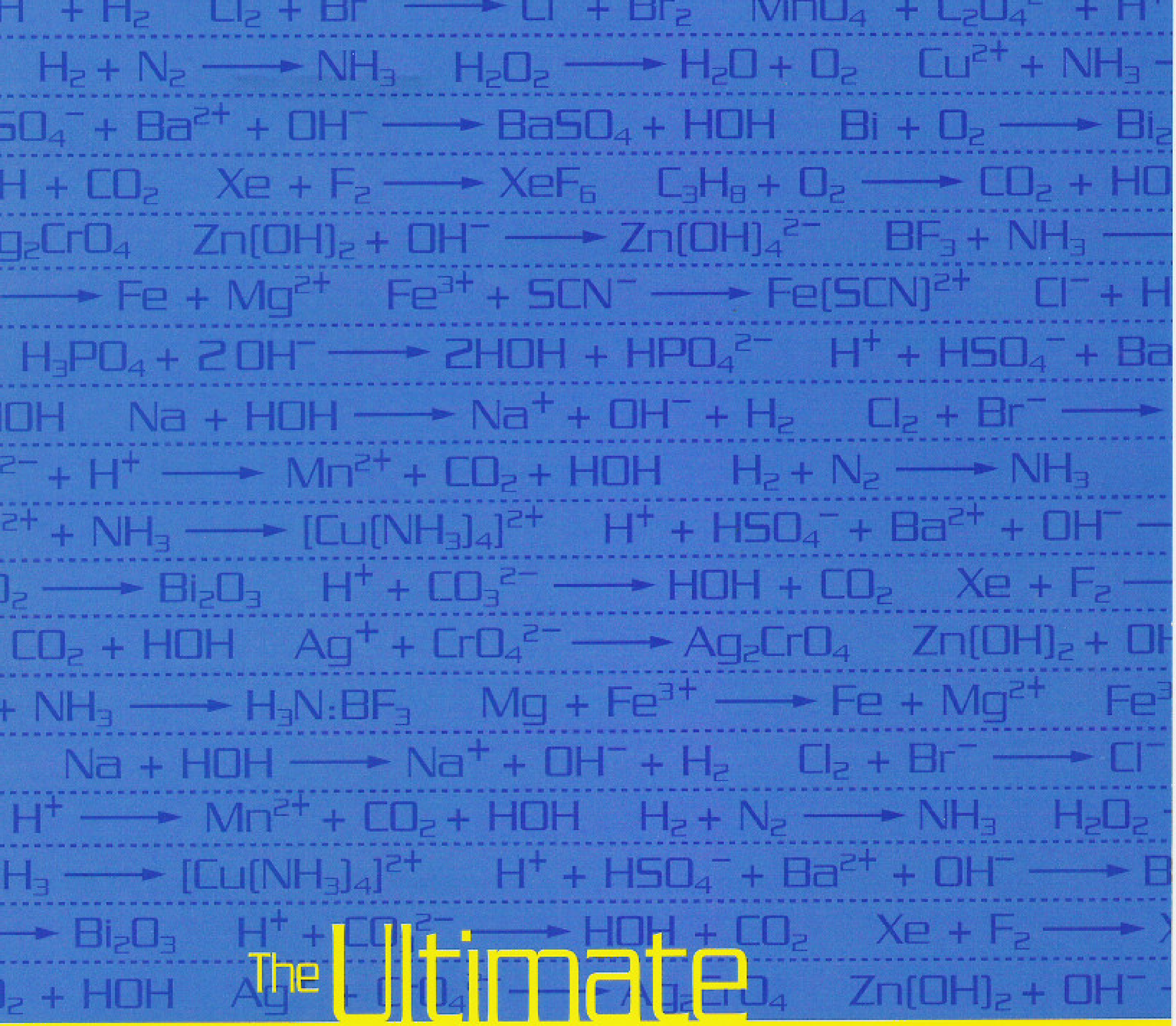

The Ultimate Chemical Equations Handbook

STUDENT EDITION

By: George R. Hague, Jr. and Jane D. Smith

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Student Edition

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George R. Hague, Jr.
and
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Table of Contents

About the Authors v

Acknowledgments vii

Introduction to Writing AP Equations ix

Chapter 1: Symbols and Nomenclature 1

Chapter 2: Simple Inorganic Formulas and Nomenclature 9

Chapter 3: Oxidation Numbers: Anions and Cations 11

Chapter 4: Ternary Nomenclature of Acids and Salts 19

Chapter 5: Complex Ion Formulas and Nomenclature 23

Chapter 6: Organic Nomenclature and Simple Reactions 29

Chapter 7: Balancing Molecular Equations 39

Chapter 8: Single Replacement Reactions 45

Chapter 9: Double Replacement (Metathesis) Reactions 47

Chapter 10: Aqueous Solutions and Ionic Equations 55

Chapter 11: Redox Equation Balancing and Reactions 63

Chapter 12: Electrolysis in Aqueous Solutions 75

Chapter 13: Complex Ion Reactions 79

Chapter 14: Summary of Reactions 83

Chapter 15: Molecular Equations for Reference 87

List of Reference Tables

Common Polyatomic Ions Table 16

Organic Functional Groups Table 34

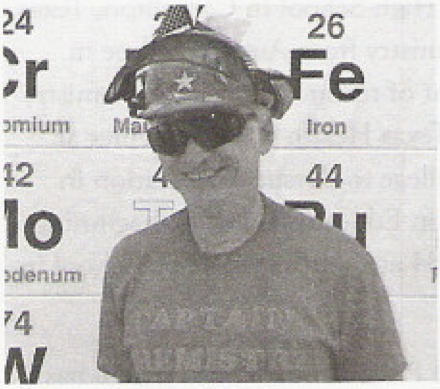
Solubility Rules Table 48

Standard Electrode Potentials Tables 71–73

Exercises

Exercise 1–1 8
Exercise 2–1 10
Exercise 3–1 12
Exercise 3–2 17
Exercise 3–3 17
Exercise 4–1 20
Exercise 4–2 20
Exercise 4–3 21
Exercise 5–1 27
Exercise 5–2 27
Exercise 6–1 35
Exercise 6–2 35
Exercise 6–3 37
Exercise 7–1 41
Exercise 7–2 43
Exercise 8–1 46
Exercise 9–1 49
Exercise 9–2 51
Exercise 9–3 54
Exercises 10–1 to 10–6 59
Exercises 10–7 to 10–12 62
Exercise 11–1 66
Exercise 11–2 66
Equation Balancing Challenge 69
Exercise 11–3 70
Exercise 12–1 78
Exercise 13–1 81

About the Authors



George R. Hague, Jr.

George Hague, well known as a teacher, mentor, and valued collegue, passed away on July 15, 2002, after a long battle with leukemia. George was a thirty-nine year teaching veteran with 22 years as a New Jersey public school teacher and 17 years as a Texas private school teacher. He last taught College Prep Chemistry and AP Chemistry at St. Mark's School of Texas in Dallas, TX, where he held the Leonard N. (Doc) Nelson Alumni Master Teaching Chair in Science. Born in East Orange, NJ, George received his BA in 1962 and MA in 1966 from Montclair State University, Upper Montclair, NJ. He did additional graduate work at Beaver, Cornell, Marquette, Rutgers, Seton Hall, NYU, Hope, and California–Berkeley.

Hague was passionate about his love for chemistry, teaching, and his students. He has been quoted as saying, "If you are teaching chemistry and you are not having fun, then you must be doing something wrong!" George believed in "hands-on" science, demonstrations, music, and gimmicks that motivated in order to teach chemistry to his students. He is probably best known for his role as "Captain Chemistry," but had also assumed the identities of Merlin the Magician, "The Wizard of Chemistry," a Chemistry Cheerleader, and Albert Einstein. He presented hundreds of workshops and demonstrations at schools, colleges, convention centers, industrial locations, and even in parking lots. Over a hundred articles with tips for teachers appeared in such publications as *The Science Teacher, The Journal of Chemical Education, Chem 13 News, NJSTA Newsletter, The STATelite, ACT$_2$ Newsletter,* and *The Southwest Retort.* Awards won by George include the 1999 National Catalyst Award, Montclair State University Alumni Award, National Tandy Technology Scholar Award, AP Special Service Award from E.T.S., Outstanding Texas Chemistry Teacher of the Year Award, ACS Southwest and Middle Atlantic Regional Awards, Dreyfus Master Teacher, Shell Merit Teacher, Fellow of the New Jersey Science Teachers Association, Who's Who Among America's Teachers, and the 1983 Presidential Award for Excellence in Science Teaching.

George taught Advanced Placement Chemistry for more than twenty-five years—the first twelve at Bernards High School in NJ and the rest at St. Mark's School of Texas. George hosted chemistry camps and served five years as an AP Chemistry reader. His students competed successfully in state and regional scientific competitions and won four National TEAMS Championships in JETS competitions along with ten Varsity State Championships and six Junior Varsity Championships.

Professional activities included serving two terms on the NSTA Board of Directors (1985–88 and 1993–95), president of the New Jersey Science Teachers Association, president of the Associated Chemistry Teachers of Texas (ACT$_2$), member of the Board of Directors of the National Mole Day Foundation, and chairperson of the NSTA High School and Safety Committees.

George will be greatly missed.

Jane D. Smith

Jane Smith has more than sixteen years of teaching experience with twelve of those years teaching Advanced Placement chemistry. Jane is currently the science department head and chemistry teacher at R. L. Turner High School in Carrollton, Texas. Jane graduated with a BA in Chemistry from Austin College in Sherman, Texas. After a short stint of research in the Biochemistry Department at the University of Texas Health Science Center at Dallas, she returned to Austin College to pursue certification in education. The result was an MA in Education and the beginning of a beloved teaching career in 1984 at Van Alstyne High School in Van Alstyne, Texas, where she was the entire science department.

In addition to the responsibilities of teaching chemistry and Advanced Placement chemistry, Jane has led a number of related activities over the years. She has been an Odyssey of the Mind coach, a University Interscholastic League Academic Science and Math coach, Science Department Chairperson and has served on a variety of committees within her school and district. She is very active in the Science Teachers Association of Texas and the Associated Chemistry Teachers of Texas. She presents at many statewide workshops and has served as president on the Executive Board of the Associated Chemistry Teachers of Texas. In 1998 she received the Werner W. Schulz Award given by the Dallas–Ft. Worth Section of the American Chemical Society. In 1998–99 she was awarded an Honorable Mention in the Radio Shack Tandy Scholar Teachers program. In 1999 she received the Outstanding Chemistry Teacher Award given by the Associated Chemistry Teachers of Texas. When she is not teaching or working for her school, Jane enjoys reading and traveling with her husband Chris.

Acknowledgments

This handbook has been a labor of love. This book is dedicated to all of the Advanced Placement Chemistry students we have ever taught. We thank them for inspiring us to become better teachers and continually restoring our faith in the youth of America. It has been both an honor and a privilege to be their chemistry teachers. *Note*: George wrote this acknowledgment in 2000.

I would like to thank the following individuals who have had a tremendous impact on molding me into the teacher and person I am today:

Irv Gawley, retired chemistry professor and early mentor, Montclair State University, Upper Montclair, NJ.

Warren Baecht, retired high school chemistry teacher and mentor, Tenafly H.S., Tenalfy, NJ.

The late Hubert Alyea, master demonstrator and Princeton University professor.

George Gross, good friend and fellow chemistry teacher, retired from Union Township H.S., Union, NJ.

Patricia Lesinski Hague, my wife, best friend, soul mate, and mother of our three sons. A special thanks for putting up with all of my strange hours and professional activities.

Alice and George R. Hague, my parents!

George R Hague Jr

I would like to thank the following individuals who have had a tremendous impact on molding me into the teacher and person I am today:

Elva Duran who ignited my love of science in the 5th grade and Rayburn Ray who kept the fires burning throughout my years at Coronado H.S., El Paso, TX.

Dr. Charles Barr and Dr. Michael Imhoff, chemistry professors at Austin College, Sherman, TX for inspiring me to pursue chemistry as a major and providing me with the opportunity to whet my appetite for teaching.

Lennie Sunthimer and Robyn Shipley-Gerko as well as so many other colleagues at R.L. Turner H.S., Carrollton, TX who encouraged and challenged me to be my best.

Carol Brown, Kristin Jones, Lisa McGaw, and Jerry Mullins, AP consultants who share generously with new AP teachers.

My family and especially my husband Chris, because he is my anchor and while he encourages me to say no, he supports me when I say yes.

Jane

Lastly, we wish to express our gratitude to Larry Flinn, III, President of Flinn Scientific, who encouraged us to write this handbook and to Geri "Hawkeye" Blomquist, Staff Chemist at Flinn Scientific, who spent many hours meticulously reviewing our manuscript and giving us advice and support. Whenever we slipped up, "Hawkeye" Blomquist would catch us and put us back on track. Thanks, Geri, it has been a pleasure working with you!

"Chem is try!"

Introduction to Writing AP Equations

The Advanced Placement (AP) Chemistry course is equivalent to the freshman General Chemistry course offered at the collegiate level. All AP Examinations are written by the Educational Testing Service (ETS) and are taken annually by high school students during the early part of the month of May. Detailed information about the AP Program may be obtained at the ETS website located on the *worldwide web*:

www.collegeboard.org/ap

The AP Chemistry Examination is a 180-minute examination, divided into two parts. The first part of the examination consists of 75 multiple-choice questions with a broad coverage of topics. Part one is 90 minutes in length and constitutes 45 percent of the final examination grade. The second part of the examination is the free response section. Part two is also 90 minutes in length and represents 55 percent of the final examination grade. For the first 40 minutes of the free-response section (Part 2), students are allowed to use a calculator as they work on several comprehensive problems. After 40 minutes have passed, calculators must be put away and may not be used for the remaining 50 minutes of the exam. During this final 50 minutes, students answer several essay questions as well as a descriptive chemistry question requiring the determination of products of chemical reactions (the Equations section).

Students are allowed considerable choice among the questions included in the free-response section (Part 2) of the examination. Answering the free-response essay questions enables a student to demonstrate his or her ability to reason by applying chemical principles to solving problems. It is expected that answers be clearly presented in a logical and coherent manner. One of the questions in Part 2—the Equations section—pertains to descriptive chemistry and asks the student to write ionic and molecular formulas for reactants and products in various chemical reactions.

In this Equations section of the exam, eight equations are given and the individual student **must** choose five of these eight equations to answer. (*Note:* Additional responses will not be graded or counted. If all eight are attempted, the grader will grade the first five, so the student must designate which five of the eight the grader should grade.) Calculators and/or other such aids are not allowed on the Equations section. The equations are of mixed types. This Equations section is worth 15 points and is equal to 15 percent of the free-response grade. It is for this section of the exam that this handbook was written.

All AP equations "work." This means that in every case, a reaction will occur—there are no "no reaction" or equilibrium type equations (double arrow/reversible) to worry about! All equations **must** be written as net ionic equations. Spectator ions are not included in net ionic equations and all other ions must be written in their ionic form. All molecular substances and insoluble compounds are to be written together, in their unionized form, as molecular formulas. Solids and pure liquids are also written using their molecular formulas. A saturated ionic solution is written in ionic form, while the ions in a suspension are written together (molecular form). AP equations are not to be balanced. Do not waste time on balancing! It is also not necessary to include descriptive phase symbols such as (s), (l), (aq) and (g). This is a waste of valuable time as it will provide no extra points.

Each equation is worth a total of three points. One point is given for correct reactants and two points for all correct products. If a reaction has three products, one point is given for two correct products and two points for all correct products. Any spectator ions you write on the reactant side will nullify the one possible reactant point, but if they appear again on the product side, there is no product-point penalty. A fully molecular equation used for ionic substances will earn a maximum of one point. Charges shown on all ions must be correct!

The best method of preparation for the Equations section of the AP Exam is simply to practice a lot of equation-writing. The equation sets each year are similar and some equations show up year after year. When predicting a reaction, first try to classify it by type. For example, if the equation mentions acidic or basic solutions, it is most likely a redox reaction. During the practice process, if you find yourself totally at a loss, look up the reactants in this handbook, in the index of your textbook, in other reference books, or on the Internet to try to find information that will help you with the equation. Read this handbook and learn strategies for predicting various types of reactions. Do the practice problems in this book. Your AP Chemistry teacher will provide you with many AP type practice equations to work on. Many of the equations come from reactions that you will perform in the laboratory. Remember, all reactions do not fit neatly into the five types of equations generally learned in first year Chemistry courses. Save the equation sheets that you work on and practice them again, just before the AP exam in May.

The types of equations most often encountered on the AP Chemistry Examination usually fit into one (or more) of the following categories:

- Acid-Base
- Addition
- Anhydrides
- Combustion
- Complex Ion
- Decomposition
- Double Replacement (Metathesis)
- Electrolysis
- Organic
- Oxidation-Reduction (Redox)
- Precipitation
- Single Replacement

Solubility rules **must** be memorized if one is to be successful at predicting reactions. Rules for writing formulas and the charges and names of common polyatomic ions must also be memorized. How to get formulas and charge information from a periodic table is a most helpful skill to learn. Both a periodic table and a table of standard reduction potentials are provided in the AP Chemistry Examination booklet and are available for student use throughout the three-hour examination.

The Number of Equations Used on the
AP Chemistry Examination is Finite!

Practicing Equations Will Help to Improve Your AP Score!

CHAPTER 1

A Brief Look at the Symbols and Nomenclature of the Elements

"Elementary Speaking, Mr. Spock, It Is a Logical System!"

Mr. Spock, the Science Officer and second-in-command of the Starship Enterprise, gained great fame in the movies and television series known as *Star Trek*. Spock was a Vulcan. Vulcans, according to the *Star Trek* series, were known for not having emotions and for having extremely logical minds.

Before the untimely demise of *Star Trek*, it was rumored that Mr. Spock questioned the supposedly illogical earthling system of naming the elements, the building blocks of matter. After all, four elements had been named after the town of Ytterby, Sweden, (that's right, four elements!); and others had been named after the planet Uranus, a budding twig, the state of California, a father and his daughter, a subterranean gnome, and Albert Einstein. What logic could possibly exist in such a system? The system appears to be based on a mixture of unrelated facts that have absolutely nothing at all to do with chemistry!

But wait, Mr. Spock, there is earthling logic to the naming of the elements. The discovery or creation of a new element must be verified by other scientists and then must be accepted by the International Union of Pure and Applied Chemistry (IUPAC). The new element must then be named. Certain rules apply, for example, metals names are supposed to use the suffix "ium." Yet for the most part, the discoverer chooses the name. In other words, if you were to discover a new element, you would have the right to name it–you may even name it after your high school, or your hometown!

The names of the known 115 elements (only the first 109 have official names) fit into one or more of the following eight categories:

- Properties of the elements
- Sources of the elements
- Countries and regions of the world
- Cities
- Heavenly bodies
- Mythological individuals
- Individuals
- Miscellaneous names–in most cases, names applied to some of the elements discovered by the ancients.

For Mr. Spock's benefit, let us take a look at uranium and a number of the transuranium elements that were discovered at the University of California–Berkeley. Uranium was discovered just after the discovery of the planet Uranus. The element was named in honor of the new planet.

In 1940, when element 93 was first prepared at the University of California–Berkeley's Lawrence Radiation Center, it only seemed logical to name the new element next to uranium after the planet next to Uranus, which at that time was Neptune. The same line of reasoning was used to name element number 94. Because the planet beyond Neptune was Pluto, the name plutonium resulted. How is that for logic, Mr. Spock?

Since many of the transuranium elements were prepared at the Lawrence Radiation Center, University of California at Berkeley, California, U.S.A., it is logical to find the following names:

Americium—named after the Americas (after all, one must be patriotic!). Furthermore, americium is in the same family (homologs) as europium, which is also a continent (logic strikes again).

Californium—named after the state and university where it was first discovered.

Berkelium—named after the city where it was first synthesized.

Lawrencium—named after the Lawrence Radiation Center. Ernest O. Lawrence was a professor at the University of California–Berkeley where he invented the cyclotron.

Now let's look at some names of elements that have been logically derived from their properties:

Actinium—from the Greek word *aktis* which means beam or ray. Actinium is an alpha ray emitter with a very short half-life.

Argon—from the Greek word *argon* meaning inactive.

Bromine—from the Greek word *bromos* for stench, a perfect description of its suffocating odor.

Hydrogen—comes from two Greek words *hydro* and *genes* that together mean "water former."

Astatine—from the Greek word *astatos* or unstable. Astatine is a radioactive element with a very short half-life.

Mercury—from the Greek word *hydrargyrum* for "quick silver" or "liquid silver."

Radium—from the Latin word *radius* for ray. It is highly radioactive and glows in the dark.

Many other elements have names relating to their colors. Five are named from the colors they emit when burned and when their spectra are observed through a spectroscope.

Helium—from the Greek word *helios* or "sun," where its first spectral lines were discovered.

Cesium—from the Latin word *caesius* for "sky blue."

Rubidium—from the Latin word *rubidius* for the dark red colors emitted in its excited state.

Indium—named for its indigo-blue spectrum.

Thallium—from the Latin word *thallos* and means a "budding twig" or "young shoot" or a "green branch," a very logical description of the green line formed in its spectrum. (*Note:* This is your authors' favorite name for an element.)

Other elements have been named from the properties of their salts:

Aluminum—from the Latin word *alumen* or alum, which has an astringent taste.

Boron—derived from the Arabic word *buraq,* which refers to the white color of borax.

Chromium—from the Greek word *chroma* or *chromos* meaning color; many of chromium's salts are colored.

Iodine—from the Greek word *iodes* for violet, the color of its vapor when it sublimes.

Lanthanum–from the Greek term *lanthanein,* which means concealed. It is very difficult to separate lanthanum out from other rare earth elements.

Praseodymium and **neodymium** were discovered together. Praseodymium (Greek: *prasios* and *didymos*) means "green twin" while neodymium (Greek: *neos* and *didmos*) means "new twin."

Osmium–from the Greek word *osme* or odor; the element is a metal with a pungent odor.

Rhodium–from the Greek word *rhodon* and means rose; its salts form rose-colored solutions.

We hate to admit it, Mr. Spock, but some elements received their names from "mistakes" or "errors." We are sure you will find the following names to be unforgivable:

Manganese–comes from the Latin word *magnes* or "magnet." Unfortunately, its ore was first confused with magnetic iron ore.

Nickel–from the Swedish abbreviation for *kopparnickel* or "false copper." This was the result of confusing a reddish ore that looked like copper ore but was found to contain nickel instead.

Oxygen–this is the all-time "mistake" in terms of naming an element. Antoine Lavoisier, "The Father of Modern Chemistry," made the mistake. Oxygen comes from two Greek words (*oxys* and *genes*) and means "acid former." With logic like that, hydrochloric acid could not possibly exist! Score one for Mr. Spock!

Elements named after their sources include the following:

Calcium–from the Latin word *calx,* or "lime" which is now known as calcium oxide.

Carbon–from the Latin word *carbo,* which means coal or charcoal.

Potassium–from the Latin word *kalium,* which means potash (potassium carbonate).

Sodium–from the Latin word *natrium* or soda (sodium carbonate).

Tellurium–from the Latin word *tellus,* which means earth and describes where it is found in nature.

A number of countries and regions in the world have given their names to the elements. Many of these elements were named by patriotic individuals in honor of their "homeland" or region of origin.

Francium–France.

Germanium–Germany.

Polonium–Poland.

Gallium–from the old Latin name *Gallia* for France.

Rhenium–from the old Latin name for the Rhine provinces in Germany.

Scandium–Scandinavia.

Thulium–from *Thule*, the ancient name for Scandinavia.

Ruthenium–from the Latin name *Ruthenia* for Russia.

Hassium–from *Hassia,* the Latin name for the German state of Hesse, the home of the large German nuclear research facility. The actual location is Darmstadt, Germany in the state of Hesse.

Under cities we find the "King of them all," Ytterby, Sweden! Four elements were discovered in the rich mineral fields near the small town of Ytterby, and were named in its honor. These elements include **erbium, terbium, ytterbium**, and **yttrium**. Once again, logic prevails!

Other cities with elements named after them include:

> **Copenhagen, Denmark**–has the Latin name *Hafnia*, hence the element **hafnium**. Interestingly enough, neither of its co-discoverers was Danish. The element was named by Dick Coster, who was Dutch, and George Charles de Hevesy, who was Hungarian, while both were connected with the Neil Bohr Institute of Theoretical Physics in Copenhagen.
>
> **Holmia, Sweden**–the home city of the discoverer of **holmium**.
>
> **Paris, France**–this city has given its name to **lutetium** since *Lutetia* is the ancient name of the city. A logical guess will give you the hometown of Georges Urbain, the discoverer of lutetium.
>
> **Strontian, Scotland**–the site where the element **strontium** was first found. Once again, Mr. Spock, we have more logic for you to ponder!
>
> **Dubna, Russia**–the element **dubnium** was named in honor of the Joint Institute for Nuclear Research in Dubna, Russia.
>
> **Darmstadt, Germany**–the element darmstadtium was named after the place of its discovery.

We have already discussed a number of elements named after astronomical objects. Two others are worthy of mention. Both were discovered at approximately the same time as astronomical discoveries and, as a result, were named in their honor.

> **Cerium**–after the asteroid Ceres.
>
> **Palladium**–from the asteroid Pallas.

A number of mythological individuals have given their names to elements.

> **Vanadium, niobium**, and **tantalum**–all are found in the same family (homologs). Niobium is always found in nature with tantalum. Tantalum derives its name from the Greek mythological figure known as King Tantalus. His daughter, Niobe, has given her name to niobium. Just like the elements, the father and daughter are closely related. The other member of the family, vanadium, was named after the Scandinavian goddess Vanadis.
>
> **Promethium**–the first artificial element produced in a laboratory. It was named after Promethius who stole fire from the heavens for the use of mankind. The analogy being that the element promethium was prepared (stolen) by harnessing nuclear fission.
>
> **Titanium**–one of our modern day super metals; was named from the supermen in Greek mythology known as the Titans.
>
> **Cobalt**–a very interesting name; derived from the German word *kobald* which is a subterranean gnome, goblin, or evil spirit. The name came into being because the poisonous ores of cobalt were very treacherous for miners to mine.

Several elements have been named in honor of famous scientists.

Curium–named in honor of Pierre and Marie Curie for their investigations in radioactivity.

Einsteinium–named after the brilliant physicist Albert Einstein, *Time* magazine's "Man of the Twentieth Century."

Fermium–honors the great Italian nuclear physicist Enrico Fermi.

Gadolinium–first isolated from the mineral *gadolinite*. Gadolinite was named after John Gadolin, a chemist from Finland.

Mendelevium–named after Demitri Mendeleev, the Russian scientist who is considered to be the "Father of the Periodic Table of the Elements."

Nobelium–honors Alfred Nobel, a Swedish scientist, who was the inventor of dynamite. He was also responsible for establishing the Nobel Prizes.

Samarium–this element gets its name from the mineral *samarkite* from where the element was first discovered. Samarkite was named after a Russian engineer and mine official by the name of Colonel V. E. Samarsky.

Rutherfordium–named after Lord Ernest Rutherford who was born in New Zealand and did his research in England. There he developed the nuclear theory of the atom and discovered the proton; he is considered to be the founder of nuclear physics.

Seaborgium–named after the great American nuclear chemist Glenn T. Seaborg, who was responsible for synthesizing many of the transuranium elements (those beyond uranium) now found on the periodic table. Seaborium is the only element ever named after a person who was actually alive at the time of the official naming. Such a practice had been in conflict with IUPAC policies prior to that time.

Bohrium–named after Niels Bohr, the Danish physicist who formulated the quantum theory of the electronic structure of the hydrogen atom and the origin of the spectral lines of hydrogen and helium.

Meitnerium–named after the great Austrian female physicist, Lise Meitner. Her discoveries in nuclear physics played a major role in developing nuclear energy.

Mr. Spock will surely point out that some of the ancient elements such as antimony, iron, lead, sulfur, tin, and zinc are not very logically named. The names of those elements have been derived from old words and their original meanings have become obscured with time. But fear not, Mr. Spock, a LOGICAL system for the preliminary naming of elements without official names has been developed by the IUPAC Commission on the Nomenclature of Inorganic Chemistry.

The IUPAC Commission has made the following recommendations for the unofficial names of new elements:

- Names should be short and obviously related to the atomic numbers of the elements.
- Names should end in "ium" for both metals and nonmetals.
- Symbols for these systematically-named elements should consist of three letters.
- Symbols should be derived from the atomic number and be related visually, as much as possible, to their names.

The three-letter system was developed in order to avoid duplication of already existing two-letter symbols. The following roots are used from which the names of new elements are to be derived:

0 = nil
1 = un (pronounced with a long u to rhyme with "moon")
2 = bi
3 = tri
4 = quad
5 = pent
6 = hex
7 = sept
8 = oct
9 = enn

To name an element, the roots are put together in the order of the digits found in the atomic number of the element and then "ium" is added to the name. According to the system, element #118 would be called ununoctium and its symbol would be Uuo since the first letter of each root in the name is used. The final "i" in bi or tri is dropped when these letters appear before "ium." The final "n" in enn is dropped when it appears before nil.

Atomic Number	IUPAC Name	Symbol
110	ununnilium	Uun
111	unununium	Uuu
112	ununbium	Uub
113	ununtrium	Uut
114	ununquadium	Uuq
115	ununpentium	Uup
116	ununhexium	Uuh
117	ununseptium	Uus
189	unoctennium	Uoe

Mr. Spock, is there a glimmer of a smile on that unemotional face of yours? Let us warn you, however, that the discoverers of a new element will continue to have the right to suggest another name to the IUPAC Commission once their discovery has been established beyond all doubt in the scientific community.

The three-letter system was developed in order to avoid duplication of already existing two-letter symbols. The following roots are used from which the names of new elements are to be derived:

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Atomic Number	IUPAC Name	Symbol
110	ununnilium	Uun
111	unununium	Uuu
112	ununbium	Uub
113	ununtrium	Uut
114	ununquadium	Uuq
115	ununpentium	Uup
116	ununhexium	Uuh
117	ununseptium	Uus
189	unoctennium	Uoe

Mr. Spock, is there a glimmer of a smile on that unemotional face of yours? Let us warn you, however, that the discoverers of a new element will continue to have the right to suggest another name to the IUPAC Commission once their discovery has been established beyond all doubt in the scientific community.

Let us, just for a moment, imagine what it would be like if the IUPAC alternative "root" system were expanded to cover all of the elements. Water would be composed of the elements unium and octium. Table salt would contain ununium and unseptium. FORGET IT! Give us the old system of naming elements! Maybe Mr. Spock is right, our method of naming elements is not perfectly logical. As things now stand, the names of the first 109 elements tell 109 different stories. These stories tell about "The Romance of Chemistry" and the humanizing of science. This is something logical Mr. Spock could never understand, but as for us, we are ever thankful for the humanizing of chemistry!

Determine the formula for EbE_6 using the IUPAC alternative "root" system. Follow the two examples given below.

Example 1: U_2O = unium octium
= atomic #1 atomic #8
= H_2O

Example 2: UuUs = ununium unseptium
= atomic #11 atomic #17
= NaCl

Practice Problem: EbE_6 = ????

Exercise 1–1: Symbols and Formulas

Chemical symbols are used for convenience to represent the names of the elements. Some are merely initials of the names. All of these are older elements. No new future elements that are discovered will be allowed to have symbols with only one letter.

H ________________ **O** ________________ **C** ________________

F ________________ **I** ________________ **B** ________________

U ________________ **P** ________________ **N** ________________

Y ________________ **S** ________________ **V** ________________

Others consist of the first letter in the name of the element and a second letter which is prominent in pronouncing the name of the element. (This is the modern day rule that is followed.)

Si ________________ **Ca** ________________ **Bi** ________________

Ra ________________ **Al** ________________ **Mn** ________________

Cl ________________ **Cd** ________________ **Br** ________________

Li ________________ **Ni** ________________ **Zn** ________________

Mg ________________ **As** ________________ **Ba** ________________

Pt ________________ **Pu** ________________ **Np** ________________

Co ________________ **Ti** ________________ **Cr** ________________

Sg ________________ **Sr** ________________ **Ga** ________________

Some symbols are derived from non-English words. i.e., Latin, Greek, or German names.

Fe (ferrum) ________________ **Cu** (cuprum) ________________

Na (natrium) ________________ **K** (kalium) ________________

Ag (argentum) ________________ **Hg** (hydrargyrum) ________________

Sn (stannum) ________________ **Sb** (stibium) ________________

Pb (plumbum) ________________ **Au** (aurium) ________________

W (wolfram) ________________

Symbols are used as a sort of shorthand in writing the names of elements. The use of symbols to represent atoms, or definite quantities by mass of the elements is also important in writing chemical formulas and in describing reactions. Thus, the symbol C represents the element carbon, but it also represents one atom of carbon. ***Note:*** The first letter of the symbol is **always** printed uppercase; the second letter is **always** printed lowercase!

Fill in the blanks given above with the names of the elements the symbols represent. Be able to give either the symbol or its name from memory.

CHAPTER 2

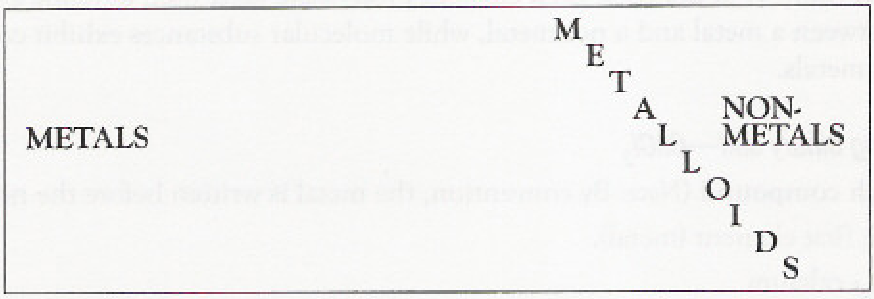
Simple Inorganic Formulas and Nomenclature

Compounds consisting of two different type elements are considered to be *binary compounds*. Binary compounds usually end in the suffix "ide." There are two types of binary compounds—binary molecules and binary salts. A binary molecule consists of two nonmetals bonded via covalent bonding. A binary salt consists of a metal and a nonmetal exhibiting ionic bonding.

General Rules:

A. *Binary Molecules (Nonmetal + Nonmetal Compounds) i.e., CO_2 or N_2O_3*

Molecules are formed when two nonmetals or metalloids combine and prefixes must be used to designate the number of atoms of each element present in one molecule. Nonmetals are found just to the right of the zigzag line on the periodic table. Metalloids are near the zigzag line and have some properties of metals and some properties of nonmetals.



Prefixes are used to designate the number of atoms of each element present in the formula of a binary compound. *Mono* is **never** used in front of the first element (standard convention). If there is only one atom, the mono is assumed.

1 = mono
2 = di
3 = tri
4 = tetra
5 = penta
6 = hexa
7 = hepta
8 = octa
9 = nona
10 = deca
11 = undeca
12 = dodeca

Name the following binary molecules—CO_2 and N_2O_3

First word in the compound:

1. Give the prefix designating the number of atoms of the first element present. Remember, *mono* is never used (by standard convention) for the first element.

   CO_2: No prefix for C
   N_2O_3: di

2. Name the first element.

   CO_2: carbon
   N_2O_3: dinitrogen

Second word in the compound:

3. Give the prefix designating the number of atoms of the second element present.
   CO_2: carbon di
   N_2O_3: dinitrogen tri

4. Name the root of the second element.
   (*Note:* The root is the base name which designates the element.)
   CO_2: carbon diox
   N_2O_3: dinitrogen triox

5. Add *–ide* to the root of the second element.
   CO_2: carbon dioxide (official name)
   N_2O_3: dinitrogen trioxide (official name)

B. Binary Salts (Metal + Nonmetal compounds) i.e., $CaCl_2$

Prefixes giving the number of atoms of each element present are *never* used to name a salt. Salts exhibit ionic bonding between a metal and a nonmetal, while molecular substances exhibit covalent bonding between two nonmetals.

Name the following binary salt—$CaCl_2$

First word in each compound (*Note:* By convention, the metal is written before the nonmetal.):

1. Name the first element (metal).
   $CaCl_2$: calcium

Second word in the compound:

2. Name the root of the second element (nonmetal).
   $CaCl_2$: calcium chlor

3. Add the suffix *–ide* to the second element.
   $CaCl_2$: calcium chloride

Exercise 2–1: In column 1, classify each of the following compounds as binary molecules (M) or binary ionic salts (I). Then in column 2, use the rules to name each binary compound.

1. CaF_2 ______ ____________________
2. P_4O_{10} ______ ____________________
3. K_2S ______ ____________________
4. NaH ______ ____________________
5. Al_2Se_3 ______ ____________________
6. N_2O ______ ____________________
7. O_2F ______ ____________________
8. SBr_6 ______ ____________________
9. Li_2Te ______ ____________________
10. SrI_2 ______ ____________________
11. CO ______ ____________________
12. Cs_2Po ______ ____________________
13. $ZnAt_2$ ______ ____________________
14. P_2S_3 ______ ____________________
15. AgCl ______ ____________________
16. Na_3N ______ ____________________
17. Mg_3P_2 ______ ____________________
18. XeF_6 ______ ____________________

CHAPTER 3

Oxidation Numbers: Anions and Cations

Metals with Variable Charges (Oxidation Numbers)

A number of metallic elements can form compounds in which the metallic ions (cations) may have different charges. These charges are known as oxidation numbers and are sometimes referred to as valences. The transition metals in the middle of the periodic table have variable oxidation numbers as do many of the representative elements in columns III, IV, V, and VI. Cations with variable oxidation numbers use a Roman numeral system (the Stock System) enclosed in parentheses to designate the charge on the cation (metallic ion). For example, the oxidation number of iron in the following two compounds cannot be the same: $FeCl_2$ and $FeCl_3$. Calling both of these compounds iron chloride would only lead to confusion. The Stock System is used to differentiate between ions that have two or more possible charges. $FeCl_2$ is known as iron(II) chloride and $FeCl_3$ is officially called iron(III) chloride. The Roman numeral represents the charge on the cation (metal) and does *not* represent the number of atoms of the element present. To name these types of ionic compounds, the oxidation numbers of all the elements present must be known.

Here are some simple rules that should help in the determination of the oxidation numbers of metallic ions (cations) from the formulas of their compounds.

1. The oxidation number of any **element** in its free state (uncombined with other elements) is zero. e.g., Fe in a bar of iron is zero. O_2 and N_2 in the Earth's atmosphere both have oxidation numbers of zero. When an element has equal numbers of protons and electrons, its overall charge is zero.

2. The oxidation number of **alkali metals** in a compound is always 1+, e.g., Li^+, Na^+, K^+, etc.

3. The oxidation number of **alkaline earth metals** in a compound is always 2+, e.g., Mg^{2+}, Ca^{2+}, Sr^{2+}, etc.

4. **Fluorine** is always assigned a value of 1^- in a compound, e.g., F^-.

5. The oxidation number of **oxygen** is almost always 2^- in a compound. Exceptions to this rule would be peroxides, O_2^{2-} where the oxidation number of each oxygen is 1^-, and superperoxides, O_2^- where the oxidation number of each oxygen is $\frac{1}{2}^-$. Neither peroxides nor superperoxides are common. Peroxides are only known to form compounds with the elements in the first two columns of the periodic table, e.g., H_2O_2, Na_2O_2, CaO_2, etc. Potassium, rubidium, and cesium are the only elements that form superperoxides, e.g., KO_2.

6. In covalent compounds (with nonmetals), **hydrogen** is assigned an oxidation number of 1+, e.g., HCl, H_2O, NH_3, CH_4. The exception to this rule is when hydrogen combines with a metal to form a **hydride**. Under these conditions, which are rare, hydrogen is assigned an oxidation number of 1^-, e.g., NaH.

7. In **metallic halides** the halogen (F, Cl, Br, I, At) always has an oxidation number equal to 1^-.

8. Sulfide, selenide, telluride, and polonide are always 2^- in binary salts.

9. Nitrides, phosphides, and arsenides are always 3^- in binary salts.

10. All other oxidation numbers are assigned so that the sum of the oxidation numbers of each element equals the net charge on the molecule or polyatomic ion. In neutral compounds, the sum of the positive and negative charges must equal zero.

Example:

Determine the oxidation number of the underlined element: $K\underline{Mn}O_4$. Since K is an alkali metal, its charge must be 1+. Oxygen is 2– but there are four of them, therefore, 4 times 2– equals 8–. If 1+ and 8– are added together, we get 7–. In order for the compound to be neutral, the Mn must be 7+.

Other Examples:

$\underline{N}H_4^+$: The sum of the charges on this polyatomic ion must equal 1+. Since hydrogen has a 1+ charge and there are four hydrogen atoms, the nitrogen must be 3– because (3–) + (4+) = 1+!

$K_2\underline{Cr}_2O_7$: Potassium is 2 times 1+ = 2+ and oxygen is 7 times 2– = 14–. (14–) + (2+) = 12–. Since there are two chromium atoms and the compound is neutral overall, the charge on the two chromium atoms must be equal to 12+ and each chromium atom must have a charge of 6+ (since 12+/2 = 6+).

$\underline{O}_2$: This is an element in its free state, so the oxidation number must be zero.

(*Note:* Ions written alone, such as peroxide, must be written with a charge on them, e.g., O_2^{2-}. In a compound, the charges on individual atoms or ions are not shown.)

Exercise 3–1: Determine the oxidation number of each underlined element.

1. $K_2\underline{S}$
2. $Na\underline{Cl}O_4$
3. $\underline{Br}Cl$
4. $Li_2\underline{C}O_3$
5. $\underline{O}F_2$
6. $\underline{S}_8$
7. $\underline{Mg}$
8. $K_2\underline{W}_4O_{13}$
9. $Mg(\underline{B}F_4)_2$
10. $\underline{Au}_2O_3$
11. $\underline{C}_{60}$
12. $\underline{Zr}O_2$
13. $\underline{Nb}OF_6^{3-}$
14. $Al_2(\underline{Cr}O_4)_3$
15. $Cs_2\underline{Te}F_8$

Remember, free elements, no matter how complex the molecule, have an oxidation number (valence or charge) equal to zero. The following are diatomic or polyatomic elements in nature which must be committed to memory. These elements exist as neutral molecules in nature!

Polyatomic Elements

Hydrogen, H_2

Nitrogen, N_2

Oxygen, O_2

Fluorine, F_2

Chlorine, Cl_2

Bromine, Br_2

Iodine, I_2

Ozone, O_3

Phosphorus, P_4

Sulfur, S_8

Most common forms of buckminsterfullerenes (buckyballs): C_{60} & C_{70}

Representative Elements (s- or p-Differentiating) Cations and Anions

Charges can be determined by position (family) on the Periodic Table. Cations (+ ions) come from metals that lose electrons (oxidation) in order to become isoelectronic with a noble gas. Anions (– ions) come from nonmetals that gain electrons (reduction) to become isoelectronic with a noble gas.

Oxidation Numbers (Valence) of Representative Element Cations and Anions

Cations		Anions	
1+		1–	
Alkali metals	lithium, Li$^+$; sodium, Na$^+$; potassium, K$^+$; rubidium, Rb$^+$; cesium, Cs$^+$; francium, Fr$^+$; hydrogen, H$^+$	*Halogens*	fluoride, F$^-$; chloride, Cl$^-$; bromide, Br$^-$; iodide, I$^-$; astatide, At$^-$
2+		2–	
Alkaline Earth metals	beryllium, Be^{2+}; magnesium Mg^{2+}; calcium, Ca^{2+}; strontium, Sr^{2+}; barium, Ba^{2+}; radium, Ra^{2+}	*Oxygen family*	oxide, O^{2-}; sulfide, S^{2-}; selenide, Se^{2-}; telluride, Te^{2-}; polonide, Po^{2-}
3+		3–	
	aluminum, Al^{3+}; boron, B^{3+}	*Nitrogen family*	nitride, N^{3-}; phosphide, P^{3-}; arsenide, As^{3-}
		4–	
			carbide (covalent), C^{4-}

More on Metallic Elements with Variable Oxidation Numbers

Transition metals, representative metals with *p* and *d* sublevels, and the inner transition metals typically have more than one oxidation state in compounds. Electrons for these metallic elements are lost (oxidized) in the following order: *p*, *s*, *d*. Such elements are *not* isoelectronic with a noble gas when the outermost (valence) electrons are lost and if enough energy is available, will begin to lose *d* level electrons.

Example 1: A neutral vanadium atom has an electron configuration of [Ar] 4s^2 3d^3. The outermost electrons are always lost first, therefore, vanadium will lose its 4s^2 electrons and form the vanadium(II) ion, V^{2+}. With additional energy, the V^{2+} cation can lose its 3d^3 electrons in order, forming vanadium(III), V^{3+}, vanadium(IV), V^{4+}, and vanadium(V), V^{5+} cations.

Example 2: The electron configuration for an atom of Fe is [Ar] 4s^2 3d^6. The first cation that forms when the 4s^2 electrons are lost is the iron(II) ion, Fe^{2+}. Additional energy will cause the iron(II) ion to lose one of its 3d electrons to form the iron(III) ion, Fe^{3+}. The remaining *d* electrons are all spinning in the same direction and the energy required to oxidize them is greater than normally encountered in an ordinary chemical reaction. The repulsive forces between the only two paired electrons in the 3d sublevel make the formation of the iron(III) ion relatively easy.

Example 3: The electronic configuration of a neutral lead atom is [Xe] 6s^2 4f^{14} 5d^{10} 6p^2. The two common oxidation numbers of lead are lead(II) when the two 6p^2 electrons are lost and lead(IV) when the two 6s^2 electrons are also oxidized. Tin behaves in a similar manner when it forms tin(II) and tin(IV) cations. Bismuth with an electron configuration of [Xe] 6s^2 4f^{14} 5d^{10} 6p^3, forms bismuth(III) and bismuth(V) ions.

Inner transition elements are sometimes called by such names as the lanthanides, actinides, rare earth elements, and the transuranium elements. All of these elements are quite rare, and many of them exist for only short periods of time. Reactions involving such elements are seldom encountered in a beginning chemistry course and there is little need to pursue this topic in any detail. Two inner transition elements worth mentioning are uranium (U^{3+}, U^{4+}, and U^{5+}) and cerium (Ce^{3+} and Ce^{4+}).

Both inner transition and transition elements are known for their variable oxidation numbers. The most common oxidation number for transition elements is 2+. The *d* sublevel in transition elements is responsible for the various oxidation numbers that result. Incomplete *d* sublevels are also responsible for the many colorful transition compounds that are known to exist. Complete *d* sublevels in cations of silver and zinc result in white compounds.

Summary of Cations with Variable Oxidation Numbers—Stock System

1+, 2+	copper(I), Cu^+; copper(II), Cu^{2+};
	mercury(I)*, Hg_2^{2+}; mercury(II), Hg^{2+}
	**Note: mercury(I) actually exists as a diatomic ion and is written as* Hg_2^{2+} *and not* Hg^+*.*
1+, 3+	gold(I), Au^+; gold(III), Au^{3+};
	indium(I), In^+; indium(III), In^{3+};
	thallium(I), Tl^+; thallium(III), Tl^{3+}
2+, 3+	chromium(II), Cr^{2+}; chromium(III), Cr^{3+};
	cobalt(II), Co^{2+}; cobalt(III), Co^{3+};
	iron(II), Fe^{2+}; iron(III), Fe^{3+};
	manganese(II), Mn^{2+}; manganese(III), Mn^{3+}
2+, 4+	lead(II), Pb^{2+}; lead(IV), Pb^{4+};
	platinum(II), Pt^{2+}; platinum(IV), Pt^{4+};
	tin(II), Sn^{2+}; tin(IV), Sn^{4+};
	zirconium(II), Zr^{2+}; zirconium(IV), Zr^{4+}
3+, 4+	cerium(III), Ce^{3+}; cerium(IV), Ce^{4+}
3+, 5+	antimony(III), Sb^{3+}; antimony(V), Sb^{5+};
	arsenic(III), As^{3+}; arsenic(V), As^{5+};
	bismuth(III), Bi^{3+}; bismuth(V), Bi^{5+};
	phosphorus(III), P^{3+}; phosphorus(V), P^{5+}
2+, 3+, 4+	iridium(II), Ir^{2+}; iridium(III), Ir^{3+}; iridium(IV), Ir^{4+};
	titanium(II), Ti^{2+}; titanium(III), Ti^{3+}; titanium(IV), Ti^{4+}
2+, 4+, 5+	tungsten(II), W^{2+}; tungsten(IV), W^{4+}; tungsten(V), W^{5+}
3+, 4+, 5+	uranium(III), U^{3+}; uranium(IV), U^{4+}; uranium(V), U^{5+}
2+, 3+, 4+, 5+	vanadium(II), V^{2+}; vanadium(III), V^{3+};
	vanadium(IV), V^{4+}; vanadium(V), V^{5+}

Note: When reading the name of an ion such as Pb^{2+}*, the ion is read in English as the "lead two ion."*

Special Metallic Cations

The following transition metal cations do not exhibit variable oxidation numbers and normally are written without Roman numerals:

cadmium, Cd^{2+} silver, Ag^{+} zinc, Zn^{2+}

Nickel, on the other hand, has variable oxidation numbers, and even though it almost always appears as the nickel(II) ion, Ni^{2+}, the Roman numeral must be written.

The ions of the representative elements gallium, germanium, and indium do not have variable oxidation numbers, but are written with Roman numerals:

gallium(III), Ga^{3+} germanium(IV), Ge^{4+} indium(III), In^{3+}

Polyatomic Ions

The term *polyatomic ion* is used to describe a group of atoms that behave as a single ion. The bonding within a polyatomic ion is covalent, but because there is always an excess or shortage of electrons when compared to the number of protons present, an ion results. A common polyatomic positive ion (cation) is the ammonium ion, NH_4^{+}. A common polyatomic negative ion (anion) is the sulfate ion, SO_4^{2-}. Polyatomic ions *must be memorized!* There is no simple way to learn these ions. Remember, polyatomic ions stay together as a group. The ammonium ion is always written as NH_4^{+} and *never* as $N^{3-} + 4H^{+}$ or H_4^{+} or H_4^{4+}. If two or more of the same polyatomic ion are needed within a compound in order to reach electrical neutrality, the polyatomic group is enclosed in parentheses. For example, ammonium sulfate is written as $(NH_4)_2SO_4$. The compound consists of two ammonium ions and one sulfate ion. The letters are read as "N, H, four taken twice, S, O, four."

Common Polyatomic Ions

Anions

1–

acetate, CH_3COO^-

amide, NH_2^-

azide, N_3^-

benzoate, $C_6H_5COO^-$

bromate, BrO_3^-

chlorate, ClO_3^-

chlorite, ClO_2^-

cyanate, OCN^-

cyanide, CN^-

dihydrogen phosphate, $H_2PO_4^-$

formate, $HCOO^-$

hydrogen carbonate, HCO_3^- (bicarbonate)

hydrogen sulfate, HSO_4^- (bisulfate)

hydrogen sulfide, HS^- (bisulfide or hydrosulfide)

hydroxide, OH^- (called hydroxyl when aqueous)

hypochlorite, ClO^-

iodate, IO_3^-

nitrate, NO_3^-

nitrite, NO_2^-

perchlorate, ClO_4^-

permanganate, MnO_4^-

thiocyanate, SCN^- (thiocyanato)

triiodide, I_3^-

vanadate, VO_3^-

2–

carbide, C_2^{2-} (saltlike)

carbonate, CO_3^{2-}

chromate, CrO_4^{2-}

dichromate, $Cr_2O_7^{2-}$

imide, NH^{2-}

manganate, MnO_4^{2-}

metasilicate, SiO_3^{2-}

monohydrogen phosphate, HPO_4^{2-}

oxalate, $C_2O_4^{2-}$

peroxide, O_2^{2-}

peroxydisulfate, $S_2O_8^{2-}$

phthalate, $C_8H_4O_4^{2-}$

polysulfide, S_x^{2-}

selenate, SeO_4^{2-}

sulfate, SO_4^{2-}

sulfite, SO_3^{2-}

tartrate, $C_4H_4O_6^{2-}$

tellurate, TeO_4^{2-}

tetraborate, $B_4O_7^{2-}$

thiosulfate, $S_2O_3^{2-}$

tungstate, WO_4^{2-}

zincate, ZnO_2^{2-}

3–

aluminate, AlO_3^{3-}

arsenate, AsO_4^{3-}

borate, BO_3^{3-}

citrate, $C_6H_5O_7^{3-}$

phosphate, PO_4^{3-}

4–

orthosilicate, SiO_4^{4-}

pyrophosphate, $P_2O_7^{4-}$

5–

tripolyphosphate, $P_3O_{10}^{5-}$

Cations

1+

ammonium, NH_4^+

hydronium, H_3O^+

Exercise 3–2: Name the following substances.

1. $FeSO_3$
2. $Cu(NO_3)_2$
3. Hg_2Cl_2
4. $AgBr$
5. $KClO_3$
6. $MgCO_3$
7. BaO_2
8. KO_2
9. SnO_2
10. $Pb(OH)_2$
11. $Ni_3(PO_4)_2$
12. $CuCH_3COO$
13. N_2O_4
14. Rb_3P
15. S_8
16. Fe_2O_3
17. $(NH_4)_2SO_3$
18. $Ca(MnO_4)_2$
19. PF_5
20. LiH
21. $Ti(HPO_4)_2$

Exercise 3–3: Write formulas for the following substances.

1. vanadium(V) oxide
2. dihydrogen monoxide
3. ammonium oxalate
4. polonium(VI) thiocyanate
5. tetraphosphorus decaoxide
6. zinc hydroxide
7. potassium cyanide
8. cesium tartrate
9. oxygen molecule
10. mercury(II) acetate
11. silver chromate
12. tin(II) carbonate
13. sodium hydrogen carbonate
14. manganese(VII) oxide
15. copper(II) dihydrogen phosphate
16. francium dichromate
17. calcium carbide
18. mercury(I) nitrate
19. cerium(IV) benzoate
20. potassium hydrogen phthalate

CHAPTER 4

Ternary Nomenclature: Acids and Salts

The halogens, with their variable oxidation numbers, allow for a great variety of compounds. The problem arises on how these compounds should be named. For example, chlorine is found with a different oxidation state in each of the following five compounds:

$HClO_4$ (Cl = 7+)
$HClO_3$ (Cl = 5+)
$HClO_2$ (Cl = 3+)
$HClO$ (Cl = 1+)
HCl (Cl = 1-)

A good way to learn ternary nomenclature is to start with a certain "home base" polyatomic ion. This is the polyatomic ion ending with the suffix *–ate* (see page 16). Remembering that salts are named by adding the name of the metallic ion (cation) to the nonmetallic polyatomic ion (anion), the following rules apply:

Number of Oxygen Atoms (Compared to Home Base)	Polyatomic Ion Name		Acid Name (H+ Combined with Polyatomic Ion)	
Plus One Oxygen Atom	ClO_4^-	*per*chlor*ate*	$HClO_4$	*per*chlor*ic* acid
Home Base	ClO_3^-	chlor*ate*	$HClO_3$	chlor*ic* acid
Minus One Oxygen Atom	ClO_2^-	chlor*ite*	$HClO_2$	chlor*ous* acid
Minus Two Oxygen Atoms	ClO^-	*hypo*chlor*ite*	$HClO$	*hypo*chlor*ous* acid
No Oxygen Atoms	Cl^-	chlor*ide*	HCl*	*hydro*chlor*ic* acid

*Water solutions of binary hydrides form acids. The root derived from the hydride is given the prefix *hydro-* and the suffix *-ic* and is followed by the word acid. The binary hydride HCl is called hydrogen chloride (hydrogen monochloride) gas, but is known as hydrochloric acid when it is aqueous.

Common Binary Acids

Formula	Name	Anion
HF(aq)	*hydro*fluor*ic* acid	F^-, fluor*ide* ion
HCl(aq)	*hydro*chlor*ic* acid	Cl^-, chlor*ide* ion
HBr(aq)	*hydro*brom*ic* acid	Br^-, brom*ide* ion
HI(aq)	*hydro*iod*ic* acid	I^-, iod*ide* ion
H_2S(aq)	*hydro*sulfur*ic* acid	S^{2-}, sulf*ide ion*

Many common acids contain only oxygen, hydrogen, and a nonmetallic ion or a polyatomic ion. Such acids are called ***oxyacids.*** The suffixes *-ous* and *-ic* give the oxidation state of the atom bonded to the oxygen and the hydrogen. The *-ous* suffix always indicates the lower oxidation state and *-ic* the higher.

Common Oxyacids

Formula	Name	Anion	
$HClO_4$	*per*chlor*ic* acid	ClO_4^-	*per*chlor*ate*
$HClO_3$	chlor*ic* acid	ClO_3^-	chlor*ate*
$HClO_2$	chlor*ous* acid	ClO_2^-	chlor*ite*
$HClO$	*hypo*chlor*ous* acid	ClO^-	*hypo*chlor*ite*
HNO_3	nitr*ic* acid	NO_3^-	nitr*ate*
HNO_2	nitr*ous* acid	NO_2^-	nitr*ite*
H_2SO_4	sulfur*ic* acid	SO_4^{2-}	sulf*ate*
H_2SO_3	sulfur*ous* acid	SO_3^{2-}	sulf*ite*
CH_3COOH or $HC_2H_3O_2$	acet*ic* acid	CH_3COO^- or $C_2H_3O_2^-$	acet*ate*
H_2CO_3	carbon*ic* acid	CO_3^{2-}	carbon*ate*
$H_2C_2O_4$	oxal*ic* acid	$C_2O_4^{2-}$	oxal*ate*
H_3PO_4	phosphor*ic* acid	PO_4^{3-}	phosph*ate*

Exercise 4–1: Name the following compounds.

1. HIO_3
2. $NaBrO_2$
3. $Ca_3(PO_4)_2$
4. HIO_4
5. $Fe(IO_2)_3$
6. $HAt(aq)$
7. C_6H_5COOH
8. $Hg_2(IO)_2$
9. H_3PO_3
10. NH_4BrO_3

Exercise 4–2: Write formulas for the following compounds.

1. tartaric acid
2. calcium hypochlorite
3. hydrotelluric acid
4. copper(II) nitrite
5. carbonic acid
6. hypoiodous acid
7. cyanic acid
8. phthalic acid
9. tin(IV) chromate

DO YOU KNOW YOUR ACIDS?

-IC FROM -ATE -OUS FROM -ITE HYDRO-, -IC, -IDE

Exercise 4–3: Complete the following table.

Name of Acid	Formula of Acid	Name of Anion
*hydro*chlor*ic* acid	HCl	chlor*ide*
sulfur*ic* acid	H_2SO_4	sulf*ate*
	HI	
		sulf*ite*
chlor*ous* acid		
		nitr*ate*
	$HC_2H_3O_2$ *or* CH_3COOH	
*hydro*brom*ic* acid		
		sulf*ide*
	HNO_2	
chrom*ic* acid		
		phosph*ate*

CHAPTER 5

Complex Ion Formulas and Nomenclature

(Coordination Chemistry)

Coordination compounds usually involve transition metal ions, which are typically colored and often paramagnetic. A neutral coordination compound normally consists of a *complex ion*—a transition metal ion with attached ligands—and *counter ions*, anions or cations needed to produce a neutral compound.

- Complex ion – Transition metal ion with attached ligands
- Counter ions – Anions or cations

Example:

$[Co(NH_3)_6]Cl_3$ $[Co(NH_3)_6]^{3+}$ is the complex ion consisting of the transition metal ion Co^{3+} and six attached NH_3 ligands, and the Cl^-'s are the counter ions.

Ligands are Lewis bases with lone pairs of electrons. These electrons can be donated to the empty *d* orbitals of a transition metal ion, which in turn can act as a Lewis acid. This sharing of electrons in which one partner does all of the donating is called a *coordinate covalent bond.*

Common ligands include: H_2O (aquo), NH_3 (ammine), Cl^- (chloro), CN^- (cyano), and OH^- (hydroxo).

Some ligands such as the carbonate ion, CO_3^{2-}, or ethylenediamine, $NH_2CH_2\ CH_2\ NH_2$ (frequently abbreviated *en*), can provide more than one pair of electrons to a Lewis acid.

The number of ligands which attach to a central metal ion is referred to as the *coordination number.* Two, four, and six are the most common coordination numbers. Often the number of ligands attached is two times the metal's oxidation number.

The colors of coordinate compounds are quite varied. Transition metals with completely filled *d* sub-levels tend to form white compounds, or colorless solutions.

Complex ions add ligands one at a time and have associated formation constants with associated formation equilibria. The greater the formation constant, the more stable the complex ion.

Naming Complex Ions

Complex cations, such as $Cr(H_2O)_6^{3+}$, are named by giving the number and name of the groups attached to the central metallic atom followed by the name of the central atom, with its oxidation number indicated by a Roman numeral in parentheses.

e.g., hexaaquochromium(III)

Complex anions, such as $PtCl_6^{2-}$, are named by giving the number and name of the groups attached to the central metallic atom followed by the name of the central atom, with an *-ate* ending and its oxidation number in parentheses.

e.g., hexachloroplatinate(IV)

IUPAC Rules for Naming Coordination Compounds

(Note: IUPAC stands for the International Union of Pure and Applied Chemistry)

1. The cation is always named before the anion, with a space between the names.
2. In naming a complex ion, the ligands are named before the metallic ion.
3. Ligands have special endings. Names of some common ligands are listed in the table below. Notice that an *-o* ending is used in place of any *-ide* ending for anions. For anions ending in *-ate*, the *-o* is substituted for the *-e*. For neutral ligands, the name of the molecule is used, with the exception of H_2O, NH_3, CO, and NO.

Names of Some Common Ligands

Anions

fluoro	F^-
chloro	Cl^-
bromo	Br^-
iodo	I^-
carbonato	CO_3^{2-}
cyano	CN^-
hydrido	H^-
hydroxo	OH^-
nitrato	NO_3^-
nitro	NO_2^-
oxalato	$C_2O_4^{2-}$ or *ox*
oxo	O^{2-}
sulfato	SO_4^{2-}
thiocyanato	SCN^-
thiosulfato	$S_2O_3^{2-}$

Neutral Molecules

aquo	H_2O
ammine*	NH_3
benzene	C_6H_6
carbonyl**	CO
ethylenediamine	$H_2NCH_2CH_2NH_2$ or *en*
methylamine	CH_3NH_2
dimethylamine	$(CH_3)_2NH$
nitrosyl	NO

*Note the spelling ammine (two m's) for neutral ammonia. An amine (one m) is a derivative of ammonia found in organic compounds.

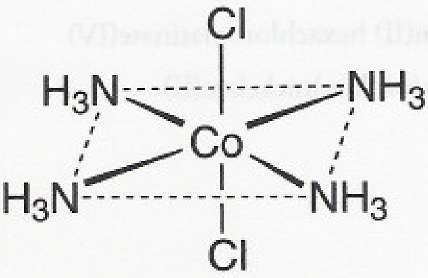
**Ligand is attached via the carbon atom.

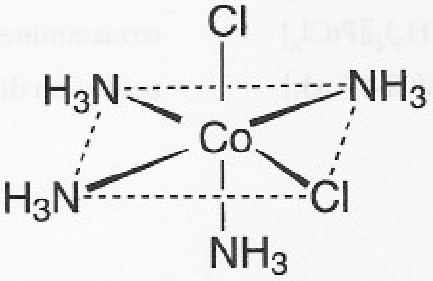
4. Ligands are named first, in alphabetical order, followed by the metal name. The Greek prefixes *di* = 2, *tri* = 3, *tetra* = 4, *penta* = 5, *hexa* = 6 and so on are used to denote the number of simple ligands present. *Mono* is omitted for 1. For more complicated ligands the prefixes *bis* (twice), *tris* (thrice), *tetrakis* (four times), *pentakis* (five times), and *hexakis* (six times) are used. *Note:* Prefixes do not affect the alphabetical order.
5. Many metals exhibit variable oxidation numbers. The oxidation number of the metal is designated by a Roman numeral in parentheses following the name of the complex ion or molecule. The Roman numeral is omitted if a metallic cation does not exhibit variable oxidation numbers. For example, silver is always 1+ in a compound or complex ion, so no Roman numeral is used.

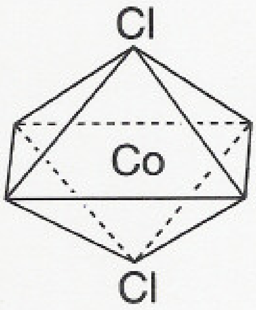
6. For anionic complex ions (those having negative charges), the suffix *-ate* is added to the name of the metal. The English name for the metal is used, except in the following cases where the Latin name is used to identify the metal (see table below). The suffix *-ate* indicates that the complex is an anion. Neutral and cationic complexes do not use suffixes.

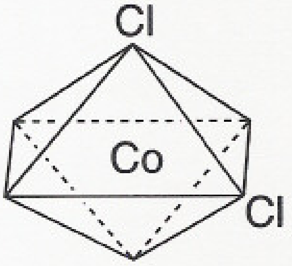
Latin Names for Some Metals Ions Found in Anionic Complex Ions	
copper	cuprate
gold	aurate
iron	ferrate
lead	plumbate
silver	argentate
tin	stannate

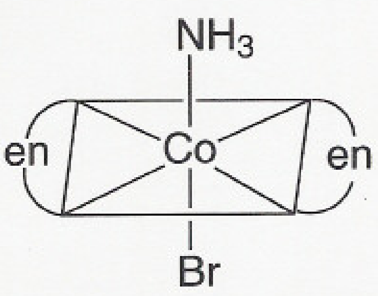
7. In the case of complex-ion isomerism, the names *cis* or *trans* may precede the formula of the complex-ion name to indicate the spatial arrangement of the ligands. *Cis* means the ligands occupy adjacent coordination positions; *trans* means opposite positions.

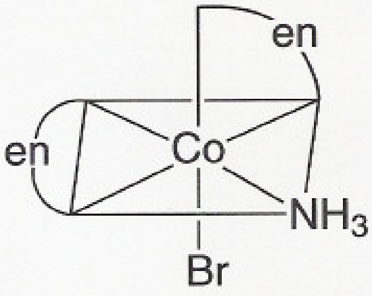












In the examples given above, the trans isomers appear on the left and their cis isomers on the right.

Examples:

$[Cr(H_2O)_4Cl_2]^+$	tetraaquodichlorochromium(III)
$[Cr(H_2O)_2Cl_4]^-$	diaquotetrachlorochromate(III)
$[Cr(NH_3)_5(H_2O)]^{3+}$	pentaammineaquochromium(III)
$[GaCl_3(OH)]^-$	trichlorohydroxogallate(III)
cis-$[PtBrCl(NO_2)_2]^{2-}$	*cis*-bromochlorodinitroplatinate(II)
trans-$[CoCl(en)_2\ (OH)]^+$	*trans*-chlorobis(ethylenediamine)hydroxocobalt(III)
$[Mn(C_6H_6)\ (CO)_3]^+$	benzenetricarbonylmanganese(I)
$[Ni(CO)_4]$	tetracarbonylnickel(0)
$[Zn(NH_3)_4]Cl_2$	tetraamminezinc chloride (The oxidation state of Zn is not given because it is always 2+ in compounds.)
$K_2[CoCl_4]$	potassium tetrachlorocobaltate(II)
$Na[Al(OH)_4]$	sodium tetrahydroxoaluminate (The oxidation state of Al is not given because it is always 3+ in compounds.)
$[Pt(NH_3)_4][PtCl_6]$	tetraammineplatinum(II) hexachloroplatinate(IV)
$K_4[Ni(CN)_2(ox)_2]$	potassium dicyanobis(oxalato)nickelate(II)

Note that complex ions are always enclosed in brackets [ ]. The names of complicated ligands are enclosed in parentheses. e.g., ethylenediamine, oxalato, methylamine, dimethylamine, carbonato, sulfato, thiosulfato, nitrato.

Charges within a complex ion are fairly easy to obtain. For example, in the compound $Na[Al(OH)_4]$, we know the sodium ion must be 1+ and, therefore, the tetrahydroxoaluminate complex ion must be 1–. The 1– results because the Al is 3+ and the hydroxide is 4 times 1–; (3+) + (4–) equals 1–. In the compound $[Cr(H_2O)_4Cl_2]Cl$ we know the charge of the chloride ion is 1–. Therefore, the complex ion tetraaquodichlorochromium(III) must have a total charge of 1+. The charge on four water molecules is zero (a neutral compound), and the two chloride ions equal 2 times 1– or 2–. The charge on the chromium must be 3+ because [3+ plus 4(0) plus 2(1–)] = 1+, the charge of the complex cation.

Example:
Given the compound $[Cu(NH_3)_4](NO_3)_2$, determine the charge on the copper ion and name the compound according to the IUPAC system.

Solution:
The charge on the nitrate ion is 1– and 2 times 1– = 2–. NH_3 is a neutral compound (ammonia); therefore, 4 times 0 = 0. Since the compound must be neutral overall, $x + 4(0) + 2(1-) = 0; x = 2+$. Cu must be 2+. The IUPAC name of $[Cu(NH_3)_4](NO_3)_2$ is tetraamminecopper(II) nitrate!

Exercise 5–1: Name the following.

1. $[Ag(NH_3)_2]Cl$
2. $(NH_4)_3\,[Fe(SCN)_6]$
3. $Na_2\,[Ni(CN)_4]$
4. $[Fe(ox)_3]^{3-}$
5. $[Co(NH_3)_6]\,Br_2$
6. $[Cr(H_2O)_4Cl_2]\,Cl$
7. $[Pt(NH_3)_2]Cl_2$
8. $K_2\,[Cu(CN)_4]$
9. $[Cr(H_2O)_6]\,(NO_3)_3$
10. $[Co(en)_3]\,Br_3$

Exercise 5–2: Write formulas for the following.

1. potassium hexacyanoferrate(III)
2. sodium hexafluoroaluminate
3. diamminesilver ion
4. tetraamminezinc nitrate
5. sodium tetrahydroxochromate(III)
6. trans-dichlorobis(ethylenediamine)cobalt(III) chloride
7. hexaammineruthenium(III) tetrachloronickelate(II)
8. tetraamminecopper(II) pentacyanohydroxoferrate(III)
9. sodium tetracyanocadmate
10. diamminezinc iodide

CHAPTER 6

Organic Nomenclature and Simple Reactions

Organic chemistry involves the chemistry of compounds containing carbon. Because of carbon's unique ability to bond with itself in a large variety of ways, the field of organic chemistry involves over six million compounds. Not only are organic compounds a vital constituent of all living things but they also contribute to the wide variety of materials we use in our modern lifestyles. Plastics we recycle, gasoline that we burn, and synthetic materials that we wear are all organic. In addition to carbon, organic compounds contain other elements as well, most commonly hydrogen, oxygen, nitrogen, sulfur, phosphorus and the halogens.

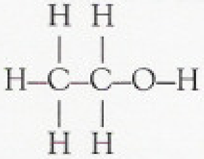
The properties of organic compounds differ from those of inorganic compounds most notably in their relatively low melting points (generally under 300 °C), low boiling points, solubility in other organic solvents rather than water, and poor electrical conductivity. Organic reactions often have slow reaction rates and provide low yields of product due to the tendency for many side reactions to occur.

References to organic compounds may be made either by name or by formula. Because of the variations in structures, three different types of formulas are commonly used. The definition and an example of each type of formula is given below, using ethanol (ethyl alcohol) as the example compound.

Molecular formulas indicate the type and number of each atom in the compound, yet give no information about the bonds or the structure of the compound.

C_2H_5OH

Structural formulas indicate the complete two-dimensional structure of the compound, showing all of the bonds present.



$$\begin{array}{ccccccccc} & & H & & H & & & & \\ & & | & & | & & & & \\ H & - & C & - & C & - & O & - & H \\ & & | & & | & & & & \\ & & H & & H & & & & \end{array}$$

Condensed structural formulas are short-hand representations that leave the bond lines out, yet still indicate what is bonded to each carbon or other atom.

CH_3CH_2OH

Hydrocarbons

A large number of organic compounds fall into a category known as the hydrocarbons. As the name implies, these compounds consist of only carbon and hydrogen but even those two elements can produce a wide variety of compounds. Hydrocarbons can also be subdivided into two groups—open or acyclic hydrocarbons, and closed or cyclic (ring) hydrocarbons.

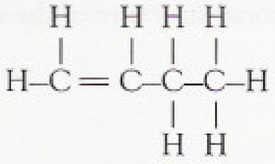
The acyclic hydrocarbons consist of chains of carbon atoms with hydrogen attached to the outsides of the chain. Since the chain of carbons can be covalently bonded with either single, double or triple pairs of shared electrons, three groups of acyclic hydrocarbons emerge—alkanes, alkenes, and alkynes.

Alkanes are hydrocarbons in which there are only single covalent bonds between the carbon atoms. The general formula for alkanes is C_nH_{2n+2}, where *n* is the number of carbon atoms in the chain. Because carbon exhibits only single bonds and it has four effective electron pairs, it displays sp^3 hybridization in all alkanes. The length of the carbon chain tends to affect physical properties such as boiling point and melting point due to the variation in strength of the dispersion forces. Naming alkanes is straightforward—simply use the prefix stem listed in the box below to indicate the number of carbons in the chain and add the suffix *–ane* to the end. Thus an alkane containing six carbons is named hexane, while one containing three carbons is named propane.

Prefix Stems for Organic Compound Names

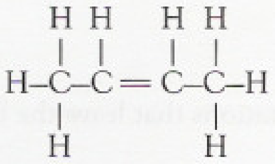
1 meth-	6 hex-
2 eth-	7 hept-
3 prop-	8 oct-
4 but-	9 non-
5 pent-	10 dec-

Alkenes are hydrocarbons in which there is at least one double covalent bond between the carbon atoms. The general formula for alkenes is C_nH_{2n}, where *n* is the number of carbon atoms in the chain. Because carbon exhibits one double bond and two single bonds (in a typical alkene), it has three effective electron pairs and displays sp^2 hybridization. To name alkenes, indicate where the double bond occurs by numbering the carbon chain starting with the end closest to the double bond. Then use the prefix stem to indicate the number of carbons in the chain and add the suffix *–ene* to the end. For example,



$\mathrm{H{-}\overset{H}{C}{=}\overset{H}{C}{-}\underset{H}{\overset{H}{C}}{-}\underset{H}{\overset{H}{C}}{-}H}$

is named 1-butene



$\mathrm{H{-}\underset{H}{\overset{H}{C}}{-}\overset{H}{C}{=}\overset{H}{C}{-}\underset{H}{\overset{H}{C}}{-}H}$

is named 2-butene

For chains that contain two double bonds, list the location of the two double bonds and use the suffix *–diene* at the end. Draw the structural formula for 1,3-butadiene.

Alkynes are hydrocarbons in which there is at least one triple covalent bond between the carbon atoms. The general formula for alkynes is C_nH_{2n-2}, where *n* is the number of carbon atoms in the chain. Because carbon exhibits one triple bond and one single bond in alkynes, it has two effective electron pairs and displays sp hybridization. To name alkynes, indicate where the triple bond occurs by numbering the carbon chain starting with the end closest to the triple bond. Then use the prefix stem to indicate the number of carbons in the chain and add the suffix *–yne* to the end.

The most common cyclic organic compounds are the ones that are derivatives of benzene, C_6H_6. This six-member carbon ring has three alternating double bonds and can be found with many different components attached to it, including other benzene rings. Other cyclic hydrocarbons include cyclobutane and cyclopentane.

Naming Branched Hydrocarbons

Thus far, the naming of different types of straight chain hydrocarbons have been considered. Hydrocarbons can also be formed by attaching hydrocarbon groups onto a hydrocarbon chain. These are generally referred to as branched hydrocarbons. General rules for naming these compounds are as follows:

- For *alkanes,* locate the longest continuous chain of carbon atoms and count the number of atoms–this chain determines the prefix stem name for the compound. For *alkenes and alkynes,* locate the carbon atoms in the longest carbon chain that contains the multiple bond–this will give the prefix stem name for the compound.
- Look for any groups other than hydrogen that may appear in the molecule. These are called substituent groups. There will be a special prefix for each such substituent group. For example:

Substituent Group		Prefix
$-CH_3$	1-carbon group	methyl
$-CH_2CH_3$	2-carbon group	ethyl
$-CH_2CH_2CH_3$	3-carbon group	propyl
–Cl	chlorine atom	chloro
–Br	bromine atom	bromo

Note: Take the time to memorize the first 10 prefixes–it will help in naming thousands of compounds.

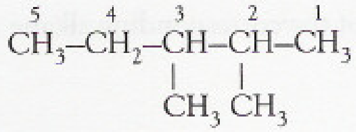
- If more than one substituent group of any kind is present, use Greek prefixes to indicate the number. For example, use:

di-	for 2
tri-	for 3
tetra-	for 4

- Number the longest continuous carbon chain beginning with the end of the chain nearest the substituent. Use the numbers to designate the location of the substituent group(s). If there are more than two substituent groups of the same kind, give each group a number.
- For *alkanes,* always count from the end of the chain that will give the lowest possible combination of numbers. In other words, start counting from the end closest to the substituent group. For *alkenes and alkynes,* always count from the end of the chain that the multiple bond is closer to; disregard the branch chain rule used for alkanes.
- Use hyphens to separate numbers from names, and commas to separate numbers from each other. Substituent groups should be listed alphabetically, disregarding the Greek prefixes.

Example 1:

$CH_3\ CH_2\ CH\ (CH_3)\ CH\ (CH_3)\ CH_3$ *Condensed Formula*



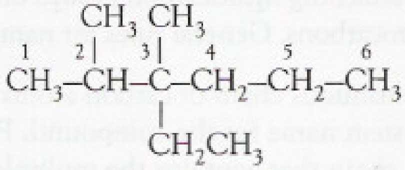
$$\overset{5}{CH_3}-\overset{4}{CH_2}-\underset{\displaystyle CH_3}{\overset{3}{CH}}-\underset{\displaystyle CH_3}{\overset{2}{CH}}-\overset{1}{CH_3}$$

Structural Formula

Name: 2,3-dimethylpentane

Example 2:

$\mathrm{CH_3\,CH\,(CH_3)\,C\,(CH_3)\,(CH_2CH_3)\,CH_2\,CH_2\,CH_3}$ *Condensed Formula*



$$\mathrm{\overset{1}{CH_3}-\overset{CH_3}{\overset{2|}{CH}}-\overset{CH_3}{\overset{3|}{\underset{\underset{CH_2CH_3}{|}}{C}}}-\overset{4}{CH_2}-\overset{5}{CH_2}-\overset{6}{CH_3}}$$

Structural Formula

Name: 3-ethyl-2,3-dimethylhexane

Other Organic Functional Groups

Many remaining organic compounds can be divided into groups based on their unique structure. They include variations with oxygen and nitrogen and the means by which they bond to carbon and hydrogen. Each group has recognizable structural characteristics and names which are an extension of the general hydrocarbon naming rules.

Note: R = a general symbol to represent any carbon chain; and
Systematic name = the official IUPAC name of the compound.

A. *Alcohols* R-OH

1. Can be oxidized to aldehydes, carboxylic acids or ketones.
2. Systematic name:
    - indicate the number of the carbon to which the –OH group is attached
    - drop the "e" from the name of the corresponding alkene, and add the suffix *-ol*

B. *Ethers* R–O–R′

1. Relatively unreactive compounds
2. Systematic name:
    - use the root for R, add the suffix *-oxy* followed by the corresponding alkane for R′

C. *Carboxylic Acids* R-COOH

1. Formed from the oxidation of primary alcohols (–OH on the end carbon)
2. Tend to be polar and to form hydrogen bonds
3. Systematic name:
    - drop the "e" from the name of the corresponding alkane and add the suffix *-oic* followed by the word *acid*

D. *Esters* R–COO–R′

1. Derived from an acid and an alcohol
2. Low molecular mass esters tend to have fruity odors
3. Systematic name:
   - name the alcohol part of the compound (the group to the right of the **COO**) with its *-yl* ending
   - name the acid part of the compound (the group to the left of the **COO** and including the carbon in **COO**) with an *-oate* ending

E. *Aldehydes* R–**CHO**

1. Derived from the oxidation of a primary alcohol
2. Can be oxidized to a carboxylic acid
3. Systematic name:
   - take the parent alkane name, drop the “e” and add the suffix *-al*

F. *Ketones* R–CO–R′

1. Derived from the oxidation of a secondary alcohol
2. Systematic name:
   - consider the total number of carbons—take the parent alkane name, drop the “e” and add the suffix *-one*

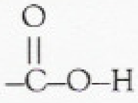
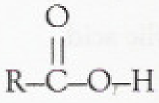
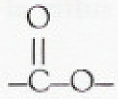
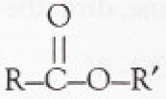
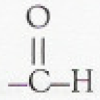
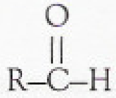
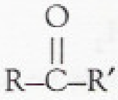
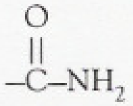
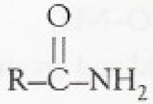
G. *Amines* R–NH_2

1. Are weakly basic compounds (may be considered to be derivatives of ammonia)
2. Tend to have offensive odors (think of decaying fish)
3. Systematic name:
   - name the R group and add the word *amine*

H. *Amides* R–CO–NH_2

1. Derived from a carboxylic acid and an amine
2. Significant in synthetic polymers and proteins
3. Systematic name:
   - consider the total number of carbons—take the parent alkane name, drop the “e”, add the suffix *-yl*, and add the word *amide*.

Organic Functional Groups

Category	Functional Group	General Formula	Example
Alcohols	-OH	R-OH	CH_3OH methanol
Ethers	-O-	R-O-R′	CH_3OCH_3 methoxymethane
Carboxylic acids	 $-\overset{O}{\overset{\|}{C}}-O-H$	 $R-\overset{O}{\overset{\|}{C}}-O-H$	CH_3COOH ethanoic acid
Esters	 $-\overset{O}{\overset{\|}{C}}-O-$	 $R-\overset{O}{\overset{\|}{C}}-O-R'$	CH_3COOCH_3 methylethanoate
Aldehydes	 $-\overset{O}{\overset{\|}{C}}-H$	 $R-\overset{O}{\overset{\|}{C}}-H$	CH_3CHO ethanal
Ketones	 $-\overset{O}{\overset{\|}{C}}-$	 $R-\overset{O}{\overset{\|}{C}}-R'$	$CH_3CH_2COCH_3$ 2-butanone
Amine	$-NH_2$	$R-NH_2$	CH_3NH_2 methylamine
Amide	 $-\overset{O}{\overset{\|}{C}}-NH_2$	 $R-\overset{O}{\overset{\|}{C}}-NH_2$	$CH_3\ CH_2\ CONH_2$ propylamide

Exercise 6–1: Using condensed formulas provided, name the following hydrocarbon compounds. It may be helpful to draw the structural formula first.

1. $CH_3CH_2CH_2CH(CH_3)CH_3$
2. $CH_3CH(C_2H_5)CH_2CH_3$
3. $CH_3CH_2CHClCH_2CH_2CH_2CH_2Cl$
4. $CH_3CH_2CH_2CH_2OH$
5. $CH_3CH_2CH_2CH_2COOH$
6. $CH_2{=}C(CH_3)CH_2CH(CH_3)CH_3$
7. $(CH_3)_2CHCl$
8. $CH_3C(CH_3)_2CH_2C(CH_3)_2CH_2CH_2CH_3$
9. $CH_3C(CH_3)_2CH{=}C(CH_3)CH_2CH_3$
10. $CH_3C{\equiv}CCH_3$

Exercise 6-2: Draw the condensed formula for each of the following compounds.

1. 2,3 - dimethyl - 2 - butene
2. 4 - ethyl - 2 - hexyne
3. 3,3,6 - trimethylnonane
4. 3 - ethyl - 4 - propylheptane
5. 3 - octanol
6. 2 - methyl - 2 - pentene
7. 5 - methyl - 1 - hexene
8. 2,2,4,5 - tetramethylhexane
9. propanoic acid
10. 2 - pentyne

ROUND 1

Simple Organic Reactions

Although organic compounds can undergo a great many reactions, some of the most common types of reactions include addition, substitution, combustion and esterification.

Addition reactions generally occur when halogens (halogenation) or hydrogens (hydrogenation) are added to alkenes or alkynes. The net effect is that the double or triple bond is eliminated and the product contains singly-bonded components. This process takes an unsaturated compound and causes it to become saturated. For example,

Bromine added to ethene forms 1,2-dibromoethane

$$Br_2 + CH_2{=}CH_2 \longrightarrow CH_2Br{-}CH_2Br$$

Hydrogen added to ethene (with high temperature & catalyst) forms ethane.

$$H_2 + CH_2{=}CH_2 \longrightarrow CH_3{-}CH_3$$

Chlorine added to ethyne forms 1,2-dichloroethene. Excess chlorine will result in 1,1,2,2-tetrachloroethane.

$$Cl_2 + CH{\equiv}CH \longrightarrow CHCl{=}CHCl + Cl_2 \longrightarrow CHCl_2{-}CHCl_2$$

Substitution reactions occur when an atom attached to a carbon is removed and something else takes its place. No change in bonding occurs. A common substitution is when a halogen is added to a saturated (only single covalent bonds present) hydrocarbon compound. For example,

Chlorine added to methane forms chloromethane. Often this compound as well as some dichloromethane, trichloromethane and tetrachloromethane will be formed.

$$Cl_2 + CH_4 \longrightarrow CH_3Cl + HCl$$

Combustion reactions involve the oxidation of an organic compound. Incomplete combustion products are carbon/carbon monoxide and water. The more commonly seen, complete combustion products include carbon dioxide and water.

Ethane burns in oxygen.

$$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$$

Ethanol is burned in oxygen gas.

$$C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O$$

Esterification reactions occur when a carboxylic acid is combined with an alcohol. The products which form are an ester and water. The reactions are usually aided by the addition of a small amount of an inorganic acid such as sulfuric acid is added to act as a dehydrating agent. In essence the hydroxyl group from the alcohol and the acidic hydrogen from the carboxylic acid are removed to form water. The ester group bonds to the alcohol's remaining carbon chain. For example, ethanoic acid (acetic acid) when combined with methanol (methyl alcohol) will form methoxyethane (methyl acetate) and water.

$$CH_3COOH + CH_3OH \longrightarrow CH_3COOCH_3 + \mathbf{HOH}$$

Ethanoic (acetic) acid is reacted with 1-octanol in the presence of sulfuric acid.

$$CH_3COOH + C_8H_{17}OH \longrightarrow CH_3COO\ C_8H_{17} + \mathbf{HOH}$$

Exercise 6–3: Predict and balance the following organic reactions.

1. Ethanol (ethyl alcohol) is burned completely in air.

2. Propane gas is heated with chlorine gas.

3. Ethanol (ethyl alcohol) and methanoic acid (formic acid) are mixed and warmed.

4. Ethene gas is bubbled through a solution of bromine.

5. Hydrogen gas is added to 2 - pentene.

6. Octane is burned in oxygen.

7. 2 - butene is combined with hydrogen gas in the presence of a nickel catalyst.

8. Ethanoic acid is combined with propanol.

9. An excess of chlorine gas is added to pure ethyne (acetylene) gas.

10. A limited amount of liquid bromine is added to an excess of benzene (C_6H_6).