the species involved in the oxidation and reduction processes. For simplicity, the states of the reactants and products are omitted during the balancing procedure.

Step 2 **Balance the atoms in the half reactions other than O and H with coefficients where necessary.**

Step 3 **Balance the oxygen atoms by adding water to the side that is oxygen deficient.**

Step 4 **Balance the hydrogen atoms with H^+ ions.**

Step 5 **Balance the charge by adding electrons to the side with the more positive or less negative total charge.** The charge on each side is the sum of the charges of all of the ions on that side. The half-reactions are now balanced if the reactions occur in acidic solution.

Step 5a **(Basic solutions only) Add OH^- to both sides to eliminate the H^+ ions on one side.** The number of hydroxide ions added is equal to the number of H^+ ions in the equation. In Step 4, hydrogen atoms were balanced with H^+ ions. Although the use of H^+ ions is acceptable in an acidic solution, it is unacceptable in a basic solution where there is an excess of OH^- ions. Thus, the H^+ ions are changed into OH^- ions and H_2O molecules in this step because OH^- + H^+ → H_2O.

Step 6 **Determine the lowest common multiple (LCM) of the electrons gained and lost.** This is the number of electrons transferred in the redox process. Multiply each half-reaction by the integer required to make the number of electrons gained or lost equal to the number that is transferred.

Step 7 **Add the two half-reactions.** The electrons must cancel, but also be careful that the final reaction does not contain the same substance on both sides of the equation. If a substance does appear on both sides, subtract the smaller number of moles from each side, thus eliminating it from one side. The states of the reactants and products are now placed back into the reaction.

Step 8 **Check the atom and charge balance.**

**Example F.1**

Balance the following reaction in acidic solution:

\[ \text{Zn}(s) + \text{NO}_3^- \rightarrow \text{Zn}^{2+} + \text{N}_2\text{O} \]

**Step 1** Zinc metal is oxidized and nitrate ion is reduced.

**Step 2** The zinc atoms in the Step 1a reaction are already balanced, but the nitrate ions must be multiplied by two to balance the nitrogen atoms.

\[ \text{a) Zn} \rightarrow \text{Zn}^{2+} \quad \text{b) } 2\text{NO}_3^- \rightarrow \text{N}_2\text{O} \]

**Step 3** The zinc half-reaction contains no other atoms and is unaffected by this step. Reaction b in Step 2 has six oxygen atoms on the left but only one on the right. We, therefore, add five water molecules to balance the oxygen atoms.

\[ \text{a) Zn} \rightarrow \text{Zn}^{2+} \quad \text{b) } 2\text{NO}_3^- \rightarrow \text{N}_2\text{O} + 5\text{H}_2\text{O} \]

**Step 4** There are 10 hydrogen atoms on the right side of the Step 3b reaction and none on the left side. Therefore, ten H^+ ions must be added to the left side to balance the hydrogen atoms.

\[ \text{a) Zn} \rightarrow \text{Zn}^{2+} \quad \text{b) } 10\text{H}^+ + 2\text{NO}_3^- \rightarrow \text{N}_2\text{O} + 5\text{H}_2\text{O} \]
Step 5 We now balance charge by adding electrons to the more positive side of each half-reaction in Step 4. The left side of the Step 4a reaction has no charge, but the right side carries a $+2$ charge. Two electrons must, therefore, be added to the right side of the Zn half-reaction. The right side of the Step 4b reaction carries no charge while the left side carries a charge of $+8$ ($+10 - 2 = 8$), so eight electrons must be added to the more positive side.

a) $\text{Zn} \rightarrow \text{Zn}^{2+} + 2e^{-}$

b) $8e^{-} + 10 \text{H}^{+} + 2\text{NO}_3^{-} \rightarrow \text{N}_2\text{O} + 5\text{H}_2\text{O}$

The two half reactions are now balanced.

Step 5a Not necessary in acidic solution.

Step 6 Zinc undergoes a two-electron oxidation while nitrate undergoes an eight-electron reduction. LCM - eight, and eight electrons are therefore transferred in this reaction. The zinc half-reaction is multiplied by four to get the eight electrons.

a) $4\text{Zn} \rightarrow 4\text{Zn}^{2+} + 8e^{-}$

b) $8e^{-} + 10 \text{H}^{+} + 2\text{NO}_3^{-} \rightarrow \text{N}_2\text{O} + 5\text{H}_2\text{O}$

Step 7 The two half-reactions can now be added, and the states of the reactants and products are also added at this point.

$$4\text{Zn} \rightarrow 4\text{Zn}^{2+} + 8e^{-}$$
$$8e^{-} + 10 \text{H}^{+} + 2\text{NO}_3^{-} \rightarrow \text{N}_2\text{O} + 5\text{H}_2\text{O}$$

$$4\text{Zn}(s) + 10\text{H}^{+} + 2\text{NO}_3^{-} \rightarrow \text{N}_2\text{O}(g) + 4\text{Zn}^{2+} + 5\text{H}_2\text{O}$$

Step 8 The number of each atom and the overall charge (+8) balance.

Example F.2

Balance the following reaction in basic solution:

$$\text{CN}^{1-}(aq) + \text{MnO}_4^{1-}(aq) \rightarrow \text{CNO}^{1-}(aq) + \text{MnO}_2(s)$$

Step 1 Write abbreviated half-reactions.

a) $\text{CN}^{1-} \rightarrow \text{CNO}^{1-}$

b) $\text{MnO}_4^{1-} \rightarrow \text{MnO}_2$

Step 2 The atoms other than oxygen and hydrogen are already balanced.

Step 3 Balance oxygen atoms with water.

a) $\text{H}_2\text{O} + \text{CN}^{1-} \rightarrow \text{CNO}^{1-}$

b) $\text{MnO}_4^{1-} \rightarrow \text{MnO}_2 + 2\text{H}_2\text{O}$

Step 4 Balance hydrogen atoms with $\text{H}^{+}$.

a) $\text{H}_2\text{O} + \text{CN}^{1-} \rightarrow \text{CNO}^{1-} + 2\text{H}^{+}$

b) $4\text{H}^{+} + \text{MnO}_4^{1-} \rightarrow \text{MnO}_2 + 2\text{H}_2\text{O}$

Step 5 Balance charge with electrons. The charge on the left side of the Step 4a reaction is -1, but it is $+1 (-1 + 2 = 1)$ on the right side, so two electrons must be added to the right side. The charge on the left side of reaction b in Step 4 is $+3 (+4 - 1 = 3)$ while it is zero on the right. Consequently, three electrons must be added to the left side.

a) $\text{H}_2\text{O} + \text{CN}^{1-} \rightarrow \text{CNO}^{1-} + 2\text{H}^{+} + 2e^{-}$

b) $3\text{e}^{-} + 4\text{H}^{+} + \text{MnO}_4^{1-} \rightarrow \text{MnO}_2 + 2\text{H}_2\text{O}$

Step 5a This reaction takes place in a basic solution where $\text{OH}^{1-}$ ions are plentiful and $\text{H}^{+}$ ions are scarce. Consequently, we must replace the $\text{H}^{+}$ ions in the two half-reactions shown in Step 5. We do this by adding $\text{OH}^{1-}$ ions to both sides of each equation. The number of $\text{OH}^{1-}$ ions added must equal the number of $\text{H}^{+}$ ions present in the reaction. Consequently, we must add 2$\text{OH}^{1-}$ ions to both sides of reaction a in Step 6.

a) $2\text{OH}^{1-} + \text{H}_2\text{O} + \text{CN}^{1-} \rightarrow \text{CNO}^{1-} + 2\text{H}^{+} + 2e^{-} + 2\text{OH}^{1-}$

Substituting $2\text{H}_2\text{O}$ for $(2\text{H}^{+} + 2\text{OH}^{1-})$ on the right side of the equation yields the following.

a) $2\text{OH}^{1-} + \text{H}_2\text{O} + \text{CN}^{1-} \rightarrow \text{CNO}^{1-} + 2\text{H}_2\text{O} + 2e^{-}$

The above equation shows water on both sides. Consequently, we must subtract one $\text{H}_2\text{O}$ molecule from each side to eliminate water from the left side and obtain the balanced half-reaction in basic solution.

a) $2\text{OH}^{1-} + \text{CN}^{1-} \rightarrow \text{CNO}^{1-} + \text{H}_2\text{O} + 2e^{-}$

Reaction b in Step 5 requires the addition of 4$\text{OH}^{1-}$ to each side.

$4\text{OH}^{1-} + 3\text{e}^{-} + 4\text{H}^{+} + \text{MnO}_4^{1-} \rightarrow \text{MnO}_2 + 2\text{H}_2\text{O} + 4\text{OH}^{1-}$

Substituting $4\text{H}_2\text{O}$ for $(4\text{H}^{+} + 4\text{OH}^{1-})$ on the left side of the equation yields,

$3\text{e}^{-} + 4\text{H}_2\text{O} + \text{MnO}_4^{1-} \rightarrow \text{MnO}_2 + 2\text{H}_2\text{O} + 4\text{OH}^{1-}$.
Once again, the reaction contains water on both sides, so we subtract two water molecules from each side to obtain the final balanced half-reaction in basic solution.

\[ b) \ 3e^- + 2H_2O + MnO_4\cdot \rightarrow MnO_2 + 4 OH^- \]

**Step 6** The LCM of two and three is six. Consequently, the overall reaction is a six-electron transfer. Reaction a must be multiplied by three and reaction b by two. The result is shown in Step 7 where they are added.

**Step 7** The two half-reactions obtained in Step 6 are added. The six electrons cancel. In addition, the six hydroxide ions on the left side of reaction a cancel six of the eight hydroxide ions appearing on the right side of reaction b, and the three waters appearing on the right side of reaction a cancel three of the four water molecules on the left side of reaction b.

\[
\begin{align*}
a) & \quad 6OH^- + 3CN^- \rightarrow 3CNO^- + 3H_2O + 6e^- \\
b) & \quad 6e^- + 4H_2O + 2MnO_4^- \rightarrow 2MnO_2 + 8OH^- \\
\end{align*}
\]

\[ H_2O + 2MnO_4^- + 3CN^- \rightarrow 3CNO^- + 2MnO_2 + 2OH^- \]

**Step 8** The atoms and total charge (-5 on each side) balance.

### F.2 The Oxidation State Change Method

The half-reaction method is fine for ionic reactions, but it is not easily applied to molecular reactions where there is no charge to balance. The oxidation state change method is much more applicable in these instances. To balance a reaction by the oxidation state change method,

**Step 1** Identify the substances whose oxidation states are changing. These will usually involve a polyatomic ion or an element.

**Step 2** Draw a line connecting the oxidized and reduced forms involved in the redox process.

**Step 3** Balance the only those atoms being oxidized and reduced by inserting appropriate coefficients into the equation.

**Step 4** Assign oxidation states to the oxidized and reduced atoms. Place the oxidation states of the atoms on the connecting line. If more than one atom is oxidized or reduced, place the sum of the oxidation states on the line.

**Step 5** Determine the number of electrons gained or lost in each process and place the numbers on the lines drawn in Step 2.

**Step 6** Determine the lowest common multiple (LCM) of the electrons gained and lost. This is the number of electrons transferred during the reaction.

**Step 7** Multiply the coefficients of the species involved in the oxidation and reduction processes by the integer required to make the electrons gained and the electrons lost equal to the number of electrons transferred as determined in Step 6.

**Step 8** Balance any other non-oxygen atoms by inspection. If the reaction contains ions, balance the charge with $H^+$ in acidic solution or $OH^-$ in basic solution.

**Step 9** Balance the hydrogen atoms by adjusting the coefficient of water.

**Step 10** The reaction should now be balanced. The reaction can be checked by making sure that the oxygen atoms balance.

### Example F.3

Balance the following by the oxidation state change method.

\[ C(s) + HNO_3(aq) \rightarrow NO_2(g) + H_2O(l) + CO_2(g) \]

**Step 1** Elemental C is oxidized to $CO_2$, and nitric acid (contains a polyatomic ion) is reduced to $NO_2$.

**Step 2** Connect the oxidized and reduced forms involved in the redox process.

\[ C + HNO_3 \rightarrow CO_2 + NO_2 + H_2O \]

**Step 3** The carbon atoms and the nitrogen atoms are already balanced.

**Step 4** Assign oxidation states and place on connecting line.

\[
\begin{align*}
C & \quad +4 \\
HNO_3 & \quad +5 \\
CO_2 & \quad +4
\end{align*}
\]

**Step 5** Determine the number of electrons gained or lost in each process. Carbon’s oxidation state increases from zero to four, so...
it loses four electrons. The nitrogen atom is +5 in HNO\(_3\) and +4 in NO\(_2\), so it has gained one electron.

\[
\begin{array}{ccccc}
0 & -4e^{1-} & +4 \\
C + & HNO_3 & \rightarrow & CO_2 + NO_2 + H_2O \\
+5 & +1e^{1-} & +4 \\
\end{array}
\]

Step 6 The LCM of one and four is four.

Step 7 The coefficients of the nitrogen-containing species must be multiplied by four to make the number of electrons gained by nitric acid equal to the number lost by carbon.

\[
C + 4HNO_3 \rightarrow 4NO_2 + H_2O + CO_2
\]

Step 8 There is no charge to balance nor are there any atoms other than hydrogen or oxygen to balance.

Step 9 There are four hydrogens on the left, so the coefficient of water must be 2.

\[
C + 4HNO_3 \rightarrow 4NO_2 + 2H_2O + CO_2
\]

Step 10 The oxygen atoms balance (12 on each side), so the equation is balanced.

**Example F.4**

Balance the following reaction by the oxidation state change method.

\[
K_2Cr_2O_7(aq) + HI(aq) \rightarrow CrI_3(s) + I_2(s) + KI(aq) + H_2O(l)
\]

Step 1 The redox processes involve the reaction of a polyatomic ion (K\(_2\)Cr\(_2\)O\(_7\) \rightarrow CrI\(_3\)) and the formation of an element (HI \rightarrow I\(_2\)).

Step 2 Connect the oxidized and reduced forms involved in the redox process.

\[
K_2Cr_2O_7 + HI \rightarrow 2CrI_3 + I_2 + KI + H_2O
\]

Step 3 Balance the Cr and I atoms. Two HI and two CrI\(_3\) are required to balance the two I atoms in I\(_2\) and the two Cr atoms in K\(_2\)Cr\(_2\)O\(_7\).

\[
K_2Cr_2O_7 + 2HI \rightarrow 2CrI_3 + I_2 + KI + H_2O
\]

Steps 4/5 Assign oxidation numbers, place them on the connecting line, and determine the number of electrons gained or lost in each process. The oxidation states of the Cr atoms are +6 in K\(_2\)Cr\(_2\)O\(_7\) and +3 in CrI\(_3\), but there are two Cr atoms on each side, so we place a +12 and +6 on the connecting line. The two iodides on the left are each -1, so a -2 is placed above them while the iodine atoms on the right are each zero.

\[
\begin{array}{ccccccc}
+12 & +6e^{1-} & +6 \\
K_2Cr_2O_7 + 2HI & \rightarrow & 2CrI_3 + I_2 & + & KI & + & H_2O \\
+2 & -2e^{1-} & 0
\end{array}
\]

Step 6 LCM = 6, so this reaction involves a six-electron transfer.

Step 7 The coefficients of the HI/I\(_2\) half-reaction must be multiplied by three to make the number of electrons gained equal to six.

\[
K_2Cr_2O_7 + 6HI \rightarrow 2CrI_3 + 3I_2 + KI + H_2O
\]

Step 8 There is no charge, but the potassium and iodine atoms are not balanced. We place a two in front of KI to balance the two potassium atoms in K\(_2\)Cr\(_2\)O\(_7\).

\[
K_2Cr_2O_7 + 6HI \rightarrow 2CrI_3 + 3I_2 + 2KI + H_2O
\]

Now there are 14 iodine atoms on the right side, so the coefficient of HI must be 14. Note only six of the iodines are oxidized; the others are required for mass balance.

\[
K_2Cr_2O_7 + 14HI \rightarrow 2CrI_3 + 3I_2 + 2KI + 7H_2O
\]

Step 9 Balance the hydrogen atoms with the coefficient of water.

\[
K_2Cr_2O_7 + 14HI \rightarrow 2CrI_3 + 3I_2 + 2KI + 7H_2O
\]

Step 10 The oxygen atoms balance (7 on each side), and so the equation is balanced.
F.3 EXERCISES

1. Complete and balance the following reactions in acidic solution:
   a) \( \text{Fe}^{2+} + \text{Cr}_2\text{O}_7^{2-} \rightarrow \text{Fe}^{3+} + \text{Cr}^{3+} \)
   b) \( \text{MnO}_2 + \text{Cl}^{1-} \rightarrow \text{Mn}^{2+} + \text{Cl}_2 \)
   c) \( \text{CH}_3\text{OH} + \text{Cr}_2\text{O}_7^{2-} \rightarrow \text{Cr}^{3+} + \text{HCOOH} \)

2. Complete and balance the following reactions in acidic solution:
   a) \( \text{I}^{1-} + \text{H}_2\text{O}_2 \rightarrow \text{I}_2 \)
   b) \( \text{C}_2\text{H}_4 + \text{MnO}_4^{1-} \rightarrow \text{Mn}^{2+} + \text{CO}_2 \)
   c) \( \text{Ni(s)} + \text{VO}^{2+}(\text{aq}) \rightarrow \text{Ni}^{2+}(\text{aq}) + \text{V}^{3+}(\text{aq}) \)

3. Complete and balance the following reactions in basic solution:
   a) \( \text{Mn}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{MnO}_2 \)
   b) \( \text{MnO}_4^{1-}(\text{aq}) + \text{NO}_2^{1-}(\text{aq}) \rightarrow \text{MnO}_2(\text{s}) + \text{NO}_3^{1-}(\text{aq}) \)
   c) \( \text{NO}_3^{1-}(\text{aq}) + \text{Pb(s)} \rightarrow \text{NH}_3(\text{aq}) + \text{Pb(OH)}_4^{2-}(\text{aq}) \)

4. Complete and balance the following reactions in basic solution:
   a) \( \text{Cl}_2 + \text{S}_2\text{O}_3^{2-} \rightarrow \text{Cl}^{1-} + \text{S}_4\text{O}_6^{2-} \)
   b) \( \text{H}_2\text{O}_2 + \text{ClO}_2 \rightarrow \text{ClO}_2^{1-} + \text{O}_2 \)
   c) \( \text{I}_2 \rightarrow \text{I}^{1+} + \text{IO}_3^{1-} \)

5. Balance the following reactions:
   a) \( \text{Cu} + \text{HNO}_3 \rightarrow \text{Cu(NO}_3)_2 + \text{NO} + \text{H}_2\text{O} \)
   b) \( \text{NO} + \text{NH}_3 \rightarrow \text{H}_2\text{O} + \text{N}_2 \)
   c) \( \text{H}_2\text{S} + \text{H}_2\text{O}_2 \rightarrow \text{S} + \text{H}_2\text{O} \)

6. Balance the following reactions:
   a) \( \text{C} + \text{HNO}_3 \rightarrow \text{NO}_2 + \text{CO}_2 + \text{H}_2\text{O} \)
   b) \( \text{H}_2\text{SO}_4 + \text{HI} \rightarrow \text{H}_2\text{S} + \text{I}_2 + \text{H}_2\text{O} \)
   c) \( \text{NH}_3 + \text{O}_2 \rightarrow \text{NO} + \text{H}_2\text{O} \)
Absolute (or Kelvin) temperature scale is used for the temperature in all calculations involving T. The unit is the kelvin (K). The average kinetic energy of the molecules in a system is directly proportional to its temperature in kelvins.

Absolute zero is 0 K, which is -273.16 °C. It is the temperature at which molecules have no kinetic energy.

Absorbance is a measure of the amount of light absorbed by a substance. The absorbance of a solution depends upon both the concentration and the molar absorptivity of the absorbing substance at the wavelength of the light, and the distance through the solution that the light travels. See Beer’s Law.

Absorption of a photon increases the energy of an atom or a molecule by the energy of the photon \( h\nu \). A photon can be absorbed only if its energy matches the energy difference between two energy levels in the atom or molecule.

An absorption spectrum presents the absorbance of a substance as a function of the wavelength or frequency of light.

The acceptor orbital is the orbital on an oxidizing agent that accepts the transferred electrons in a redox reaction.

The acid dissociation or ionization constant is the equilibrium constant for the reaction of an acid with water: \( HA + H_2O \rightarrow H_3O^+ + A^- \).

An acidic salt is a salt in which the acidity of the cation is greater than the basicity of the anion.

An acidic solution is one with \([H_3O^+] > [OH^-]\). As a result, pH < 7.0 at 25 °C for acidic solutions.

The activation energy is the energy of the transition state relative to that of the reactants or products. It is the minimum energy that the reactants must have in order for a reaction to occur.

An active electrode is one that is a participant in a reaction. For example, a copper electrode in a \( Cu^{2+} + 2e^- \rightarrow Cu \) half-cell is active because copper metal participates in the reaction.

The activity is the ratio of the concentration of a substance to its concentration in the standard state. It is unitless. The activities of pure solids and liquids are unity. The activity of a gas equals the partial pressure of the gas in atmospheres divided by 1 atm, while the activity of a solute equals its molar concentration divided by 1 M.

Addition polymers are formed by addition reactions.

An addition reaction is a reaction in which two reactants combine to form a single product.

Adhesive forces are forces between different molecules (compare with cohesive force).

An alcohol is a compound with the general formula R-OH, where R is a generic group of atoms and OH is the hydroxyl group.

An alkali metal is an element that belongs to Group IA.

An alkaline earth metal is an element that belongs to Group 2A.

An alkane is a saturated hydrocarbon, i.e., a hydrocarbon that contains no multiple bonds.

An alkene is a hydrocarbon that contains carbon-carbon double bonds.

An alkyl group is an organic group formed by removing one hydrogen atom from an alkane.

Allotropes are different crystalline forms of the same element that have different properties. Graphite and diamond are allotropes of carbon.

Alpha decay is the emission of an alpha particle. It is common among the heavy isotopes because it is the best way to reduce mass.

An alpha particle is a helium nucleus.

An amide is an amine attached to a carbonyl.

An amine is an ammonia molecule in which one or more of the hydrogen atoms have been replaced with other groups.

An amino acid is a compound that contains both amine and carboxylic acid functional groups.

Amorphous solids have ordered arrangements of particles over short distances only. This is referred to as local order.

The ampere (A) is the SI unit for electrical current. 1 A = 1C/s.

An amphiprotic substance is able to function as either an acid or a base.

An analyte is a substance that is being analyzed.

The angstrom (Å) is \( 10^{-10} \) m. It is commonly used for bond lengths because most bond lengths are between 1 and 2 Å.
Angular momentum \((L)\) is a property of a rotating object. It is equal to the mass of the object times its velocity times its distance from the center of rotation; \(i.e., L = mv\).

The angular momentum quantum number \((l)\) is an integer between 0 and \(n-1\) that defines the shape of an atomic orbital.

An anion is a negatively charged ion.

The anode compartment or electrode is where oxidation occurs in an electrochemical cell.

Antibonding interactions occur in molecular orbitals when the atomic orbitals on adjacent atoms used to construct the molecular orbital have opposite phases.

An antibonding MO is one in which the number of antibonding interactions exceeds the number of bonding interactions.

An antiferromagnetic substance is not magnetic because all of its electron spins are paired.

An Arrhenius acid is a substance that contains \(H\) atoms and produces \(H^+\) ions in water.

An Arrhenius base is a substance that contains \(OH\) and produces \(OH^-\) ions in water.

The Arrhenius equation relates a rate constant to the temperature and activation energy of the reaction: \(k = Ae^{-E_a/R}t\) or \(ln k = ln A - E_a/R\).

An Arrhenius plot is a plot of \(ln k\) (rate constant) versus \(1/T\). The slope is \(-E_a/R\) and the intercept is \(ln A\) (the pre-exponential).

Atoms are the building blocks of matter. Elements consist of only one type of atom.

Atomic mass or atomic weight is the average mass of the atoms of an element relative to that of carbon-12, which is assigned a relative mass of exactly 12.

The atomic mass unit (amu) is a unit of mass that is \(\frac{1}{12}\) the mass of a single atom of carbon-12.

The atomic number \((Z)\) is the number of protons in the nucleus. It identifies the atom.

The atomization energy \((\Delta H_{atom})\) is the energy required to break all of the bonds in a molecule in the gas phase to produce the atoms.

Autoionization of water is the reaction of water with itself: \(2H_2O \rightarrow H_3O^+ + OH^-\).

Avogadro's law states that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.

Avogadro's number is \(6.02 \times 10^{23}\). It is the number of items in a mole.

B

The band gap is the energy separation between the valence and conduction bands of a metallic or covalent solid.

The band or belt of stability is the region of a plot of the number of neutrons versus the number of protons in a nucleus in which the stable nuclei fall.

Band theory is an extension of mo theory to metals. A very large number of atomic orbitals in a metal combine to form a very large number of molecular orbitals. The resulting molecular orbitals are so close in energy that they form an energy band.

A barometer is a device used to determine atmospheric (or barometric) pressure.

A base pair consists of two complementary, \(N\)-containing bases whose structures maximize H-bonding between them. Guanine and cytosine are base pairs as are adenine and thymine. Base pairs hold the two strands of DNA together.

A basic salt is one in which the basicity of the anion exceeds the acidity of the cation.

Basic solutions are solutions in which \([H_2O^+] < [OH^-]\). A basic solution has a pH > 7.0 at 25 °C.

A battery is a galvanic cell or a collection of galvanic cells. Batteries harness the free energy changes in redox reactions.

Beer's Law: The absorbance \((A)\) of a solution equals the product of its molar absorptivity \((\varepsilon)\), its molar concentration \((c)\), and the path length \((l)\) of the cell in which its absorbance is measured; \(A = \varepsilon c l\).

Belt of stability See band of stability.

Beta decay is the ejection from the nucleus of an electron produced by the decay of a neutron. Beta decay reduces the neutron/proton ratio, so it is common among nuclei that lie above the band of stability.

A beta particle \((\beta)\) is a high energy electron.

A bimolecular process is one that involves two molecules.

Binary compounds are composed of only two elements; \(Al_2O_3\) is a binary compound because it contains only \(Al\) and \(O\).

The binding energy is the energy that holds the nucleus together. It is related to the mass defect by \(\Delta E = \Delta mc^2\).

Blackbody radiation is the light emitted by a solid when it is heated.

A body-centered cubic \((bcc)\) unit cell is one in which the particles that lie on the corners are also in the body center.

The boiling point is the temperature at which the vapor pressure equals the external pressure. If the external pressure is 1 atm, then the temperature is called the normal boiling point.
Boiling point elevation ($\Delta T_b$) is the increase in the boiling point caused by the addition of a non-volatile solute to a solvent.

The boiling point elevation constant ($k_b$) is the proportionality constant that relates the boiling point elevation of a solution to its colligative molality. $\Delta T_b = k_b m_c$.

The bond angle is the angle formed by two bonds to an atom.

The bond dipole is a measure of bond polarity. It is represented by an arrow pointing from the less electronegative atom toward the more electronegative atom.

The bond energy or bond dissociation energy is the amount of energy required to break one mole of bonds in the gas phase.

The bond length is the distance between two bound nuclei.

The bond order is the number of shared pairs in a bond. As the bond order increases, the length of the bond decreases and its strength increases. The bond order in a diatomic molecule is also equal to 1/2 the difference between the number of its bonding and antibonding electrons.

The bonding electrons are the shared electrons in a covalent bond.

A bonding interaction occurs in a molecular orbital when the phases of the atomic orbitals of two adjacent atoms are the same.

A bonding MO is a molecular orbital in which the number of bonding interactions exceeds the number of antibonding interactions.

Boyle’s law states that the pressure-volume product of a fixed amount of gas at constant temperature is constant. $PV = k(n,T)$.

A branched chain hydrocarbon contains a chain of carbons atoms in which at least one carbon is bound to three or four other carbon atoms.

A Bronsted acid is a proton donor.

A Bronsted base is a proton acceptor.

A buffer is a solution that contains a weak acid and its conjugate base in appreciable and comparable amounts. Buffers reduce pH changes brought about by the addition of strong acids and bases.

The buffer capacity is the amount of strong acid or base on which a buffer can act.

The buffer range is the pH range over which a buffer can function.

A bulk property is a property of a material (such as a pure solid or liquid) as opposed to individual atoms or molecules. Bulk properties are different than the atomic or molecular properties of its components due to the interactions between the components.

The calorie (cal) is the heat required to raise 1 g of water 1 °C. 1 cal = 4.184 J. The dietary calorie (Cal) is actually a kilocalorie (kcal).

A calorimeter is a piece of equipment used to determine the amount of heat released or absorbed during a reaction.

A carbonyl contains the C=O group.

A carboxyl group is the combination of a carbonyl (C=O) and a hydroxyl (O-H) group. Molecules with carboxyl groups are called carboxylic acids (RCOOH), and the deprotonated ions are called carboxylates (RCOO$^-$_).

A catalyst is a substance that speeds up a reaction but is unchanged by it.

The cathode compartment or electrode is where reduction occurs in an electrochemical cell.

A cathode ray is light emitted from the cathode (negative electrode) of a gas discharge tube.

A cation is a positively charged ion.

The cell potential is the potential difference between the cathode and anode of an electrochemical cell. $E_{cell} = E_{cathode} - E_{anode}$

The Celsius (or centigrade) scale is the temperature scale based on the freezing (0 °C) and boiling points (100 °C) of water.

A chain reaction is a reaction in which a product initiates more reaction.

Charles’ law states that the volume of a fixed amount of gas at constant pressure is proportional to its absolute temperature. $V = k(n,P)T$.

A chemical property is a property of a substance that requires the substance to change into another substance. Hydrogen and oxygen react to produce water is a chemical property of hydrogen.

Chemistry is that branch of science that deals with matter and the changes it undergoes.

A cis configuration is one in which two groups are on the same side of a bond or atom.

Cohesive forces are forces between like molecules (compare with adhesive force).

The colligative concentration is the concentration of all solute particles in a solution. The colligative concentration of a solute equals its concentration times its van’t Hoff factor.

Colligative properties are those properties of a solution that depend upon the concentration, but not the identity, of the solute particles.
The **collision frequency** is the number of collisions per unit volume per unit time, which normally has units of (moles of collisions)/(liter·s).

**Combustion** is a reaction with oxygen.

A **common ion** is an ion that appears in an equilibrium but has at least two sources.

A **complex ion** is an ion in which a central metal is surrounded by molecular or anionic ligands.

A **compound** is a pure substance that consists of more than one element.

The **concentration** of a solute is the amount of solute divided by the volume in which it is contained.

A **concentration cell** is an electrochemical cell in which the two compartments differ only in their concentrations. The cell potential depends upon the concentration difference.

**Condensation** is the process of converting a vapor into its liquid.

**Condensation polymers** are formed by condensation reactions.

A **condensation reaction** is a reaction in which two reactants combine to form two products (one of which is often a small molecule such as water or an alcohol).

The **conduction band** is the lowest energy unfilled band in a solid that has no partially filled bands. Electrons in a conduction band are free to move throughout the metal due to the presence of unfilled orbitals. Thus, electrons can conduct electricity only when they are in the conduction band.

A **conductor** is a substance that conducts electricity at all temperatures. Its conduction decreases slightly with increasing temperature.

A **conjugate acid-base pair** is a Bronsted acid and base that differ by one proton only.

**Connectivity** is the manner in which the atoms in a molecule are connected.

**Constitutional isomers** are compounds with the same formula but different connectivities.

A **continuous chain hydrocarbon** is a chain of carbon atoms in which no carbon is bound to more than two other carbon atoms.

A **continuous spectrum** is a spectrum in which all wavelengths of light in the region are present. Thus, they merge into one another continuously. A rainbow is a continuous spectrum of visible light.

A **coordinate covalent bond** is a bond in which both bonding electrons are contributed by the same atom. The bonds formed in Lewis acid-base reactions are coordinate covalent because both bonding electrons always come from the base.

The **coordination number** of a particle is the number of its nearest neighbors in a crystal or in a compound.

**Core electrons** are the tightly bound electrons that are unaffected by chemical reactions. They reside in filled sublevels and form a spherical shell of negative charge around the nucleus that affects the amount of nuclear charge that the outermost electrons experience.

**Corrosion** is the natural oxidation of a metal.

The **coulomb** (C) is the SI unit of electrical charge. The charge on one electron is $1.602\times 10^{-19}$ C.

**Coulomb’s law** states that two charged particles experience a force that is proportional to the product of their charges and varies inversely with the dielectric of the medium and the square of the distance that separates them. Negative forces are attractive, while positive forces are repulsive.

A **counter ion** is an ion that accompanies a desired ion in order to maintain the electrical neutrality of the compound that contains the desired ion. Counter ions are spectator ions in net chemical equations.

A **covalent bond** results when electrons are shared. It can be viewed as the attraction of the bonding electrons for the bound nuclei.

The **covalent radius** of an atom X is equal to one-half of the distance between the X atoms in X$_2$.

The **critical mass** is the minimum mass of a radioactive material required to maintain a chain reaction.

The **critical point** is the temperature and pressure beyond which the liquid cannot exist. Substances beyond their critical point are supercritical fluids.

The **critical pressure** is the pressure required to liquefy a gas at its critical temperature.

The **critical temperature** is the highest temperature at which a gas can be liquefied.

A **crystal orbital** is to a crystal what a molecular orbital is to a molecule.

**Crystalline solids** are solids with well defined and ordered repeat units. The order, which exists throughout the crystal, is said to be long range order.

**Degrees of freedom** are the basic set of motions (translations, rotations, and vibrations) that a molecule undergoes. The kinetic energy of a molecule is distributed amongst its degrees of freedom. A molecule with N atoms has 3N degrees of freedom.

**Delocalized** electrons or bonds are spread over several atoms.
**Density** is the mass to volume ratio of a substance or solution. $d = \frac{m}{V}$

The **density of states** is the number of allowed energy states in a region of energy.

**Deposition** is the process in which a vapor is converted into its solid.

A **detergent** is a substance that has both a hydrophobic region that interacts well with nonpolar molecules such as grease, and a hydrophilic region that interacts well with polar molecules such as water.

**Diamagnetism** is the tendency of certain atoms not to be attracted by a magnetic field. It is an atomic property associated with atoms that have no unpaired electrons.

**Diatomic molecules** contain two and only two atoms.

The **dielectric constant** ($\varepsilon$) is a number that relates the ability of a medium to shield two charged particles from one another. A medium with a high dielectric constant shields the charges better than one with a low constant.

A **dipole** consists of two electrical poles, one positive and one negative. Bonds dipoles arise between atoms of different electronegativities. A molecular dipole is the vector sum of its bond dipoles.

**Dipole-dipole or dipolar forces** are the inter-molecular forces that result from the interaction of the oppositely charged poles of two polar molecules.

**Dispersion forces** are forces between molecules that result from the interaction of temporary or induced dipoles. Dispersion forces increase approximately with molecular size.

The **dissociation constant** is the equilibrium constant for the dissociation of a complex ion into its component ions and/or molecules. Also see acid dissociation constant.

The **dissociation or bond energy** is the energy required to break one mole of bonds in the gas phase.

**Dissolution** is the process in which an ionic substance dissolves in water to produce ions.

A **donor orbital** is the orbital on the reducing agent that contains the electrons to be transferred in a redox reaction.

The **double helix** is the structure adopted by DNA. It consists of a pair of intertwined polynucleotide strands held together by hydrogen bonding between base pairs.

**Dynamic equilibria** are attained when two competing processes occur at equal rates. Contrast to a static equilibrium where the competing processes stop.

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**Effective nuclear charge** ($Z_{\text{eff}}$) is the nuclear charge experienced by an electron in an atom. It is less than the nuclear charge due to shielding by the other electrons.

An **electrical current** is the rate at which charge flows through a circuit. A current of one ampere is a rate of one Coulomb of charge per second.

An **electrochemical cell** is a device used to extract the free energy change of a spontaneous redox reaction (see Galvanic cells) or to inject the energy required to drive a redox reaction that is not spontaneous (see electrolytic cells).

**Electrochemistry** is the combination of electrical conduction through a circuit and electron transfer reactions.

An **electrode** is a metal that provides a surface at which electrons can be transferred between an electrical circuit and a reactant in a redox reaction.

Electrodes are active if they participate in the reaction and passive if they do not.

**Electrolysis** is a non-spontaneous redox reaction that is driven uphill in free energy by the application of an external electrical potential.

An **electrolyte** is a material that produces ions when dissolved in water. Electrolytes can be weak or strong depending upon the extent to which they produce ions. Substances that dissolve in water as molecules rather than ions are called non-electrolytes.

An **electrolytic cell** is an electrochemical cell that converts electrical potential energy into chemical potential energy. See electrolysis.

**Electrolytic conduction** is conduction of electricity through a solution as a result of the migration of ions in the solution.

**Electromagnetic radiation** is an electric and a magnetic field oscillating perpendicular to one another that travels through space in the form of radio waves, microwaves, infrared waves, visible light, ultraviolet light, etc.

An **electron** is the basic quantity of negative charge. It carries a charge of $-1.602 \times 10^{-19}$ C and has a mass of $5 \times 10^{-4}$ amu.

**Electron capture** is the capture of a core electron by the nucleus. It converts a proton into a neutron.

The **electron configuration** of an atom is a listing of the sublevels that are occupied and the number of electrons in them.

**Electron density** is the probability of finding an electron in a particular region of space. The electron density is high in regions where the probability of finding an electron is high.
Electronegativity ($\chi$) is a relative measure of the ability of an atom to attract bonding electrons to itself. Atoms with high electronegativities have unfilled orbitals that are low in energy.

An electronic transition is the changing of the energy of an electron from one quantum state to another.

An element is a pure substance that cannot be broken down into a simpler substance by chemical means.

The elemental composition of a compound is a listing of the relative masses, usually expressed as percents, of the elements in the compound.

An elementary reaction is a reaction that occurs in one step.

Emission is the ejection of a photon by an atom or a molecule. The energy of the atom or molecule decreases by the energy of the photon ($h\nu$).

An empirical or simplest formula is a chemical formula that indicates only the smallest whole number ratio of the atoms present in the compound.

Enantiomers are two molecules that are non-superimposable mirror images of one another.

An endothermic process absorbs heat.

The end point is the point at which an indicator changes color. The end point should be nearly the same as the equivalence point.

Energetics is a combination of thermodynamics and kinetics.

Energy is the capacity to do work or to transfer heat.

An energy band is a region of allowed energy in a metal in which there is no separation between adjacent energy levels.

The energy of interaction is the energy of two interacting particles relative to the energy of the two particles when they are not interacting. Energies of interaction in chemistry result from the electrostatic interactions.

The enthalpy or heat of combustion is the heat absorbed when one mole of a substance reacts with oxygen. Heats of combustion are negative because they are exothermic.

The enthalpy or heat of reaction is the heat absorbed by a reaction run at constant temperature and pressure. A negative heat of reaction simply means that the heat is given off not absorbed.

Entropy is the thermodynamic measure the number of ways in which a system can distribute its energy. It is often related to the disorder in the system.

An enzyme is a biological compound (usually a protein) that acts as a catalyst.

The equilibrium constant ($K$) is the value of the reaction quotient ($Q$) when equilibrium activities are used.

The equivalence point is the point in a titration at which stoichiometric amounts of reactants are present.

Esters are compounds with the general formula $RCOOR'$, i.e., two groups connected by a carboxyl group.

Esterification is a condensation reaction between a carboxylic acid and an alcohol to produce an ester and water.

Evaporation is the conversion of a liquid to its vapor.

An excited state is an allowed state that is not the lowest energy state.

An exothermic process gives off heat.

Exponential decay is a decrease in concentration that goes as $e^{-kt}$. First order reactions undergo exponential decay: $[A] = [A]_0e^{-kt}$.

An extensive property is one that depends upon the amount of material. Mass and volume are extensive properties. Also see intensive property.

An extensive reaction is one with a large equilibrium constant. If a reaction is extensive, then the equilibrium concentration of least one of the reactants will be very small.

A face centered cubic (fcc) unit cell is one in which the atoms that are located in the corners are also found in the centers of the faces.

The factor label method is a method that uses the labels (units) of the factors to determine the order and manner in which the factors should be used to convert one quantity into another.

Family See group.

The Faraday (F) is the charge of one mole of electrons. $1\text{F} = 96,485 \text{C/mol}$.

A fatty acid is a carboxylic acid with a long hydrocarbon chain.

The Fermi level is the highest occupied energy level in a band.

A ferrimagnet is a magnetic material whose particles have opposing but unequal spins.

A ferromagnet is a magnetic material whose particles have aligned spins.

Ferromagnetism is a bulk magnetism in a material (such as iron) resulting from the alignment of the spins of adjacent atoms in the same direction.

The first law of thermodynamics states that energy is neither created nor destroyed in any process.

Fission is the process in which a heavy nucleus splits into lighter nuclei.
**Formal charge** is the charge an atom would have if the bonds were completely covalent, i.e., if its bonding electrons were assigned equally between the atoms in each bond.

The **formation constant** \((K_f)\) is the equilibrium constant for the formation of a complex ion. For example, \(\text{Ag}^{1+} + 2\text{NH}_3 \rightarrow \text{Ag(NH}_3)_2^{1+}\).

**Free energy** is the energy that is required to drive a non-spontaneous process. The negative of the free energy is the amount of work that can be extracted from a spontaneous process.

The **freezing point depression** \((\Delta T_f)\) is the decrease in the freezing point of a liquid caused by the addition of a non-volatile solute.

The **frequency** of a light wave is the number of oscillations per second that the wave undergoes.

A **functional group** is a group of connected atoms within a molecule that has a specific reactivity.

**Fusion** is the state change from a solid to a liquid or the combination of two lighter nuclei to produce a heavier one.

\(G\)

A **galvanic cell** is a spontaneous electrochemical cell. Galvanic cells convert chemical potential energy into electrical potential energy.

**Geometric isomers** are stereoisomers that differ because two groups can be on the same side (cis isomer) or on the opposite side (trans isomer) of some structural feature.

**Gibbs free energy** \((\Delta G)\) is the change in free energy at constant temperature and pressure.

The **ground state** is the state of an atom or molecule that has the lowest energy.

A **group (or family)** is a vertical column in the periodic table. The elements in a group have similar properties.

\(H\)

A **half-cell** is that portion of an electrochemical cell in which one half-reaction takes place.

The **half-life** \((t_{1/2})\) is the time required for one-half of a reactant to disappear.

A **half-reaction** is half of a redox reaction. They represent the electron gain or loss by showing the electrons explicitly. \(\text{Ox} + \text{ne}^{-} \rightarrow \text{Red}\) is the general form of a reduction half-reaction.

A **halogen** is an element that belongs to Group 7A. The common halogens are fluorine, chlorine, bromine, and iodine. The elemental halogens are diatomic.

**Hard water** contains \(\text{Mg}^{2+}\) and \(\text{Ca}^{2+}\), which form insoluble salts with soaps.

**Heat** \((q)\) is that form of energy that is transferred as a result of a temperature difference. By definition, \(q\) is the heat absorbed by the system, and \(-q\) is the heat released by the system.

The **heat capacity** \((C)\) of an object is the amount of heat required to raise the temperature of the object by 1 °C or 1 K.

**Heat of combustion** \((\Delta H_{\text{comb}})\) is the heat absorbed when one mole of a substance reacts with oxygen.

**Heat of formation** \((\Delta H_f)\) is the enthalpy change resulting when one mole of a substance is formed from its elements in their standard states.

**Heat of fusion** \((\Delta H_{\text{fus}})\) is the heat required to melt one mole of a substance at its melting point.

**Heat of sublimation** \((\Delta H_{\text{sub}})\) is the heat required to convert one mole of a solid into its gas.

**Heat of vaporization** \((\Delta H_{\text{vap}})\) is the amount of heat required to convert one mole of a liquid into its gas.

The **Henderson-Hasselbalch equation** is used to calculate the pH of a buffer solution:

\[
pH = pK_a + \log \left( \frac{n_b}{n_a} \right)
\]

Hess’ law of heat summation states that if a process can be expressed as the sum of several steps, then the enthalpy change of the process is the sum of the enthalpy changes of the steps.

A **heterogeneous catalyst** is in a different phase than the reactants. Typically it is a solid for gas or solution reactions.

A **heterogeneous mixture** is one whose composition varies as in a mixture of water and oil.

A **high spin metal** is one in which the splitting of the d orbitals is small enough that the d electrons remain unpaired in the higher energy set rather than pairing in the lower energy set.

**Homo** is the abbreviation for the highest occupied molecular orbital.

A **homogeneous catalyst** is in the same phase as the reactants.

A **homogeneous mixture** is a mixture whose composition is the same throughout, i.e., one in which the concentration of each component is the same regardless of the volume that is sampled. Homogeneous mixtures are called solutions.

A **homonuclear diatomic molecule** is one in which the two atoms are the same.

**Hund’s rule** states that the number of electrons with identical spin is maximized when filling the orbitals of a sublevel.

A **hybrid orbital** is an orbital constructed by mixing two atomic orbitals on the same atom. They are used to explain bonding in the valence bond model.
Hybridization is the process by which hybrid orbitals are produced from atomic orbitals.

A **hydrate** is a compound with a characteristic number of water molecules associated with it.

**Hydration** is the process in which a solute particle interacts with the surrounding water molecules.

A **hydrocarbon** is a compound that contains only carbon and hydrogen.

**Hydrogenation** is the addition of hydrogen to a compound.

The **hydrogen bond** is an especially strong dipolar interaction that occurs in compounds containing a hydrogen atom attached to N, O, or F.

The **hydronium ion** (H_3O^+) is the conjugate acid of water. Therefore, it is the strongest acid that can be present in aqueous solutions.

A **hydrophilic** molecule interacts well with water.

A **hydrophobic** molecule is excluded from water because it does not interact well with water.

The **hydrophobic effect** is the tendency of water to exclude hydrophobic molecules by establishing an ice-like structure around them.

A **hypothesis** is a proposed explanation of an observation. If a hypothesis proves successful in explaining many other experiments, it becomes a theory, but if it fails to explain a test, it is discarded or modified.

**Ideal gas** is a hypothetical gas composed of molecules that do not interact with one another.

The **ideal gas law** is the relationship between the pressure (P), volume (V), temperature (T) and number of moles (n) of an ideal gas. PV = nRT.

An **ionic bond** is an electrostatic (Coulombic) force between oppositely charged ions.

The **ionic radius** of an ion is determined from the distances between it and adjacent ions in an ionic crystal. The distance between the two adjacent ions equals the sum of their ionic radii.

The **ionization energy** is the energy required to remove an electron from an atom or molecule.

**Ionizing radiation** is high energy radiation that can remove electrons from a substance. X-rays are ionizing radiation.

Two substances are **isoelectronic** if they have the same number of electrons.

**Isomers** are different molecules with the same formula.

**Isotopes** are atoms with the same atomic number but different mass numbers, i.e., isotopes have the same number of protons but different numbers of neutrons.

The **joule** (J) is the SI unit of energy.

\[ 1 \text{ J} = 1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \]

**Kaolinite clays** are composed of silicate and aluminate layers (aluminosilicates). They are the main component of china clay.

The **kelvin** (K) is the SI unit of temperature. \( K = ^\circ \text{C} + 273.15 \).

**Kinetics** is the study of reaction rates and mechanisms.

**Kinetic energy** (\( KE = \frac{1}{2}mv^2 \)) is energy of motion. Anything in motion has the capacity to do work on another object by simply colliding with it.
Kinetic-molecular theory is the model used to explain the ideal gas law. One of its postulates is that the average kinetic energy of the molecules in a gas is directly proportional to the absolute temperature of the gas.

The kinetic region of a reaction is the period of the reaction in which concentrations are changing.

A liquid junction is a device that allows ion migration between the electrodes of an electro-chemical cell to complete the electrical circuit.

A load is a device in a galvanic cell that utilizes the free energy given off by the transferred electrons.

A lone pair is a pair of nonbonding valence electrons.

A low-spin metal is a metal in which the d electrons pair in the lower energy set of orbitals before occupying the higher energy set.

The lumo is the lowest unoccupied molecular orbital.

The magnetic quantum number \( m_l \) is an integer between \(-l\) and \(+l\) that specifies the directional character of an atomic orbital.

A main group element is an element in one of the groups designated as ‘A’ in the periodic table. Other elements are either transition or inner transition elements.

A manometer is a device used to determine the pressure of a gas.

The mass fraction of a substance in a mixture is the mass or reactants and products remains constant during a chemical reaction; \( i.e. \), mass is neither created nor destroyed in a chemical reaction.

The law of combining volumes states that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.

The law of conservation of energy is stated by the first law of thermodynamics; \( \Delta E_{\text{uni}} = 0 \).

The law of conservation of mass states that the total mass of reactants and products remains constant during a chemical reaction; \( i.e. \), mass is neither created nor destroyed in a chemical reaction.

The law of definite or constant proportions states that the elements of a compound are always present in definite proportions by mass.

The law of multiple proportions states that the masses of one element that combine with a fixed mass of another element in different compounds of the same elements are in a ratio of small whole numbers.

Le Châtelier’s principle states that a system at equilibrium will respond to a stress in such a way as to minimize the effect of the stress.

A level or shell is an allowed energy designated by the principal quantum number \( n \).

The leveling effect of a solvent requires that no acid in a solvent can be stronger than the conjugate acid of the solvent and no base can be stronger than the conjugate base of the solvent. Thus, hydronium ion is the strongest acid that can exist in water and hydroxide ion is the strongest base.

A Lewis acid is a substance with a low lying, empty orbital that can be used to form a covalent bond to a Lewis base. Lewis acidic sites are characterized by less than four electron regions.

A Lewis base is a substance with a lone pair that can be shared with a Lewis acid to form a covalent bond between the acid and the base.

A Lewis acid-base reaction is the conversion of a lone pair on a Lewis base and the empty orbital on a Lewis acid into a covalent bond between the acid and the base.

A Lewis structure is a representation of a molecule that shows all of the valence electrons. The nonbonding electrons are represented as dots, but the bonding pairs are usually shown as lines.

The Lewis symbol shows the atom’s valence electrons as dots in four regions around an atom.

A ligand is a molecule or ion that is attached to a metal.

The ligand field splitting energy \( \Delta \) is the energy difference between the sets of d-orbitals in an atom. It results from the electrostatic field of the ligands, \( i.e. \), the ligand field.

The limiting reactant is that reactant whose amount limits the amount of product that can be obtained in a reaction, \( i.e. \), the reactant that is totally consumed.

A line spectrum is a spectrum in which only certain wavelengths (lines) are present. Atomic spectra are line spectra.

A manometer is a device used to determine the pressure of a gas.

The magnetic quantum number \( m_l \) is an integer between \(-l\) and \(+l\) that specifies the directional character of an atomic orbital.

A main group element is an element in one of the groups designated as ‘A’ in the periodic table. Other elements are either transition or inner transition elements.

A manometer is a device used to determine the pressure of a gas.

The mass fraction of a substance in a mixture is the fraction of the whole, so they are less than one. However, they can be expressed as fractions of 100, in which case they are called mass percents.

The mass defect \( \Delta m \) is the difference between the mass of a nucleus and the sum of the masses of its neutrons and protons.

Mass-energy is a term used to show that mass and energy are interchangeable \( (E = mc^2) \).

The mass number \( A \) is the number of protons plus the number of neutrons in the nucleus.
The **mechanical surroundings** is that portion of the surroundings that exchanges energy with the system in the form of work.

The **melting point** is the temperature at which the solid and liquid states are in equilibrium.

A **meniscus** is the curved shape of the top of a liquid.

A **metal** is a material that is shiny, malleable, and a good conductor of electricity. Elements that are metals lie on the left side of the periodic chart and represent about 80% of the elements.

A **metallic bond** is one delocalized over the entire metal. The large number of atoms involved in a typical metallic bond is so large that the bonding electrons occupy bands of energy.

**Metalloids** have properties intermediate between the metals and nonmetals. The eight metalloids are shiny and brittle. They are not good conductors of heat or electricity (they are semiconductors).

A **micelle** is spherical arrangement of detergent molecules in which the heads form a polar outer shell and the tails form a hydrophobic liquid center.

**Micro** (μ) is the SI prefix for $10^{-6}$, a millionth.

**Milli** (m) is the SI prefix for $10^{-3}$, a thousandth.

Two liquids are **miscible** if they are soluble in one another in all proportions.

The **molality** (m) of a solute is the number of moles of solute present in 1 kg of solvent.

The **molar absorptivity** (ε) is the absorbance of a 1 M solution in a 1 cm cell.

The **molarity** (M) of a solute is the number of moles of solute present in a liter of solution.

The **molar mass** ($M_m$) is the mass of one mole of substance. It is equal to the atomic or molecular mass (weight) expressed in grams.

The mole (mol) is $6.02 \times 10^{23}$ items. It is the number of molecules or atoms in a sample of a compound or element that has a mass equal to its molecular or atomic mass expressed in grams.

The **mole fraction** (X) of a substance in a mixture is the number of moles of that substance divided by the number of moles of all components of the mixture.

A **molecular dipole** is equal to the product of the charges on the two poles of a polar molecule and the distance between them. It is represented by an arrow pointing from the center of positive charge toward the center of negative charge.

The **molecular formula** of a compound shows the actual numbers of atoms present in the molecule. Contrast with the simplest or empirical formula that shows only the smallest integers that are in the same ratio as in the molecular formula.

**Molecularity** is the number of reacting molecules in an elementary reaction.

The **molecular mass or weight** is the relative mass of a molecule relative to the mass of a carbon-12 atom.

**Molecular orbital theory** is a bonding theory in which bonds are formed from the combination of several atomic orbitals on several atoms.

**Molecular weight** See molecular mass

A **molecule** is an independent particle that consists of two or more chemically bound atoms.

A **monatomic ion** is derived from a single atom.

A **monomer** is a single unit building block that can be bound to other monomers to form larger molecules. Linking two monomers produces a dimer, linking three produces a trimer, and linking many produces a polymer.

A **nonbonding MO** has an equal number of bonding and antibonding interactions.

A **nonelectrolyte** is a substance whose aqueous solution does not conduct electricity. Electricity is not conducted because the electrolyte produces no ions in solution.

**Nano** (n) is the SI prefix for $10^{-9}$, a billionth.

**Nanotechnology** is science and engineering of systems on the nanoscale (1-50 nm).

The **Nernst equation** relates a cell’s potential to its standard potential and its reaction quotient.

$$E_{\text{cell}} = E^\circ - (RT/nF) \ln Q$$

A **net chemical equation** shows only those substances that are changed during the reaction.

In a **network covalent solid**, all of the atoms are bound covalently with no discernable molecules.

A **neutral salt** is a compound in which the acid and base strengths of the cation and anion are equal.

In **neutral solutions**, $[\text{H}_3\text{O}^+] = [\text{OH}^-]$. The pH of a neutral solution is 7.0 at 25 °C.

In **neutralization reactions**, an acid reacts with a base to produce water and a salt.

A **neutron** is a subatomic particle found in the nucleus. It has no charge and a mass of ~1 amu.

A **noble gas** is an element that belongs to Group 8A. The noble gases are helium, neon, argon, krypton, xenon, and radon.

A **nodal plane** is a plane of zero electron density that lies between regions of opposite algebraic sign in an orbital. A p orbital and a π orbital each contain a single nodal plane.

A **nonbonding MO** has an equal number of bonding and antibonding interactions.

A **nonelectrolyte** is a substance whose aqueous solution does not conduct electricity. Electricity is not conducted because the electrolyte produces no ions in solution.
Non-ionizing radiation, such as visible light, does not have sufficient energy to ionize matter.

Nonmetals are elements on the right side of the periodic table. They can be gases, liquids, or solids and are dull, brittle, and poor conductors of electricity. Nonmetals react with one another to form covalent compounds or with metals to form ionic compounds.

The normal boiling point is the temperature at which the vapor pressure of a liquid is 1 atm.

The nuclear binding energy is the energy required to break one mole of nuclei into their constituent nucleons.

Nuclear chemistry or radiochemistry is the study of reactions that involve changes in the nucleus.

Nuclear fission is the splitting of a heavier nucleus into lighter nuclei.

Nuclear fusion is the combination of two lighter nuclei into a heavier one.

Nucleons are the particles found in the nucleus. Protons and neutrons are nucleons.

A nucleotide is a unit of a nucleic acid that consists of a phosphate, a sugar, and an N-containing base. Nucleic acids are polymers built with nucleotides.

The atomic nucleus contains all of the positive charge, virtually all of the mass, but occupies almost none of the volume of an atom.

Nylon is a polyamide produced in the reaction of a diamine and a diester.

The octet rule states that atoms in molecules strive to obtain an octet (eight) of valence electrons by sharing the bonding electrons with other atoms.

An orbital is a solution to the wave equation. Electrons reside in atomic or molecular orbitals, and bonding results from the interaction of atomic orbitals of different atoms.

An organic compound is one that is based on carbon.

Osmosis is the net movement of solvent molecules from a dilute solution into a more concentrated one through a semipermeable membrane, *i.e.*, one that allows only solvent molecules to pass.

Osmotic pressure is the pressure caused at a semipermeable membrane bounded by solutions of different concentration. It results because solute particles cannot pass through the membrane but solvent molecules can.

Overpotential is the amount by which the applied potential for electrolysis must be increased above that predicted from half-cell potentials to carry out the electrolysis at a reasonable rate. Overpotentials are due to high activation energies.

An oxidant is an oxidizing agent.

Oxidation is the loss of electrons or increase in oxidation state that accompanies electron transfer.

The oxidation state of an atom is the charge it would have if its bonds were assumed to be ionic, *i.e.*, if its bonding electrons were assigned to the more electronegative atom in each bond.

An oxidizing agent is a substance that promotes oxidation in other substances. The oxidizing agent is reduced by the electron transfer.

An oxoacid is a Brønsted acid in which the proton is attached to an oxygen atom.

An oxoanion has a central atom surrounded by oxygen atoms. The central atom is usually in a high oxidation state because it is surrounded by the very electronegative oxygen atoms.

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**P**

Packing efficiency is the fraction of the volume of the unit cell that is occupied by particles.

Paramagnetism is the tendency of certain atoms to be attracted by a magnetic field. It is an atomic property that is related to the number of unpaired electrons on the atom.

Partial ionic character See percent ionic character.

The partial pressure of a gas is the pressure exerted by the gas in a mixture of gases. The total pressure exerted by a mixture is the sum of the partial pressures of all of the components of the mixture.

Parts per billion (ppb) is the number of grams of solute in $10^9$ g of solution.

Parts per million (ppm) is the number of grams of solute in $10^6$ g of solution.

Parts per thousand (ppt) is the number of grams of solute in 1000 g of solution.

The pascal (Pa) is the SI unit of pressure.

$1 \text{ Pa} = 1 \text{ kg.m}^{-1}.\text{s}^{-2} = 9.9 \times 10^{-6} \text{ atm}$

A passive electrode is one that does not participate in the half-reaction. For example, a platinum electrode in a $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ half-cell is passive.

The Pauli Exclusion Principle states that no two electrons in an atom can have the same set of quantum numbers.

A peptide is an amide produced from the reaction of two amino acids.

The percent ionic character is a measure of the charge separation in a bond, which results from electronegativity differences between the bound atoms. A bond is considered to be ionic if it is has over 50% ionic character.
The **percent yield** is the fraction of the theoretical yield, expressed as a percent, that is actually isolated in a chemical reaction.

A **period** in the periodic table is a horizontal row. The properties of the elements in a period vary gradually across the period.

The **periodic law** states that the elements exhibit a periodicity in the chemical and physical properties when they are arranged in the order of their atomic numbers.

The **periodic table or chart** is an arrangement of the elements into rows (periods) and columns (groups) such that the elements in the same group have similar properties.

**pH** is the negative base 10 logarithm of the hydronium ion concentration in a solution.

\[ \text{pH} = -\log[H_3O^+] \]

A **phase diagram** shows the state of a substance as a function of its temperature and pressure.

A **photon** is a quantum of energy in the form of electromagnetic radiation.

**Photosynthesis** is the process in which plants use solar energy to covert CO\(_2\) and H\(_2\)O into carbohydrates.

A **physical property** is one that is independent of other substances. Melting point, boiling point, color, and hardness are some physical properties.

A **pi (\(\pi\)) bond** is formed from the side-on interaction of two p orbitals. Pi bonds have nodal planes that contain the internuclear axis.

The **pK\(_a\)** of an acid is the negative base 10 logarithm of the acid dissociation constant. \[ \text{pK}_a = -\log K_a \]

**Planck’s constant (h)** is the proportionality constant that relates the frequency of a photon to its energy. \[ h = 6.626 \times 10^{-34} \text{ J/s} \]

A **polar covalent bond** is a covalent bond in which the bonding electrons are NOT shared equally. Thus, the bonds are between atoms of different electronegativities.

**Polar molecules** have asymmetric charge distributions. The result is a molecular dipole.

The **polarizability** of an atom or molecule is a measure of the ease with which its electron cloud can be deformed.

A **polyamide** is a condensation polymer that contains many amide linkages. Nylons and peptides are polyamides.

A **polyatomic ion** is an ion, such as CO\(_3^{2-}\), in which two or more atoms are covalently bound.

A **polyene** is an organic compound with many double bonds.

A **polymer** is a large molecule consisting of many single unit building blocks called mers.

A **polypeptide** is a polyamide produced from the reaction of many amino acids.

**Polyprotic acid acids** have more than one acidic proton. Examples: H\(_2\)SO\(_4\) is a diprotic acid and H\(_3\)PO\(_4\) is a triprotic acid.

**Polyunsaturated** organic compounds contain many C-C multiple bonds.

A **positron** is an elementary particle with the mass of an electron and a positive charge. It is the antimatter analog of the electron.

**Positron decay** is the emission of a positron from the nucleus. Positron decay increases the neutron/proton ratio, so it is common in nuclei that lie below the band of stability.

**Potential energy** is energy due to position. In chemistry, potential energy arises from the interaction of charged particles, and the closer they are, the stronger they interact.

A **precipitate** is a solid formed when two solutions are mixed, or the act of forming the solid. Thus, AgCl precipitates and is a precipitate when it does.

The **precision** of a number is given by the number of significant figures to which it is reported. 1.00 m is more precise than 1.0 m.

A **pre-exponential** preceded an exponential. Typically used in the Arrhenius equation: \[ k = A\exp\{\frac{-E}{RT}\} \]

where A is the pre-exponential.

**Pressure (P)** is force per unit area: \[ P = \frac{F}{A} \]

**Pressure-volume or PV work** is done when the volume of a gas changes against an external pressure.

The **principal quantum number (n)** specifies the energy level of an electron in an atom.

A **protein** is a large polypeptide.

A **proton** is a subatomic particle found in the nucleus. It carries a +1 charge and has a mass of ~1 amu.

A **proton acceptor** is called a Bronsted base.

A **proton donor** is called a Bronsted acid.

A **purely covalent bond** is a covalent bond in which the bonding electrons are shared equally. Thus, the bonds between atoms of the same electronegativity are purely covalent.

A **quantitative observation** is one that does involve numbers.

A **quantitative observation** is one that does involve numbers.

A **quantity** in the factor label method is an amount and is characterized by a single unit. For example, 3 m is a quantity, but 3 m/s is a factor.

A **quantum** is a packet of energy.
A **quantum number** is a number (usually an integer) that designates an allowed state. All atomic and molecular states (e.g., electronic, vibrational, rotational, and nuclear) are described by quantum numbers.

A **radioactive** nucleus is unstable and disintegrates spontaneously to another nucleus by emitting or capturing particles.

**Radioactive dating** is the determination of the age of a material from the amount of material involved in the radioactive decay of one of its components.

**Radiochemistry** See nuclear chemistry.

**Radioisotopes** are radioactive nuclei.

The **rate of change** of a quantity is the rate at which it changes as a function of the change in another quantity.

A **rate constant** (k) is the proportionality constant between the concentrations of the components (usually reactants) of a reaction and the rate of reaction.

The **rate-determining step** (RDS) is the elementary reaction in a mechanism that is so much slower than the other elementary reactions that it dictates the rate of the overall reaction.

The **rate law** expresses the rate of a reaction as a function of the concentrations of the substances (usually reactants) involved in the reaction.

The **rate of disappearance** is the rate at which a reactant reacts.

The **rate of formation** or **appearance** is the rate at which a product is produced.

The **rate of reaction** is the rate at which a product is produced or a reactant reacts divided by its coefficient in the chemical equation.

A **reactant order** is the exponent of the concentration of a reactant in the rate equation for a reaction.

The **reaction coordinate** is the combination of intermolecular distance, bond length and bond angle changes required to convert reactant molecules into product molecules.

A **reaction mechanism** is a series of elementary processes that leads to the overall reaction.

The **reaction order** is the sum of all of the reactant orders in a reaction.

The **reaction quotient** (Q) is expressed as the activities of the products divided by the activities of the reactants. Each activity is raised to an exponent equal to the coefficient of the substance in the balanced equation. When the activities are equilibrium activities, the reaction quotient is called the equilibrium constant.

A **redox couple** is the oxidized and reduced forms of the species involved in a half-reaction. For example, Cu$^{2+}$/Cu is a redox couple.

The **redox electrons** are the electrons that are transferred in a redox reaction.

**Redox reactions** involve an electron transfer from a reductant to an oxidant.

A **reducing agent** or **reductant** is a substance that promotes reduction in another material. It is oxidized in the process.

**Reduction** is the gain of electrons, which results in a decrease in oxidation state of the species being reduced.

A **residue** in a protein is one of the amino acids making up the protein.

A **resonance structure** is a Lewis structure of a molecule that differs from another Lewis structure only in the placement of electrons.

**Respiration** is the process whereby animals extract energy from carbohydrates.

**Rotational degrees of freedom** are spinning motions about an axis through the center of mass of the molecule. Linear molecules have two rotational degrees of freedom, and nonlinear molecules have three.

**Salts** are ionic compounds formed in an Arrhenius acid-base reaction. The anion of a salt is supplied by the acid, and the cation by the base.

A **salt bridge** is a liquid junction that consists of a saturated solution of a strong electrolyte, such as KCl. Ions enter and leave the bridge so as to maintain electrical neutrality in the two half-cells of an electrochemical cell.

**Saturated carbons** are involved in four sigma bonds.

**Science** is that branch of knowledge that is gained by the application of the scientific method.

The **Schrödinger equation** relates the energy of an electron to its wavefunction.

The **scientific method** is used to further scientific knowledge. It involves observation, hypothesis formulation, prediction, and testing.

The **second law of thermodynamics** states that the entropy of the universe increases in all spontaneous processes.

A **semiconductor** is a substance whose electrical conductivity increases with temperature. Semiconductors are characterized by small but nonzero band gaps.
A **semipermeable membrane** allows the passage of solvent molecules but not of solute particles.

**Shell** See level.

**Shielding** is the amount by which the nuclear charge experienced by an electron is reduced by interference from other electrons. Core electrons shield valence electrons much better than do other valence electrons because most of the electron density and charge of the core electrons lies between the valence electrons and the nucleus.

**Sigma bonds** are formed from the interaction of s orbitals or the end-on interaction of p or d orbitals. The electron density in a sigma bond contains the internuclear axis.

**Significant figures** are used to express the precision of a measurement or result.

In a **simple cubic (sc)** unit cell, the particles are found only at the corners.

The **simplest or empirical formula** is a chemical formula whose subscripts indicate only the smallest whole numbers that are in the same ratio as the actual numbers of atoms present in the molecule.

**Smectic clays** are also called swelling clays, they consist of a layer of aluminate octahedra sandwiched between two layers of silicate tetrahedra.

**Soaps** are similar to detergents except the polar head is a COO⁻ (carboxylate) group because soaps are the salts of fatty acids.

The **solubility** of a solute is the maximum amount of the solute that can dissolve in a solvent at a given temperature.

The **solubility product constant (K_{sp})** is the equilibrium constant for the dissolution of a salt in water.

A **solute** is a component of a solution that is not the solvent.

A **solution** is a homogeneous mixture.

**Solvation** is the process in which the solvent molecules interact with solute particles.

The **solvent** is the substance responsible for the phase of a solution. If one of the components of a solution is a liquid, then the liquid is considered the solvent.

An **sp hybrid orbital** is one of the two orbitals obtained by mixing one s and one p orbital on an atom. The two sp hybrids are separated by 180°.

An **sp² hybrid orbital** is one of the three orbitals obtained by mixing one s and two p orbitals on an atom. The three sp² hybrids lie in the plane and are separated by 120°.

An **sp³ hybrid orbital** one of the four orbitals obtained by mixing one s and three p orbitals on an atom. The four sp³ hybrids point toward the corners of a tetrahedron and are separated by 109°.

The **specific heat (s)** of a substance is the amount of heat required to raise the temperature of 1 g of the substance by 1 °C.

**Spectator ions** are ions in solution that do not undergo reaction. When KCl(aq) is added to AgNO₃(aq), the Ag¹⁺ and Cl⁻ ions react, but the K¹⁺ and NO₃⁻ ions are spectator ions. Spectator ions are brought into solution as counter ions to the ions that do react.

**A spectrum** is a display of radiant energy arranged in order of it frequency or wavelength.

The **spin quantum number** (m_s) of an electron is ±1/2 or -1/2. It indicates the direction of the magnetic field produced by the electron.

**A spontaneous** process is one that takes place without intervention. ΔG_{\text{rev}} > 0 for all spontaneous processes, or ΔG < 0 for spontaneous processes at constant temperature and pressure.

The **standard cell potential (ε^°)** is the cell potential when all reactants and products are in their standard states.

The **standard enthalpy or heat of reaction (ΔH^°)** is the enthalpy change for a reaction when it is carried out with all reactants and products in their standard states.

The **standard heat or enthalpy of formation (ΔH_f^°)** is the heat absorbed when one mole of a substance is formed from its elements in their standard states.

The **standard hydrogen electrode (SHE)** is a half-cell containing 1 M H¹⁺ and 1 atm H₂. It is used as the reference for standard reduction potentials. The standard reduction potential of the SHE is assigned a value of exactly 0 V.

The **standard reduction potential** of a redox couple is a measure of the free energy of the redox electrons relative to those in a reference couple such as the H¹⁺/H₂ couple. The more positive the standard reduction potential, the lower is the energy of the electrons.

A **standard solution** is a solution of known concentration that is used to determine an unknown concentration.

The **standard state** is a reference state used to compare thermodynamic quantities. It is 1 atm pressure for a gas, a concentration of 1 M for a solute, and the pure substance for a solid or a liquid.

A **state function** is a quantity that depends only upon the initial and final states.

A **stereocenter** in organic chemistry is a carbon atom that has four different groups attached to it.
Stereoisomers have the same connectivities but different spatial arrangements of their atoms.

The steric factor in kinetics represents the probability that a collision between the particles in an elementary process have the correct orientation to react.

The stoichiometric factor or link is the conversion factor in a stoichiometric calculation that converts from one substance into another. It is the ratio of subscripts in a chemical formula or the coefficients in a balanced chemical equation.

Stoichiometry is the study of the conversion from one chemical species into a chemically equivalent amount of another. The conversion is made through the use of chemical formulas or balanced chemical equations.

A straight or continuous chain is a chain of atoms in which no atom is bound to more than two other atoms in the chain.

A strong acid is an acid that reacts extensively with water, i.e., one whose acid dissociation (ionization) constant is much greater than one. Aqueous solutions of strong acids are represented by $\text{H}_3\text{O}^+$.

A strong base is a base that reacts extensively with water to produce $\text{OH}^-$.

The sublevel of an electron is specified by the $n$ and $l$ quantum numbers. It dictates the energy, size, and shape of its orbitals.

Sublimation is the process in which a solid is converted into its vapor.

A supercritical fluid is the phase of matter beyond the critical point. It has some properties of the liquid and the gas, but it is neither.

The surface tension of a liquid is the energy required to increase its surface area by a fixed amount.

Surroundings See thermodynamic surroundings.

System See thermodynamic system.

Temperature is a measure of the average kinetic energy of the molecules in a system.

A termolecular process involves three molecules.

The theoretical yield is the amount of product predicted from the amount of limiting reactant and the stoichiometry of the reaction.

A theory is an explanation of many observations.

Thermal energy is the kinetic energy of a molecule, ion, or atom. Thermal energy depends only upon the temperature.

The thermal surroundings is that portion of the surroundings that exchanges heat with the system.

A thermochemical equation is a chemical equation that includes a thermodynamic quantity, usually $\Delta H$ or $\Delta G$.

Thermochemistry is that branch of thermodynamics that deals with energy change in chemical reactions.

Thermodynamics is the study of energy and its transformations.

The thermodynamic region of a reaction is after equilibrium has been established.

The thermodynamic surroundings is that part of the universe that exchanges energy with the system.

A thermodynamic system is that part of the universe that is under investigation.

The thermodynamic universe is the system and its surroundings.

A thermonuclear reaction is a nuclear reaction that requires a large input of energy for initiation. Fusion reactions are thermonuclear.

The third law of thermodynamics states that the entropy of a perfect crystal at 0K is zero.

The titrant is the solution whose volume is determined in a titration.

In a titration, the volume of one solution of known concentration (the titrant) that is required to react with another solution (the analyte) is determined in order to find the concentration of the analyte.

A titration curve is a plot of the pH of the solution versus the volume of titrant.

The torr is a unit of pressure. A pressure of 1 torr supports a column of Hg to a height of 1 mm.

A trans configuration is one in which two groups are on opposite sides of a bond or atom.

A transition element or metal is an element (metal) in the d-block (B groups) of the periodic table.

The transition state is the highest energy species through which the reactants must pass in order to make the transition to the products.

Translational degrees of freedom are the straight-line motions of a particle. All straight line motion can be expressed as a sum of $x$, $y$, and $z$ components, so all molecules have three translational degrees of freedom.

The triple point is the temperature and pressure at which the solid, liquid, and vapor states of a substance are in equilibrium.
The uncertainty principle states that it is impossible to know both the position and speed of subatomic particles to high accuracy. In order to measure one more accurately, you most lose accuracy in the other.

A unimolecular process involves only one particle.

A unit cell is the simplest arrangement of particles that generates the entire lattice when translated in all three dimensions.

Unsaturated carbon atoms are involved in less than four sigma bonds.

The valence band is the highest energy filled band containing the valence electrons of a metal.

In valence bond theory, bonds arise from the overlap of orbitals on adjacent atoms. The orbitals can be either atomic or hybridized.

Valence electrons are those outermost electrons that dictate the properties of the atom and are involved in chemical bonding. They reside in the outermost s sublevel and any unfilled sublevels.

Valence-shell electron-pair repulsion (VSEPR) theory is used to explain molecular shapes in terms of electron regions adopting the spatial orientation that minimizes the electron-electron repulsions between them.

The Van’t Hoff factor (i) relates the colligative concentration to the concentration of the solute. For example, \( m_c = im \).

The van der Waals radius is one-half of the distance between identical, nonbonded atoms in a crystal. Atoms that are closer than the sum of their van der Waals radii are assumed to be interacting.

Vaporization is the process by which a liquid is converted into its vapor.

The vapor pressure of a liquid is the pressure of its vapor in equilibrium with the liquid at a given temperature.

Vapor pressure lowering (\( \Delta P \)) is amount by which the vapor pressure of a solvent is reduced by the addition of a volatile solute.

Vibrational degrees of freedom of a molecule are the relative motions of its atoms that result in small oscillating changes in bond lengths and angles.

Viscosity is the resistance of a liquid to flow.

Void space is unoccupied space.

The volt is the SI unit of electrical potential. 
\[ 1 \text{ V} = 1 \text{ J.C}^{-1}. \]

The wave function of an electron is a function that contains all of the information about the electron.

The wavelength (\( \lambda \)) is the distance between two corresponding points on a wave.

Wave-particle duality is a term used to indicate that photons (light) and very small particles, such as electrons, behave as both particles and waves.

A weak acid is an acid that does not react extensively with water, i.e., it is an acid with a dissociation constant that is much less than one.

A weak base is a substance that reacts only slightly with water to produce hydroxide ions.

A weak electrolyte is a substance whose aqueous solution conducts only a small current of electricity because only a small fraction of weak electrolyte molecules produce ions in water.

Work (\( w \)) is a force through a distance, \( w = fd \). Thus, something must move, and there must be a resistance to the movement in order for work to be done. By definition, the symbol \( w \) is the work done ON the system, and \(-w\) is the work done BY the system.

X-ray diffraction is a technique in which x-rays are scattered from atoms in the solid to determine the distances between the atoms and ions in the crystal.

Zeolites are aluminosilicates built from tetrahedral \( \text{AlO}_4 \) and \( \text{SiO}_4 \) units bridged by oxygen atoms. They are filled with channels and pores, which provide many uses for the material.