AP Chemistry Course Syllabus

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Goals of the high school science program include helping students develop as observers and problem-solvers who are equipped to cope in an increasingly complex scientific world. Each student will be actively engaged in thinking processes which include: observation, inquiry, communication, comparison, organization, relationships, inferences, and application.

Goals of AP Chemistry:

- help students to develop their capacity to reason
- instill in students an appreciation of the contributions and importance of chemistry in the modern world
- improve in students their problem solving skills and the ability to think critically, both as an individual and as a member of a team
- develop students' skills in computing quantitative and qualitative relationships
- provide students with a sound base from which they can pursue further course work in science.

Advanced Placement Chemistry is a challenging, fast-paced course that will cover the topics of matter, states of matter, chemical reactions, descriptive chemistry, kinetics, equilibria, and thermodynamics. An emphasis on laboratory work and analysis is required to prepare for the AP test. College credit depends upon the AP test score and the college of choice. Students will need to complete additional study outside of class to prepare for the National College Board AP test.

Course Outline

1. Introduction - Chapters 1 and 2 (Brown, LeMay, and Bursten)
    a. Matter and Measurement
    b. Units of Measurement
    c. Atoms, Molecules, and Ions
    d. Atomic Theory of Matter
    e. Naming Inorganic Compounds

2. Stoichiometry – Chapters 3 and 4 (Brown, LeMay, and Bursten)
    a. Dimensional Analysis
    b. Formula Weights
    c. The Mole
    d. Empirical Formulas
    e. Concentrations of Solutions
    f. Limiting Reactants
    g. Titrations, Dilutions
    h. Extracting Quantitative Information from Word Problems

3. Reactions– Chapter 4 (Brown, LeMay, and Bursten) and <u>The Ultimate Chemical Equations Handbook</u>, (Hague and Smith)
    a. Solubility Rules
    b. Synthesis Reactions
    c. Decomposition Reactions
    d. Single Replacement Reactions
    e. Double Replacement Reactions
    f. Ionic Equations

    g. Net Ionic Equations

4. Thermodynamics – Chapters 5 and 19 (Brown, LeMay, and Bursten)
    a. Laws of Thermodynamics
    b. Calorimetry
    c. Hess's Law
    d. Enthalpy
    e. Entropy
    f. Gibbs Free Energy

5. Structure and Periodicity of Atoms – Chapters 6 and 7 (Brown, LeMay, and Bursten)
    a. Quantum Mechanics and Orbitals
    b. Orbitals and Energies
    c. Electron Configurations
    d. Effective Nuclear Charge
    e. Atomic Radii
    f. Ionization Energy
    g. Electron Affinity
    h. Group Trends

6. Chemical Bonding – Chapters 8 and 9 (Brown, LeMay, and Bursten)
    a. Lewis Structures and the Octet Rule
    b. Ionic vs. Covalent Bonding
    c. Polarity and Electronegativity
    d. Resonance Structures
    e. Molecular Geometries
    f. Hybridization
    g. Multiple Bonds

7. Gases – Chapter 10 (Brown, LeMay, and Bursten)
    a. Pressure
    b. Kinetic-Molecular Theory
    c. The Gas Laws
    d. The Ideal Gas Equation and Deviations
    e. Molar Mass and Density
    f. Partial Pressure
    g. Effusion and Diffusion

8. Phases of Matter, Solutions, and Their Properties – Chapters 11 and 12 (Brown, LeMay, and Bursten)
    a. Intermolecular Forces
    b. Viscosity and Surface Tension
    c. Vapor Pressure
    d. Changes of State and Phase Diagrams
    e. Structures of Solids
    f. Bonding in Solids
    g. The Solution Process
    h. Solubility
    i. Colligative Properties

9. Kinetics and Equilibrium – Chapters 14 and 15 (Brown, LeMay, and Bursten)
    a. Reaction Rates and Influences Upon Them
    b. Reaction Mechanisms

   - c. Catalysis
   - d. Equilibrium Constants
   - e. Le Chatelier's Principle

10. Acid-Base Equilibria – Chapters16 and 17 (Brown, LeMay, and Bursten)
    - a. Bronsted-Lowry Acids and Bases
    - b. pH
    - c. Strong/Weak vs. Concentrated/Dilute
    - d. Acid and Base Dissociation Constants
    - e. Lewis Acids and Bases
    - f. Titrations
    - g. Buffers
    - h. Solubility Equilibria

11. Electrochemistry – Chapter 20 (Brown, LeMay, and Bursten)
    - a. Redox Reactions
    - b. Voltaic Cells
    - c. Cell EMF
    - d. Electrolysis
    - e. Corrosion

12. Nuclear Chemistry – Chapter 21 (Brown, LeMay, and Bursten)
    - a. Radioactivity
    - b. Nuclear Stability Patterns
    - c. Transmutations
    - d. Decay
    - e. Detection
    - f. Fission
    - g. Fusion
    - h. Biological Effects

13. Organic Chemistry – Chapter 25 (Brown, LeMay, and Bursten)
    - a. General Characteristics
    - b. Nomenclature/Functional Groups
    - c. Combustion Reactions
    - d. Addition Reactions
    - e. Isomers
    - f. Aromatic Hydrocarbons
    - g. Chirality

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Assessments

Students' work is evaluated based on their performance on homework, quizzes, tests, written lab reports. Grading is done by dividing the student's point total by the total possible points.

AP Chemistry Summer Assignment List: **NAME:**

Text: CHEMISTRY The Central Science: Brown|LeMay|Bursten
13th Edition
ISBN-13: 978-0321910417

(buy used $76.69 or rent $16.52)

Read Chapter 1—Booklet

Read Chapter 2—Booklet

Read Chapter 3—Booklet

Pocket File (You need a Staples Reinforced Expanding File, Letter size, 13-Pocket)

LABELLED

Section 1- Chapter 1,2,3
Section 2- Redox Chapter 20.1-20.2 / Atomic Structure
Section 3- Aq Rxs and Solution Chem Chapter 4
Section 4- Bonding & Geometry & Forces Chapter 8 & 9 & 11
Section 5- Gases -Chapter 10
Section 6- Thermochemistry -Chapter 5 & Chapter 19
Section 7- Kinetics-Chapter 14
Section 8- Chemical Equilibrium –Chapter 15
Section 9- Equilibrium –Chapter 16
Section 10-Acids & Bases -Chapter 17
Section 11- Electrochemistry -Chapter 20
Section 12- Nuclear/Organic Chapter 21,22,24
Section 13-Reactions & Practice AP Exams

NS A1 *summer* How to “Read” Your Science Textbook

When you have been assigned an entire chapter to read, you can go about it however you want. You can start with the table of contents, the pictures, the text, the chapter summary, the worked examples, whatever you like. You are simply responsible for using the textbook to understand its contents and be able to solve the problems on your homework. Inevitably, most of you start on the first page, read to the last page, fail to remember much of anything, and find yourselves unable to do much of the homework. The reason your chosen method fails is because you don't have any framework in your minds for the content of the chapter. It doesn't stick in your mind because you have no place in your mind to put it.

So here is a suggestion on how to read a chapter from a textbook:

A. Write down the headings (create the framework), leaving about 1/4 page blank after each one. Be sure to include page numbers--after all, you still have your book to refer to.

B. Look at the pictures, graphs, worked examples, etc. Get a sense of what they're about, but don't write anything down.

C. Look over the assigned problems. Don't try to solve them; just get a sense of what they're about.

D. Read the text, writing down key information. Only write down what will fit in each 1/4 page that you left. (Remember, you have page numbers written down if you need to go back later for more detail.)

E. Read the chapter summary. If there's anything you don't recognize, go back, read that section again, and add it to your notes. When you do this, most of you will be amazed at how much you can learn from a textbook. WHile it will take a bit longer than the usual read-through method, in the end it will be less time spent, because you are much more likely to “get it” when you are done.

F. Then circle back and really work any assigned problems

Trust me and try it.

AP Chemistry 2020-2021 Summer Review

Welcome to AP Chemistry. Summer review work is meant to get us off to a running start when fall arrives. You should already know most of the material in this packet from your first year chemistry class. Nonetheless, START NOW to make your way leisurely through this review. Do not think you should wait until the very end of the summer so it is "fresh in your mind." The LONGER it is in your mind, the better it will stick. Email me with any questions or concerns. I will try to respond ASAP. Be prepared for an exam on this material the first week of school.

Nomenclature

You will be more successful in AP chemistry if you can name chemicals from their formulas, and if you can write chemical formulas from the name of the chemical. You don't need to know all polyatomic ions – just a short list will be helpful. You should be able to do this with only the assistance of a periodic table, after *memorizing* the polyatomic ions in the charts below.

Polyatomic Ions -

Memorize the shaded ions (and learn the pattern so you can easily memorize their companions)

By learning the four shaded "-ate" ions in the table to the right, **and** knowing that one less oxygen (same charge) turns the name to –*ite*, **and** two less oxygens (when possible) turns the name to *hypo*–xxx–ite **and** one more oxygen (when possible) turns the name to *per*–xxx–ate will make learning all eighteen ions in the chart below as easy as learning just four.

Polyatomic Ions to Memorize *(Use the pattern to help)*

hypo- (2 less O)	**-ite (1 less O)**	**-ate**	**per- (1 more O)**
	nitrite NO_2^-	nitrate NO_3^-	
	sulfite SO_3^{2-}	sulfate SO_4^{2-}	
	phosphite PO_3^{3-}	phosphate PO_4^{3-}	
hypochlorite ClO^-	chlorite ClO_2^-	chlorate ClO_3^-	perchlorate ClO_4^-
hypobromite BrO^-	bromite BrO_2^-	bromate BrO_3^-	perbromate BrO_4^-
hypoiodite IO^-	iodite IO_2^-	iodate IO_3^-	periodate IO_4^-

Memorize the six extra polyatomic ions in the second table below, and don't forget ammonium in the table by itself.

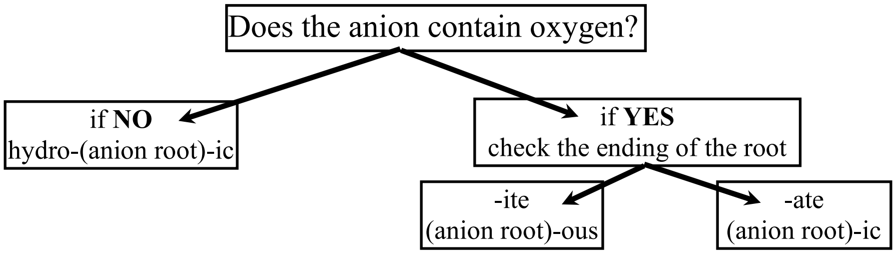
Odd Companions or No Companion

hydroxide OH^-	
cyanide CN^-	
acetate $C_2H_3O_2^-$	
carbonate CO_3^{2-}	bicarbonate HCO_3^-
permanganate MnO_4^- *purple color*	

and don't forget
ammonium NH_4^+

Acids and Bases

You will need to be able to name acids. Knowing your polyatomic ions is critical in naming the acids. Use the chart below to review the pattern and method of naming.



HF	hydrofluoric
HCl	hydrochloric

You should memorize the seven strong acids in the table. The strong bases are group I and group II metal hydroxides. Hopefully you are aware that to be a strong acid or strong base means that when dissolved in water, the molecules are fully ionized. This means that the compound will dissociate completely into ions when in solution. This is important to recognize when writing net ion ionic equations.

Seven Strong Acids

memorize them

(assume all other acids are weak)

HCl	hydrochloric acid
HBr	hydrobromic acid
HI	hydroiodic acid
HNO_3	nitric acid
H_2SO_4	sulfuric acid

Strong Bases

memorize them ***(Group I and II hydroxides)***

LiOH	lithium hydroxide	*Be & Mg hydroxides are not very*	
NaOH	sodium hydroxide	*useful, since they are not soluble*	
KOH	potassium hydroxide	$Ca(OH)_2$	calcium hydroxide
RbOH	rubidium hydroxide	$Sr(OH)_2$	strontium hydroxide

On multiple choice section of the AP exam, calculator use is NOT allowed. For many questions, this is a moot point because the question may only involves words, but for other questions, your ability to multiply and factor numbers will be very he

No kidding…..
Practice your multiplication tables.
Go to www.tablestest.com
or www.timestables.me.uk/
or some other multiplication &
division practice site.

This packet should be review. *If you find yourself struggling with any of the topics in the following practices, please email me and let me know where your struggles are, so that I can guide you to more review and practice.*
These topics are review, *and you need to know your stuff so that we can hit the gound running in August.*

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (97)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **†Ac** (227)	104 **Rf** (267)	105 **Db** (270)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (282)	112 **Cn** (285)	113 **Uut** (285)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (293)	117 **Uus** (294)	118 **Uuo** (294)

*Lanthanoid Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
†Actinoid Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Summer Review: Nomenclature problems

Given the names-write the formulas:

1. sodium sulfite
2. copper(II) nitrate
3. hydrochloric acid
4. sodium hydroxide
5. acetic acid
6. aluminum perchorate
7. silver sulfide
8. carbonic acid
9. ammonium phosphate
10. potassium permanganate
11. lead(II) cyanide
12. calcium acetate
13. nitrous acid
14. hydroiodic acid
15. sodium bicarbonate
16. nickel(III) iodate
17. chloric acid
18. aluminum sulfite
19. phosphorous acid
20. barium hydroxide

Given the formulas-write the names:

21. $Sr(CN)_2$
22. H_3PO_4
23. $ZnSO_4$
24. $Cu(SO_3)_2$
25. H_2SO_4
26. $AuOH$
27. K_2CO_3
28. $NaHCO_3$
29. $HClO_2$
30. $AgNO_2$
31. $HBrO$
32. KOH
33. $HC_2H_3O_2$
34. $Ni(BrO_2)_3$
35. HBr
36. $NaMnO_4$
37. $HBrO_2$
38. H_3PO_4
39. $(NH_4)_2SO_4$

Balanced chemical equations, written to represent chemical reactions, are an important part of chemistry.

You do *not* need to write down physical state symbols (aq, s, ppt, L, g ... etc). In fact, it's probably best if you leave them off.

The best way to prepare for writing equations is to practice writing *lots* of equations. Many of the same equation types show up year after year on the AP Exam. When you are reading the words given in a problem, and trying to write an equation, it may be helpful to try to identify the equation as a particular type in order to help you predict the products.

Sometimes you may write overall equations in which all complete chemical formulas are shown. More often, however, equations in AP Chemistry need to be written in **net ionic** form. Net ionic is a term used for balanced equations that describe chemical reactions that occur in aqueous solution. All soluble ionic substances must be written as separated ions with the *spectator ions* left out. The spectator ions are left out of the equation because they do not change form at all during the course of the reaction and do not need to be represented in the chemical equation. All molecular substances and non-soluble compounds must be written as a molecule or formula unit (not ionized!).

Solubility Rules

In first year chemistry we used a solubility chart, however, you will not be allowed to use one in AP Chemistry. The solubility rules that you need to memorize is quite a short list.

ALWAYS SOUBLE IF IN A COMPOUND	EXCEPT WITH
Alkali ions, NH_4^+,	No Exceptions (unless told otherwise in a problem)
NO_3^-, $C_2H_3O_2^-$, ClO_4^-	No Exceptions (unless told otherwise in a problem)
Cl^- , Br^- , I^-	Pb^{2+}, Ag^+ (unless told otherwise in a problem)
SO_4^{2-}	Pb^{2+} (unless told otherwise in a problem)

If a compound does not fit one of the rules above, assume it is INSOLUBLE, unless you are given other information to the contrary within the problem. Non-soluble compounds must be written as a *formula unit* (not ionized). Remember, this list is just a guide, and any information given within a problem that contradicts any rules given above will be followed.

Other considerations to remember when writing chemical equations.

1. Weak acids, (any acid other than the seven strong acids you need to memorize) are mostly *NOT* ionized in solution and thus must be written as molecules. (There are weak bases, you will learn about them during the year.)
2. Strong acids and bases will be considered fully ionized in solution and thus must be written as separated ions in net ionic equations.
3. Soluble salts as memorized from the table above will exist as separated ions in solution and thus must be written as separated ions in net ionic equations, with spectator ions dropping out of the equation.
4. Solids, liquids, and gases should be written as molecules.
5. When you see the words "solution of" to describe an ionic compound, assume that compound is dissolved and dissociated.
6. An ionic compound in a *saturated* solution (saturated: a solution with maximum that can be dissolved) is written in ionic form while an ionic compound in *suspension* (suspension: particles shaken up and floating, but not actually dissolved) should be written together as a molecule or "ionicule."
7. Know your *phantoms* − molecules that when formed as a product, will decompose into a gas and water as indicated below.
    - as a product of a double replacement reaction, H_2CO_3 decomposes into H_2O and CO_2 gas.
    - as a product of a double replacement reaction, NH_4OH decomposes into H_2O and NH_3 gas.

Single Replacement

- A reaction in which one element displaces another in a compound. One element is oxidized and another is reduced. In an oxidation reduction reaction, elements will change their oxidation states.
- Generic: A + BX → B + AX or Y + BX → X + BY
  - **Active metals replace less active metals or hydrogen (in acid or water).**

    The more easily oxidized metal replaces the less easily oxidized metal or hydrogen. You used an activity series in first year chem. You will learn more about that chart, and other methods of predicting which metal is more active than the other.

    - *Magnesium pieces are added to a solution of nickel(III) chlorate.*

      Overall Equation: $3Mg + 2Ni(ClO_4)_3 \rightarrow 2Ni + 3Mg(ClO_4)_2$ $(= 3Mg + 2Ni^{3+} + 6ClO_4^- \rightarrow 2Ni + 3Mg^{2+} + 6ClO_4^-)$

      Net Ionic Equation: $3Mg + 2Ni^{3+} \rightarrow 2Ni + 3Mg^{2+}$

      (Note that the chlorate compounds are soluble and thus the chlorate ions have been removed because they are spectators − unchanged by the reaction. The nickel and magnesium are different as reactants compared to products.)

    - *Nickel is added to hydrochloric acid.*

      Overall Equation: $Ni + 2HCl \rightarrow NiCl_2 + H_2$ $(= Ni + 2H^+ + 2Cl^- \rightarrow Ni^{2+} + 2Cl^- + H_2)$

      Net Ionic Equation: $Ni + 2H^+ \rightarrow Ni^{2+} + H_2$

      (Note that the chloride ions have been removed because nickel(II) chloride is soluble and the chloride ions are in the same form both as reactants and products, thus the chloride ions are spectators − unchanged by the reaction.)

    - *Sodium is added to water.*

      Overall Equation: $2Na + 2H_2O \rightarrow 2NaOH + H_2$

      Net Ionic Equation: $2Na + 2H_2O \rightarrow 2Na^+ + 2OH^- + H_2$

      (Remember that some metals -the alkali metals and some alkaline earth metals- can replace hydrogen in water. You may find it useful to think of water as HOH. For this equation there is no ions that are removed. Na^+ and OH^- must be included as products because those products are not ions on the reactant side.)

  - **Active nonmetals replace less active nonmetals from their compounds in aqueous solution.**

    A halogen will replace a less electronegative (lower on the Periodic table) halogen from their binary salts.

    - *Chlorine gas is bubbled into a solution of potassium iodide.*

      Overall Equation: $Cl_2 + 2KI \rightarrow I_2 + 2KCl$ $(= Cl_2 + 2K^+ + I^- \rightarrow I_2 + 2K^+ + 2Cl^-)$

      Net Ionic Equation: $Cl_2 + 2I^- \rightarrow I_2 + 2Cl^-$

      (Note that the potassium ions have been removed because they are spectators − unchanged by the reaction.)

Double Replacement

Two compounds react to form two new compounds. No changes in oxidation numbers occur, thus DR reactions are not redox. Since the movement of electrons does not "push" the reaction, all double replacement reactions must have some other "driving force" that removes a pair of ions from solution. These ions may be removed by forming a precipitate, a gas, or molecular compound. If water forms, the double replacement reaction is an acid/base reaction. If a solid substance forms the double replacement reaction is a precipitation reaction. We can assume that all solutions are aqueous solutions, unless told otherwise.

- **Formation of a precipitate:**
  A precipitate is an insoluble substance formed during the reaction of two aqueous substances. Two ions bond together so strongly that water can not pull them apart. Knowing your solubility rules will help you write these net ionic equations.
  - *Solutions of silver nitrate and sodium sulfide are mixed (Assume a precipitate forms).*

    Overall Equation: $2AgNO_3 + Na_2S \rightarrow Ag_2S + NaNO_3$ (= $2Ag^+ + NO_3^- + Na^+ + S^{2-} \rightarrow Ag_2S + Na^+ + NO_3^-$)

    Net Ionic Equation: $2Ag^+ + S^{2-} \rightarrow Ag_2S$

    (How do you know which substance is the precipitate? By knowing alkali and nitrate salts are soluble, the precipitate must be the silver sulfide)

- **Formation of a gas:**

  Gases may form from the decomposition of a product such as H_2CO_3 or NH_4OH.

  - *Acetic acid solution is added to a solution of sodium bicarbonate.*

    Overall Equation: $HC_2H_3O_2 + NaHCO_3 \rightarrow NaC_2H_3O_2 + (H_2CO_3 \rightarrow) H_2O + CO_2$

    (= $HC_2H_3O_2 + Na^+ + HCO_3^- \rightarrow Na^+ + C_2H_3O_2^- + H_2O + CO_2$)

    Net Ionic Equation: $HC_2H_3O_2 + HCO_3^- \rightarrow H_2O + CO_2$

    (Note that the acetic acid must be written as a molecule because acetic acid is a weak acid, which you should know from the strong acid chart on page 2. Remember, if an acid is not one of the seven strong acids, you can assume that acid is weak. The carbonic acid, when formed, bubbles off as carbon dioxide. You know this reaction − the classic third grade volcano trick. The sodium ions have been removed because they are spectators − unchanged by the reaction)

  - *A solution of sodium hydroxide is added to a solution of ammonium nitrate.*

    Overall Equation: $NaOH + NH_4NO_3 \rightarrow NaNO_3 + (NH_4OH \rightarrow) NH_3 + H_2O$

    (= $2Na^+ + OH^- + NH_4^+ + 2NO_3^- \rightarrow Na^+ + 2NO_3^- + NH_3 + H_2O$ +)

    Net Ionic Equation: $OH^- + NH_4^+ \rightarrow NH_3 + H_2O$

    (The ammonium hydroxide that is formed, bubbles off as ammonia with water in solution. The sodium and nitrate ions have been removed because they are spectators − unchanged by the reaction)

- **Formation of a molecular substance (often an acid base neutralization):**

  When a molecular substance such as water or a weak acid is formed, ions are removed from solution and the reaction happens. More information on the next page.

Acid base neutralization will be the focus of the next page. → → → → →

Acid/Base Neutralization *(a particular "flavor" of double replacement reaction)*

Acids react with bases to produce salts and water.

One mole of hydrogen ions react with one mole of hydroxide ions to produce one mole of water. Remember which acids are strong (and thus ionize completely) and by default, which acids are weak (should be written as a molecule). We can assume that all solutions are aqueous solutions, unless told otherwise.

- *Aqueous solutions of lithium hydroxide and hydrobromic acid are poured together.*

  Overall Equation: $LiOH + HBr \rightarrow H_2O + LiBr$ $(= Li^+ + OH^- + H^+ + Br^- \rightarrow H_2O + Li^+ + Br^-)$

  Net Ionic Equation: $OH^- + H^+ \rightarrow H_2O$

  (A strong acid will be completely ionized in solution − HBr is a strong acid. Lithium bromide is a soluble ionic compound that would be separated into ions. The ions that are unchanged as reactants and products drop out of the equation.)

- *An aqueous solutions of sulfuric acid and barium hydroxide are combined.*

  Overall Equation: $H_2SO_4 + Ba(OH)_2 \rightarrow BaSO_4 + 2H_2O$ $(= 2H^+ + SO_4^{2-} + Ba^{2+} + 2OH^- \rightarrow H_2O + Ba^{2+} + SO_4^{2-})$

  Net Ionic Equation: $H^+ + OH^- \rightarrow H_2O$

  (It's true that in the "overall reaction," 2's would show up, but then drop out of the net ionic equation.)

- **Watch out for acids or bases that should be written as a molecule, such as weak acids or weak bases and gases.**

  - *Acetic acid solution is added to a solution of sodium hydroxide.*

    Overall Equation: $HC_2H_3O_2 + NaOH \rightarrow H_2O + NaC_2H_3O_2$ $(= HC_2H_3O_2 + Na^+ + OH^- \rightarrow H_2O + Na^+ + C_2H_3O_2^-)$

    Net Ionic Equation: $HC_2H_3O_2 + OH^- \rightarrow H_2O + C_2H_3O_2^-$

    (Remember, that weak acids are mostly not ionized in solution and thus must be represented as molecules.)

  - *Hydrogen sulfide gas is bubbled through excess potassium hydroxide solution.*

    Overall Equation: $H_2S + 2KOH \rightarrow 2\ H_2O + K_2S$ $(= H_2S + 2OH^- \rightarrow 2\ H_2O + + 2K^+ + S^{2-})$

    Net Ionic Equation: $H_2S + 2OH^- \rightarrow 2\ H_2O + S^{2-}$

    (Remember, that the gas, which is also a weak acid must be written as a molecule.)

  - *A suspension of magnesium hydroxide is added to a dilute solution of hydrochloric acid.*

    Overall Equation: $Mg(OH)_2 + 2HCl \rightarrow 2H_2O + MgCl_2$ $(= Mg(OH)_2 + 2H^+ + Cl^- \rightarrow 2H_2O + Mg^{2+} + 2Cl^-)$

    Net Ionic Equation: $Mg(OH)_2 + 2H^+ \rightarrow 2H_2O + Mg^{2+}$

    (Remember, that a suspension is not actually dissolved, not ionized, and thus must be written as a formula unit − not separated.)

- **Formation of weak acids by combining a weak base with a strong acid.**

  - *Solutions of sodium fluoride and hydrobromic acid are mixed.*

    Overall Equation: $Na^+ + F^- + H^+ + Br^- \rightarrow HF + NaBr$ $(= Na^+ + F^- + H^+ + Br^- \rightarrow HF + Na^+ + Br^-)$

    Net Ionic Equation: $F^- + H^+ \rightarrow HF$

    (Remember that sodium bromide is soluble making the sodium and bromide ions the same as reactants and products, and thus drop out as spectators. The HF is a weak acid, thus must be represented as molecule.)

  - *Solutions of potassium acetate and sulfuric acid are mixed.*

    Overall Equation: $2KC_2H_3O_2 + H_2SO_4 \rightarrow 2HC_2H_3O_2 + K_2SO_4$ $(= 2K^+ + 2C_2H_3O_2^- + 2H^+ + SO_4^{2-} \rightarrow 2HC_2H_3O_2 + 2K^+ + SO_4^{2-})$

    Net Ionic Equation: $C_2H_3O_2^- + H^+ \rightarrow HC_2H_3O_2$

    (Remember $HC_2H_3O_2$ is a weak acid, thus a molecule is formed. Sulfate and potassium ions are spectators. Again, the 2's that show up in the overall and ionic equation will drop out of the net ionic equation.)

Summary Review: Atomic and Chemical Composition

Remember that on the AP exam you may only use the periodic table. No solubility chart. Assume that the reaction does occur, thus if you can recognize the single replacement reaction, you do not need to check the activity series. Look for extra information embedded in the question. Answers are on the next page.

1. A strip of magnesium is added to a solution of silver nitrate

2. Aluminum metal is dropped into an solution of zinc chloride

3. Solid silver is dropped into an solution of gold(II) nitrate

4. Aluminum foil is dropped into a solution of nitric acid.

5. Solid barium is added to chlorous acid

6. Potassium metal is dropped into water

7. Liquid bromine is added to an aqueous sodium iodide solution

8. Hydrogen gas is passed over hot copper(II) oxide.

9. Small chunks of solid sodium is added to water.

10. Magnesium metal is added to a dilute solution of nitric acid.

11. Chlorine gas is bubbled into a solution of potassium iodide.

Remember that on the AP exam you may only use the periodic table. No solubility chart. Assume that the reaction does occur, thus if you can recognize the double replacement reaction, you should be able to infer the precipitate. Look for extra information embedded in the question. Answers are on the next page.

1. Aqueous solutions of zinc sulfate and sodium phosphate are mixed.

2. Hydrofluoric acid is combined with a solution of lead(II) nitrate.

3. An aqueous solution of lead(II) acetate reacts with hydrochloric acid.

4. Solid sodium carbonate is stirred into hydrobromic acid.

5. Nitric acid is reacted with an aqueous solution of calcium acetate.

6. Hydrochloric acid is poured over powdered potassium carbonate.

7. An aqueous solution of cadmium chloride is reacted with an aqueous solution of potassium phosphate.

8. A solution of hydrofluoric acid is poured over barium carbonate crystals.

9. Hydroiodic acid is poured over potassium carbonate.

10. A solution of sodium hydroxide is poured into a solution of magnesium chloride.

11. Aqueous lead(II) nitrate is combined with potassium iodide.

Remember that on the AP exam you may only use the periodic table. No solubility chart. Look for extra information embedded in the question. Answers are on the next page.

1. A solution of acetic acid is reacted with a lithium hydroxide solution.

2. A solution of nitric acid is combined with a suspension of magnesium hydroxide.

3. A solution of sulfuric acid is poured over copper(I) hydroxide crystals.

4. A solution of sulfuric acid is added to a solution of barium hydroxide until the same number of moles of each compound has been added.

5. Hydrogen sulfide gas is bubbled through a solution of potassium hydroxide.

6. Potassium hydroxide solution is added to a solution of potassium hydrogen phosphate

7. A solution of sodium hydroxide is added to a solution of sodium dihydrogen phosphate until the same number of moles of each compound has been added.

8. Solutions of sulfuric acid and potassium hydroxide are combined.

9. Hydrochloric acid solution is added to a solution of sodium dihydrogen phosphate

Navigating all those #'s in the Periodic Table

Atoms	When you look up an element in the periodic chart, and look up its atomic number and mass number, assume you are considering an atom, as opposed to an ion. It is very important to pay close attention to this vocabulary.
Atomic number	tells you the number of protons in an atom. Atoms are neutral in charge, which of course means that the number of protons must equal the number of electrons.
Mass number	is the average atomic mass rounded to the nearest whole number. The mass number is equal to the sum of the protons + neutrons. Thus, to determine the number of neutrons, subtract the atomic number from the mass number.
Ions	During chemical reactions, atoms can lose or gain electrons. In fact they do so on a very regular basis. Since electrons are negatively charged, when electron(s) are lost, an atom turns into an ion and ends up with a positive charge. When electrons are gained, an atom turns into an ion and ends up with a negative charge. Negatively charged ions are called ***anions***. Positively charged ions are called ***cations***.

Symbolizing atoms, isotopes, ions, molecules:

- ${}_3\text{Li}$ the *atomic number* is placed in front of the atom as a subscript.
- ${}^7\text{Li}$ the *mass number* is placed in front of the symbol as a superscript
- Li^+ the + as a superscript refers to the +1 charge if the atom has turned into an ion
- Li_2 the subscript 2 refers to 2 Lithium atoms that are *stuck* together
- 5 Li the 5 refers to 5 lithium atoms that are NOT stuck together (used as coefficients to balance chemical equations)

Never would all 5 of these numbers be placed around a chemical symbol all at the same time. They would be used at different times in different contexts.

Electron Configuration

Electron configurations are a simple way of writing down the locations of all of the electrons in an atom. Electrons stay within the atom because of their attraction to the protons, they also mutually repel each other, causing them to spread out around the nucleus in regular patterns. This results in geometric areas of probability called **orbitals** (s, p, d, and f) that represent the distinct regions of probability around the nucleus in which each electron exists. The reason that electrons tend to stay in their separate orbitals rather than piling on top of one another is the **Pauli Exclusion Principle**, a theorem from quantum mechanics that dictates that no two electrons can ever be in the same place. The Pauli Exclusion Principle arises from more than just the electrostatic repulsion of negative electrons: it comes from fundamental quantum mechanical principles that constrain all subatomic particles.

The orbitals represent **identifiable "addresses"** for each electron around an atom. Think of the electrons as people going to their favorite concert. The electrons all try to be as close to the stage (the nucleus) as possible, but there is a limited number of seats Some electrons get to be closest to the nucleus, but as the number of electrons that go the concert increases, the further out some of them need to be since the rows closest to the nucleus fill up. This describes a trend observed in the periodic table: elements with small atomic number (and thus fewer electrons) tend to have most of their electrons existing in orbitals near the nucleus. As we move further down the periodic table, orbitals and energy levels further out from the nucleus begin to fill up with electrons. In order to track down where a given electron exists in an atom, you need to know not only how far from the nucleus it is found (described as the electron's **energy level**, since electrons further out from the nucleus tend to have higher energy) but also the *type of orbital* that the electron is be found in.

Example: Arsenic: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^3$ OR $[\text{Ar}]\ 4s^2\ 3d^{10}\ 4p^3$ (noble gas or condensed version)

You will probably not need to deal with f electrons on the AP exam.

Percent Composition

Laboratory experiments can give the masses of the various elements contained in the total mass of the compound. This common practice is called elemental analysis or mass percent composition or more simply percent composition. Example, H_2O: 2 (1.01 g/mole) + 16.00 g/mole = 18.02 g/mole total (these numbers are the molar masses from the periodic chart.)

$$H:\frac{2.02g}{18.02}\times 100 = 11.02\% \qquad O:\frac{16.00g}{18.02}\times 100 = 89.88\%$$

Thus water is 11 % hydrogen and 89 % oxygen

Empirical and Molecular Formulas

As you know, the chemical formulas for molecular compounds are not always written in the lowest whole number ratios. We have often used formaldehyde CH_2O and sugar $C_6H_{12}O_6$ as an example. Because of this, the elemental analysis to determine empirical formulas would not allow a chemist to distinguish between sugar and formaldehyde. Another analysis tool, mass spectroscopy would be needed to give one more piece of information: the molar mass of the particular compound being analyzed. So the first 4 steps below will help determine the empirical formula, steps 5-6 must be added to determine the molecular formula.

1. Divide each mass or mass percentage by the molar mass of the element, which will give the number of moles of each element.
2. Divide the results from step 1 by whichever number of moles is the smallest. This maintains the mole ratios from step 1 but bases them on the least abundant element being 1.
3. If some results are far from being whole numbers, multiply all the moles through by a common factor that will convert all the mole amounts to whole numbers or near whole numbers.
4. Round each mole amount to the nearest whole number.
5. If a molar mass is given for the compound, calculate the molar mass for the empirical formula just established from step 4. If the molar mass of the empirical formula is the same as the molar mass of the compound given in the problem, then the empirical formula and the molecular formula are one and the same.
6. If the molar mass of the empirical formula is smaller than the molar mass of the compound, divide the two to determine the whole number factor that the empirical formula must be multiplied by to determine the molecular formula.

Sample Problem

Determine the empirical formula for some compound that was analyzed to be 1.33 g of carbon,0.22 g of hydrogen, and 1.78 g of oxygen. Determine the molecular formula for this compound if the molar mass was measured and found to be 180 g/mole.

- First do step 1 as outlined above.

$$C:\ 1.33g\times\frac{1mol}{12.01g}=0.111mol \quad H:\ 0.22g\times\frac{1mol}{1.01g}=0.219mol \quad O:\ 1.78g\times\frac{1mol}{16.00g}=0.111mol$$

- Proceed to step 2.

$$C:\ \frac{0.111mol}{0.111mol}=1 \quad H:\ \frac{0.219mol}{0.111mol}=2 \quad O:\ \frac{0.111mol}{0.111mol}=1$$

Voilà. The empirical formula is CH_2O

- Since steps 3 and 4 are not necessary, proceed to step 5
  - For CH_2O molar mass = 30 g/mole which is of course not the same as 180 g/mole
- Proceed to step 6

$$\frac{180}{30}=6$$

  - Therefore when the factor of 6 is distributed through the empirical formula CH_2O
  - Voilà. The empirical formula converts to $C_6H_{12}O_6$

Summary Review: Atomic and Chemical Composition *(Answers on the next page.)*

1. Complete the following table to demonstrate your knowledge of sub atomic particles

symbol	# of protons	# of neutrons	# of electrons	atomic #	mass #	charge
Sc		24	21			0
P^{-3}			18	15	31	
C					13	
Cl^{-1}	17				35	−1
Fe^{+3}			23		58	

2. Write complete electron configurations for the following particles.
   a. S
   b. Zr
   c. P^{3-}
   d. Cr^{2+}

3. Write condensed electron configurations for the following particles.
   a. Ge
   b. Pb

4. Bismuth subsalicylate, is the active ingredient in Pepto-Bismol which is used to treat upset stomachs. This chemical has the formula $C_7H_5BiO_4$.
   a. Calculate the percent composition of bismuth subsalicylate.
   b. If each tablet of the medication contains 262 milligrams of $C_7H_5BiO_4$ calculate the mass of bismuth in 2 tablets.

5. Determine the empirical and molecular formula of benzene which contains only carbon and hydrogen and is 7.74% hydrogen by mass. The molar mass of benzene is 78.1 g/mol.

6. 6.394 g of compound used as a drying agent is analyzed and determined to be 2.788 g phosphous and 3.606 g oxygen. The molar mass is approximately 284 g/mol. Determine the empirical and moleculoar formulas of this compound. What is the name of this compound.

A Typical Plan for Solving Stoichiometry Problems

There is a basic pattern to all stoichiometry problems, with variations depending on what information is given and what questions must be answered. You are using dimensional analysis so be sure to set up you calculations with the starting units on top and bottom so it will cancel out and with the desired substance on the top.

A. You must start with a balanced equation.

B. Convert the units of any starting substances into moles. (USE Molar Mass (g/mol) complete this calculation) Since the stoichiometric LINK or RATIO – coefficients from the balanced equation – is in moles, you must work the problem in moles.

C. Reread the problem to determine the information that you need to calculate. Use the stoichiometric LINK to convert from a known substance to a desired substance that you need to answer the question. Note that the LINK is set up with the known substance on the bottom (so it will cancel out) and with the desired substance on the top.

D. If necessary, convert any answers back into grams.

If your problems only involve only moles, then you can skip steps B and E

Sample Problem

Lithium hydroxide is used in space vehicles to remove exhaled carbon dioxide from the living environment by forming solid lithium carbonate and liquid water. What mass of gaseous carbon dioxide can be absorbed by 1.00. kg of lithium hydroxide?

STEP A. balanced equation: $2\ LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$

Notice that the starting info is given in kilograms, so 1.00 kg should be converted to grams.

$$1.00 \times 10^3 gLiOH \times \frac{1mol}{23.99g} \times \frac{1CO_2}{2LiOH} \times \frac{44.01gCO_2}{1molCO_2} = 917gCO_2$$

Steps in the dimensional analysis: B. C. D.

STEP B. Change to moles using the molar mass of LiOH

STEP C. Change from moles of LiOH to moles of CO_2 using the coefficients from the balanced equation.

STEP D. Change from moles of CO_2 back to grams of CO_2 using the molar mass of CO_2.

Problem Solving Plan - Limiting Reactant and Percent Yield

For limiting reactant problems, the problem will give you information about two reactants as opposed to information given for only reactiant and an assumption that the other reactant is present in excess.

A. You must always start with a balanced equation.

B. If it is a limiting reactant problem.... Determine which reactant LIMITS

C. First you *must* change your mass values to moles. NOTE: The mathematical trick to determine which reactant limits is to divide the moles of each reactant by the coefficient (from the balanced equation) associated with that reactant. The number that comes out the smallest indicates which reactant is the limiting one. The limiting reactant is the one that you must base all your other calculations on because it is the substance that limits how much of everything else can be made or is needed.

D. Solve the problem using the same steps for Stoichiometry problems above based on the LR.

E. Of course, the other reactant (if there's only two) will be the excess reactant, and some of it will be left over. (Knowing which reactant limits and which is excess, use the limiting reactant to set up a stoichiometric LINK to determine the mass of the excess reactant that is actually needed to do the reaction. Then, subtract the mass of reactant that you just calculated was needed from the amount of excess reactant started with to determine the mass of excess reactant that is left over.

F. Determining Percent Yield- After determining the LR, use the link to calculate the theoretical amount of the product for which you need a yield.

G. The experimental amount actually produced will be given in the problem. Use it to set up the equation below and determine the percent yield:

$$\frac{Experimental}{Theoretical} \times 100 = Percent\,Yield$$

Molarity (M):

This is the most common method of reporting concentration used in AP chemistry.

Molarity is the number of moles of solute per liter of solution. $Molarity = \frac{MolesofSolute}{LitersofSolution}$

When a more concentrated solution is diluted, the moles of the solute will be the same before and after the dilution. This gives rise to the dilution equation, which is just a variation of the molarity equation. $M_cV_c = M_dV_d$

Sample Problems

1. What is the molarity of a solution that contains 6.57 g of magnesium chloride in 250. mL of solution?
   - *First you need to be able to write out the chemical formula for maganesium chloride, and calculate the molar mass.*
     - $MgCl_2$ 24.31 + 2 × 35.45 = 95.21 g/mol
   - *Next, convert the mass of magnesium chloride to moles.* $6.57gMgCl_2 \times \frac{1molMgCl_2}{95.21gMgCl_2} = 0.0690molMgCl_2$
   - *Next apply the molarity equation.* $\frac{0.069mol}{0.25L} = 0.276M$

Hey look! Molarity which is moles per liter, is also millimoles per milliliter!!

$$\frac{5mol}{1L} \times \frac{1000millimol}{1mol} \times \frac{1L}{1000mL} = \frac{5millimol}{1mL}$$

2. Given 25.0 mL of a 0.05 M of aluminum sulfate solution.
   (a) How many millimoles of aluminum sulfate does this solution contain?
   (b) How many millimoles of sulfate does this solution contain?
   - *To answer (a), simply apply the molarity equation* $M \times V = moles$ $0.05M \times 25ml = 1.25millimol$
   - *To answer part (b) you need to write out the chemical formula for aluminum sulfate.* $Al_2(SO_4)_3$
   - *Thus you can see there are three sulfate ions per aluminum sulfate.*
   - $1.25mmolAl_2(SO_4)_3 \times \frac{3SO_4^{2-}\ ions}{1Al_2(SO_4)_3} = 3.75mmol\ SO_4^{2-}\ ions$

3. If 38.0 mL of a 6.0 M HCl solution are diluted to a final volume of 250 mL, what is the final concentration?
   - *To answer (a), simply apply the dilution equation* $M_cV_c = M_dV_d$
   - $M_cV_c = M_dV_d \quad M_d = \frac{M_cV_c}{V_d} \quad M_d = \frac{6M \times 38mL}{250ml} \quad M_d = 0.91M$

Summer Review: Stoichiometry *(Answers on the next page.)*

1. Solutions of nickel(II) chloride and potassium phosphate will react to produce a light green precipitate .
   a) Write a balanced overall chemical equation to represent this reaction.
   b) What mass of potassium phosphate in solution would be required to react completely with 0.875 g of nickel(II) chloride in solution?
   c) Calculate the theoretical mass of nickel(II) phosphate that could be produced.
   d) Convert the overall equation to the net ionic equation.

Solution	Concentration (Molarity)	Volume (Liters)
$Na_2S_2O_3$	0.500	250.
NOCl	2.00	150.
NaOH	0.600	175

2. Gallium metal reacts with perchloric acid. *Assume that at room conditions, 24.0 L is the volume of 1.00 mole of gas.*
   a) Write both overall and net ionic balanced equations to represent this reaction.
   b) If 2.25 L of hydrogen gas were collected, what mass of gallium metal was dropped into the acid solution?

3. Aluminum will cause copper to reduce from a solution of copper(II) chloride.
   a) Write a balanced net ionic chemical equation to represent this reaction.
   b) Is 5.00 g of aluminum enough aluminum to reduce all of the copper(II) ions from 750. ml of a 0.500 M solution?
   c) If 5.00 g of aluminum is more than enough, what mass would be left over? OR if 5.00 g of aluminum is not enough, what is the additional mass of aluminum that would be needed to remove all of the copper(II) ions from solution?

4. Hydrochloric acid reacts with solid magnesium hydroxide.
   a) Write a balanced overall chemical equation to represent this reaction.
   b) What volume, in milliliters, of 0.25 M hydrochloric acid solution would be required to completely react with 4.56 g of magnesium hydroxide?
   c) Convert the balanced overall equation to a net ionic equation.

5. 1.65 g of zinc is dropped into 150. ml of 0.250 M of hydrobromic acid.
   a) Write both overall and net ionic balanced chemical equations to represent this reaction.
   b) Which reactant is the limiting reactant in this chemical reaction?
   c) Calculate the theoretical mass of solid zinc bromide that should be produced.
   d) If Consuela and Pete were able to produce 3.67 g of the zinc bromide, what is their percent yield?

6. Eldon and Sally were preparing a sulfuric acid solution for a lab and they needed 500. ml of 0.045 M
   a) Calculate the volume of 3.0 M solution that Eldon and Sally should measure out into the 500. ml volumetric flask.
   b) What is the molarity of H^+ ions for the solution that Eldon and Sally prepared?
   c) What are the number of millimol of H^+ ions that are in Eldon and Sally's 500. ml of 0.045 M sulfuric acid solution?

7. Nitric acid will react with a sodium carbonate solution.
   a) Write a balanced overall equation to represent this reaction. (Hint: one of the products is a phantom, and will turn into two products. Refer to page 5 of this packet for more information.)
   b) What volume of 0.25 M nitric acid would be required to react completely with 245 ml of 0.38 M of the sodium carbonate solution.

$$Na_2S_2O_{3(aq)} + 4\ NaOCl_{(aq)} + 2\ NaOH_{(aq)} \rightarrow 2Na_2SO_{4(aq)} + 4\ NaCl_{(aq)} + H_2O_{(L)}$$

8. Answer the following questions about the balanced redox equation shown above.
   a) The student combines the solutions shown in the table to the right. Determine the limiting reactant.

b) How many moles of water would be produced during this reaction?

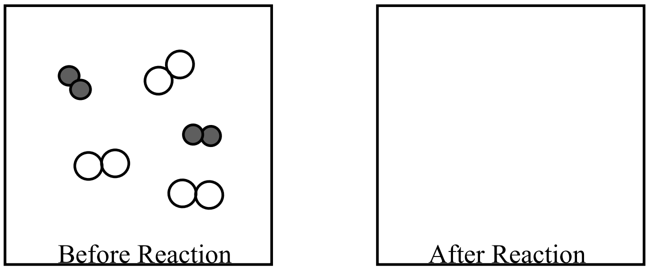
c) Convert the overall equation shown above into a net ionic equation.

Summary Review: Particulate Diagrams *(Answers on the next page.)*

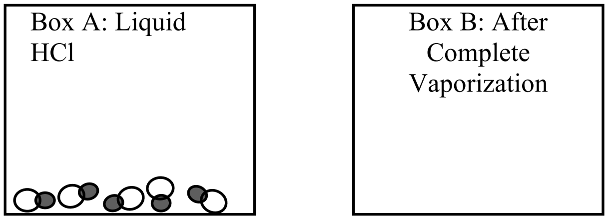
The AP Chemistry curriculum has made a point of asking students to interpret and draw particulate diagrams. A particulate diagram is a sketch that asks students conceptualize what may be happening at the atom and molecule level. You will be asked to convert between macroscopic observations in lab, to symbolic representations with chemical formulas and balanced equations, to particulate representations of the atoms, ions and molecules.

1. The picture shown to the right is a representation of a mixture of hydrogen and oxygen molecules that can be sparked to produce water. Draw a sketch that represents the resulting mixture after the reaction goes to completetion.

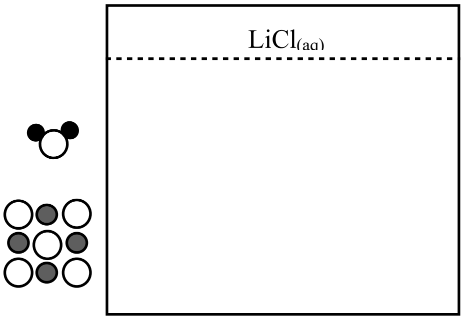
   Hint: write a balanced chemical equation first. Decide which molecule best represents oxygen and which best represents hydrogen.



2. Draw a sketch that represents five molecules of HCl in the liquid state is shown in Box A below. In Box B, draw a representation of the five molecules of HCl after complete vaporization has occurred

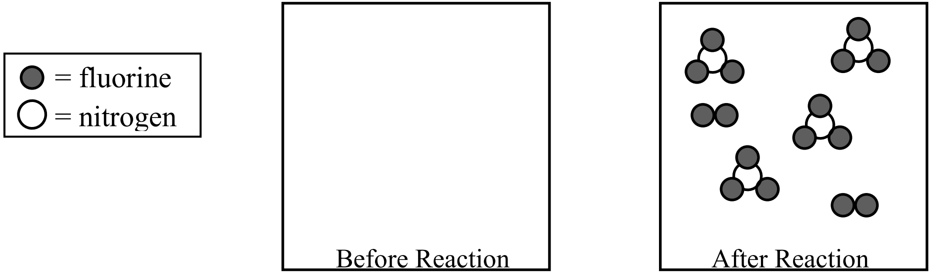


3. A section of a solid lithium chloride crystal is represented to the left of the box below. In the box, show the interactions of the components of a lithium chloride crystal dissolved in water by making a drawing that represents the different particles present in the solution. Include only **one formula unit** of lithium chloride and at least three, but no more than five molecules of water. Your drawing must include the following details.
   - identify the ions (symbol and charge)
   - the proper arrangement and orientation of the particles in the solution



$N_2 + 3 F_2 \rightarrow 2 NF_3$

4. The picture shown to the right is a representation of a mixture of ammonia and hydrogen molecules that is a result of the completion of the reaction between N_2 and H_2 as shown in the reaction above. In the box on the left, draw the particle-level representation of the reactant mixture of N_2 and H_2 that would yield the product mixture shown in the box on the right. In your drawing, represent nitrogen atoms and hydrogen atoms as shown below



AP Chemistry Equations & Constants

Throughout the test the following symbols have the definitions specified unless otherwise noted.

L, mL = liter(s), milliliter(s)
g = gram(s)
nm = nanometer(s)
atm = atmosphere(s)

mm Hg = millimeters of mercury
J, kJ = joule(s), kilojoule(s)
V = volt(s)
mol = mole(s)

ATOMIC STRUCTURE

$$E = h\nu$$

$$c = \lambda\nu$$

E = energy
ν = frequency
λ = wavelength

Planck's constant, $h = 6.626 \times 10^{-34}$ J s
Speed of light, $c = 2.998 \times 10^{8}$ m s^{-1}
Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}
Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

EQUILIBRIUM

$$K_c = \frac{[\mathrm{C}]^c[\mathrm{D}]^d}{[\mathrm{A}]^a[\mathrm{B}]^b}, \text{ where } a\,\mathrm{A} + b\,\mathrm{B} \rightleftarrows c\,\mathrm{C} + d\,\mathrm{D}$$

$$K_p = \frac{(P_{\mathrm{C}})^c(P_D)^d}{(P_{\mathrm{A}})^a(P_{\mathrm{B}})^b}$$

$$K_a = \frac{[\mathrm{H}^+][\mathrm{A}^-]}{[\mathrm{HA}]}$$

$$K_b = \frac{[\mathrm{OH}^-][\mathrm{HB}^+]}{[\mathrm{B}]}$$

$$K_w = [\mathrm{H}^+][\mathrm{OH}^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ\mathrm{C}$$
$$= K_a \times K_b$$

$$\mathrm{pH} = -\log[\mathrm{H}^+],\ \mathrm{pOH} = -\log[\mathrm{OH}^-]$$

$$14 = \mathrm{pH} + \mathrm{pOH}$$

$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[\mathrm{A}^-]}{[\mathrm{HA}]}$$

$$\mathrm{p}K_a = -\log K_a,\ \mathrm{p}K_b = -\log K_b$$

Equilibrium Constants

K_c (molar concentrations)
K_p (gas pressures)
K_a (weak acid)
K_b (weak base)
K_w (water)

KINETICS

$$\ln[\mathrm{A}]_t - \ln[\mathrm{A}]_0 = -kt$$

$$\frac{1}{[\mathrm{A}]_t} - \frac{1}{[\mathrm{A}]_0} = kt$$

$$t_{1/2} = \frac{0.693}{k}$$

k = rate constant
t = time
$t_{1/2}$ = half-life

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_{\text{A}}, \text{ where } X_{\text{A}} = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_{\text{A}} + P_{\text{B}} + P_{\text{C}} + \ldots$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = {}^{\circ}\text{C} + 273$$

$$D = \frac{m}{V}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

$$\text{Molarity, } M = \text{moles of solute per liter of solution}$$

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
m = mass
$\boldsymbol{M}$ = molar mass
D = density
KE = kinetic energy
v = velocity
A = absorbance
a = molar absorptivity
b = path length
c = concentration

Gas constant, $R = 8.314 \text{ J mol}^{-1}\text{ K}^{-1}$
$= 0.08206 \text{ L atm mol}^{-1}\text{ K}^{-1}$
$= 62.36 \text{ L torr mol}^{-1}\text{ K}^{-1}$
1 atm = 760 mm Hg
= 760 torr
STP = 0.00 °C and 1.000 atm

THERMOCHEMISTRY/ ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\begin{aligned} \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ \\ &= -RT \ln K \\ &= -nFE^\circ \end{aligned}$$

$$I = \frac{q}{t}$$

q = heat
m = mass
c = specific heat capacity
T = temperature
S° = standard entropy
H° = standard enthalpy
G° = standard free energy
n = number of moles
E° = standard reduction potential
I = current (amperes)
q = charge (coulombs)
t = time (seconds)

Faraday's constant, F = 96,485 coulombs per mole of electrons

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
†Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

(New activities added 8/15/18)

“No Calculator” Activity Options

The multiple choice section of the AP Chemistry Examination includes questions asking students to solve or estimate calculation answers without a calculator. In this packet are activities designed to strengthen skills in “no calculator” calculations.

The activities are divided into 3 groups: For AP, for “Pre-AP/Honors” sections, and resources for instructors.

Why is Mental Math Important?

Since 2000, with assistance from new technologies, science has made rapid progress in understanding how the brain solves problems. One new finding is: When solving a scientific calculation, of critical importance is the ability to recall mathematical *facts* and *procedures* from long-term memory, and to do so *fluently* (quickly and accurately).

Activity #12 in this packet is a review of the research on the importance of mental math recall, but here’s a quick summary:

- Empirical studies have found that among many factors, the best pre-course predictor of student success in college general chemistry is the ability to solve simple calculations without a calculator.
- Cognitive science has learned that during reasoning, the brain can utilize very little information that is not well-memorized. Non-memorized information, such as a calculator answers, takes up space that is very limited in the “working memory” where the brain solves problems. Information recallable from memory does not.
- Cognitive studies also emphasize that skill in solving calculations is most quickly achieved by “over-learning” math fundamentals: Practicing repeatedly over multiple days to achieve automatic, fluent recall of new facts and procedures.
- Recognizing the importance of mental math for STEM success, tests including the SAT, MCAT, and AP Chemistry Exam have sections requiring “calculations without a calculator.”

The activities in this packet are designed to help students

- fill in gaps in their mental math skills and
- overlearn math and science facts and procedures.

This packet contains

- A short **summary** of each activity option, followed by
- The detailed **activity** options, and
- An **overview of research** on the importance of mental arithmetic in chemistry.

* * * * *

Summary: Each "No Calculator" Activity Option

From this list, pick activities of interest, then check the detailed descriptions that follow.

For AP Chemistry

#1. **Quiz on Mental Math Fluency.** This 15-minute "no calculator" quiz on math facts, exponential calculations, logarithms, decimal equivalents of fractions, and basic algebra will identify strengths and weaknesses in student preparation for the math of chemistry. Results can be used to identify gaps and plan math review.

#2 **Homework Review of Chem I.** During the summer and first weeks of the school year, available for AP students are over 60 pages of self-study tutorials review numeracy, exponential calculations, the metric system, significant figures, dimensional analysis, and atomic structure.

#3. **AP MM # 1 – Converting Fractions to Decimal Equivalents.** Two pages of practice in recalling and applying decimal equivalents to simplify calculations.

#4. **AP MM # 2 - Exponentials and Fractions.** A two-page worksheet covering a variety of strategies to simplify calculations mixing numbers and exponents.

#5. **AP MM # 3 - Fractions, Estimates, and Exponentials.** A page of practice in estimation, fraction simplification, and exponential calculations.

For Honors/Pre-AP/Chem I

#6. **Try Activity #1.** The AP mental math fluency test in Activity #1 – tweaked to measure math preparation for first-year chemistry.

#7. **Numeracy Tutorial.** A 6 page homework assignment reviewing the mechanics of simple calculations without a calculator. Includes lecture notes, practice problems, and worked-out answers.

#8 **Simplifying Fractions** is a page of practice designed so that instructors can provide guidance on "no calculator" calculations.

#9 **Multi-digit Multiplication and Division.** Practice with the standard algorithms for multiplication and division without a calculator to strengthen "automaticity" in recalling math facts.

#10 **Scientific Notation and Exponential Calculations.** A 17 page homework tutorial teaches exponential basics, scientific notation, and how to simplify exponential calculations -- both with and without a calculator.

For Instructors

#11. **Other Mental Math Resources.** Contains a listing of additional mental math lessons, by topic, available for review by instructors.

#12. **How the Student Brain Solves Problems**. A summary of research on the importance of mental math skills when solving calculations in the sciences.

# # # # #

Detail: "No Calculator" Activity Options

For AP Chemistry

Activity #1 – *Quiz on Mental Math Fluency*

To the Instructor

Activity #1 is a 15-minute "no calculator" quiz on math facts, decimal equivalents of fractions, exponential and logarithm calculations, and basic algebra. The goal is to identify areas of pre-requisite math that may need review as preparation for chemistry calculations.

Timing

Given *after* either a Summer Packet or fall math review, the quiz may indicate how much the review helped *and* which topics remain to be addressed.

Given *before* a fall math review, the quiz may indicate which math topics may need particular attention during the fall review and later in the course.

Access

The fluency quiz (in an editable format) may be downloaded at www.ChemReview.Net/FluencyQuiz.docx (click and check your downloads).

Follow-Up

Most of the quiz questions have *two* components: How well do students know the math operation, and how well could they perform the mental arithmetic of the problem?

You may want to analyze:

- On question one: What percentage of your students could correctly multiply two digits times two digits without a calculator?
- On questions 2-8, what was the percentage correct for each of these questions? For problems where a number of students had difficulty, did any difficulty appear to be with the rules of the math operation, or the mental arithmetic, or both?

If mental arithmetic (recall of math facts) is a problem, there are two possibilities. One is that students once knew their math facts *well*, but have forgotten them due to calculator use. Science tells us that in the case of *forgetting*, the information is still stored in memory, but the neural "wiring" to reach it needs to be re-grown by practice. These students will "refresh their memory" (re-connect the wiring) relatively quickly when required to practice math-fact recall.

The second possibility is that students were never required to "memorize their times tables." In some states prior to 2014, state K-12 math standards required teachers to have students use calculators to do arithmetic starting in third grade, rather than memorize facts. Since 2014, Common Core-type standards have restored some emphasis on computational fluency, but this means in many states, current students at some point went from one set of standards to another in the middle of their K-8 schooling. Those students may need substantial practice to gain the fluency in recall of math facts that science says they need to ease scientific problem solving.

If the quiz and subsequent exercises indicate that some students need help with mental arithmetic, Activities 8 and 9 will provide options for additional practice.

On the fluency quiz, questions after Question 8 concern math operations and procedures needed later in the course. If learning or "refreshing of memory" is needed for those procedures, Activity #11 lists additional available resources in mental and calculator math.

# # # # #

Activity #2 – *Homework Tutorials Reviewing Chem I*

During the summer and first weeks of the school year, posted online for free student use are over 60 pages of self-study tutorials that help students *review* and *overlearn* math and Chem I fundamentals that are a foundation for AP. Topics include exponential calculations, the metric system, significant figures, dimensional analysis, word problems, and atomic structure.

"Pretests" at the start of most lessons encourage students to bypass what they remember and focus where review is needed.

The tutorial content can be viewed at www.ChemReview.Net/TutorialContent.html

Suggestions for assignment of the tutorials to students are detailed at http://bit.ly/2MgagBg

If some students have limited internet access, inexpensive paperbacks that contain the tutorial content are available and may be loaned for use during the assignment period (see "Secondary Schools" at the bottom left at https://bit.ly/2nx6CrK).

Assignment Length

Students have free access to Chapters 1-6 until September 17. Thereafter, free access is provided to Chapters 1 and 2.

If the tutorials were not part of a summer packet, it is recommended they be assigned on the first day of class.

If the tutorials have been assigned as a summer packet *or* if your schedule allows students 3 or more weeks of access to Chapters 1-6, AP students should be able to complete all 6 chapters.

If students have only two weeks of access to the tutorials, you may want to limit the assignment to Chapters 1-5.

Quizzes

To encourage timely homework completion, quizzes are provided on the tutorial content. For access, click here.

At least two quizzes on the tutorials are recommended: the first at the half-way point in terms of assignment time, the second at the end.

Quizzes are available for Chapters 1, 1-2, 1-3, 1-4, 1-5, and 4-6. All quizzes except the last are cumulative, so that for these fundamentals, if they don't get a chapter studied for the first quiz, they are encouraged to complete it before the second.

If students have 3 weeks to complete the material, a short quiz each week might encourage "keeping up." These could be the provided quizzes on Chapters 1-2, 1-4, and 4-6.

Class Coverage of Topics

For classes that have thoroughly covered each of the Chapter 1-6 topics in their first course in chemistry, instructors report the tutorial "refreshing of memory" works well, and minimal lecture on these topics is needed.

If some topics from Chapters 1-6 were missed for some students, you may want to provide some lecture on those topic as well as assign the tutorials. Some of the practice sheets in the Chem I section below might be helpful as well.

If you are not certain of the math and Chem I background for all of your students, the fluency quiz in Activity #1, given the first week of class, should help in planning which initial topics may need special attention.

# # # # #

Activity #3

AP Mental Arithmetic #1 - Converting Fractions to Decimal Equivalents

To the Instructor

In tutorial Lesson 1.2, students are asked to commit to memory the decimal equivalents of eight commonly encountered fractions. Activity #3 asks students to apply those memorized values to calculate additional decimal equivalents. Those values are then applied to solve calculations.

This practice sheet may be started at any point after tutorial Lesson 3 in Chapter 1 on exponential basics (or an equivalent exercise) is completed.

In-Class Use

The 2-pages of the problem sheet are printed below. It is suggested that you take a look at the pages now, then return here.

The activity is intended to be started in class. It could be scheduled for 20-30 minutes at the start of a class period.

The content could be projected, but it will be limit "recopying the question" if the 2 pages are printed as a handout.

Most problems can be solved in multiple ways. The activity is therefore designed for the student to try the problem first, but the instructor to answer questions, provide feedback, and demonstrate multiple ways to solve, especially on the tougher questions.

A possible procedure would be to ask students to answer Questions 1-5, allow 5 minutes, and then ask someone how they did 4c. Then ask for someone else to offer a different way (addition 3 times, or multiplication, or adding 0.125 to 0.250 could be shown on the board).

You might then ask that they finish Questions 6 and 7, and pick one part of each question to ask for multiple ways to solve that can be written up on the board.

To "distribute" this practice, you may want to have students complete page one on the first day and page 2 the second.

On Question 9, you might ask students to do two parts at a time, ask for how they solved, stop when it seems most are getting it, and ask that they finish the remaining parts for homework.

Some students may have difficulty with the "place value" concepts in 0.040 + 0.040 and 5 × 0.040 and long division with a decimal point involved. This is math that in some state standards was "de-emphasized" from 1994 to 2014. The fundamental arithmetic may need to be demonstrated a few times -- step by step.

Follow-Up

Activities #4 and #5 build on Activity #3.

The quizzes supplied with the tutorials do not contain questions on the content of these optional activities, but one or two similar problems could be added to a quiz (or a part of a quiz) on which "no calculator" is allowed.

If students see material from the activities on quizzes, attention to the work in class and "left for homework" may increase.

# # # # #

AP Mental Arithmetic #1 - Converting Fractions to Decimal Equivalents

On this exercise, do NOT use a calculator.

1. Every numeric fraction X/Y (if Y # 0) has a numeric decimal equivalent. In Lesson 1.2, for the eight fractions encountered most often in scientific calculations, you were asked to commit the decimal equivalents to memory.

   From memory, write the decimal equivalents for those fractions.

   a. $\frac{1}{2} = 0.50$ b. $\frac{1}{3} =$ c. $\frac{1}{4} =$ d. $\frac{1}{5} =$

   e. $\frac{2}{3} =$ f. $\frac{3}{4} =$ g. $\frac{1}{8} =$ h. $\frac{3}{2} =$

2. If you know the decimal equivalent for a fraction 1/X , you can calculate the value of any decimal equivalent Y/X by *adding* the 1/X decimal equivalent Y times.

   Since. $\frac{2}{5} = \frac{1}{5} + \frac{1}{5} = 0.2 + 0.2 = \mathbf{0.4}$, then (finish) $\frac{3}{5} =$

3. Or, knowing 1/X, you can find a decimal equivalent for Y/X using Y/X = Y(1/X) . .

   Finish the calculation below by multiplication to find the decimal equivalent.

   $\frac{4}{5} = 4 \times \frac{1}{5} =$

4. Some decimal equivalents can be solved by reducing the fraction to obtain a Y/X that can be recalled from memory or is easier to solve.

   Fill in any blanks in these fractions, then write the decimal equivalent in the form 0.XXX

   a. $\frac{1}{8} = \mathbf{0.}$ b. $\frac{2}{8} = \frac{1}{\ } =$

   c. $\frac{3}{8} = \mathbf{0.}$ d. $\frac{4}{8} = \frac{1}{\ } =$

5. What is the trend in the Question 4 answers?

6. Using any of the strategies above, convert these fraction to a decimal equivalent value in the format 0.XXX

   a. $\frac{5}{8} =$ f. $\frac{6}{8} =$

   c. $\frac{7}{8} =$

7. Given that 1/25 = 0.040 , convert these to a decimal equivalent in the format 0.XXX

   a. $\frac{2}{25} =$ b. $\frac{3}{25} =$ c. $\frac{5}{25} =$

d. $\frac{9}{25} =$ e. $\frac{12}{25} =$

8. If a denominator ends in a single zero before the decimal, the decimal equivalent will be the same as the equivalent for the denominator without the zero, but the equivalent will have its decimal moved one to the left.

   But let’s explain that with a formula and some examples.

   If $\frac{Y}{X} = A\mathbf{.}BC$ then $\frac{Y}{X0} = 0\mathbf{.}ABC$ or

   Since $\frac{1}{5} = 0.200$, then $\frac{1}{5\mathbf{0}} = 0.\mathbf{0}20$ Since $\frac{3}{4} = 0.75$, then $\frac{3}{40} = 0.075$

   Follow the logic of the math:

$$\frac{3}{50} = \frac{3}{5} \times \frac{1}{\mathbf{10}} = 3 \times \frac{1}{5} \times \frac{1}{10} = 3 \times 0.200 \times 0.10 = 0.600 \times 10^{-1} = \mathbf{0.060}$$

   Convert these to a decimal equivalent in the format 0.XXX**X**

   a. $\frac{1}{40} =$

   b. $\frac{1}{80} =$

9. On separate paper, using any strategy you choose, convert these to the form 0.XXX

   a. $\frac{1}{20}$ b. $\frac{3}{12}$ c. $\frac{3}{20}$ d. $\frac{9}{72}$ e. $\frac{8}{40}$ f. $\frac{2}{30}$ g. $\frac{3}{50}$ h. $\frac{8}{120}$

10. Decimal equivalents may also be solved by long division.

$$5/6 = ? = 5 \div 6 = \begin{array}{r} 0.833\ldots \\ 6\,\overline{)\,5.000} \\ \underline{48} \\ 20 \\ \underline{18} \\ 20\ \ldots \end{array} = 0.83\overline{3}$$

   On separate paper, solve by long division. Round to 3 places past the decimal.

   a. 5/12 b. 4/11

Answers: 1b. 0.333 1c. 0.25 1d. 0.20 1e. 0.667 1f. 0.75 1g. 0.125
2. 0.6 3. 4 × 0.20 = 0.80 4a. 0.125 4b. ¼ = 0.250 4c. 0.375 4d. ½ = 0.500
5. Each answer increases by 0.125 6a. 0.625 6b. 0.750 6c. 0.875
7a. 0.080 7b. 0.120 7c. 0.200 7d. 0.360 7e. 0.480 8a. 0.0250 8b. 0.0125
9a. 0.050 9b. 0.250 9c. 0.150 9d. 0.125 9e. 0.250 9f. 0.067 9g. 0.060 9h. 0.067
10a. 0.417 10b. 0.364

Activity #4

AP Mental Arithmetic #2: Exponentials and Fractions

To the Instructor

Activity #4 is 2-pages combining the decimal equivalent work in Activity #3 with the exponential notation review in tutorial Chapter 1. It is intended to be started in class at any time after both Activity #3 and Chapter 1 have been completed.

In-Class Use

The practice pages are printed below. Take a look at the pages now, then return here.

It is suggested that this activity be done in a manner similar to Activity #3.

You might start by asking students to complete Parts a and b on Questions 1 and 2, demo how you would do one part of each question, and then handle Questions 3 and 4 the same way, leaving un-done parts for homework or for class tomorrow.

How many parts each student will need to complete to become confident will depend on many factors, including the grade in which they were allowed to first use calculators for arithmetic (which will vary by state and district). Student skills in mental math *should* improve a bit with each passing year, since most states since 2014 have forbidden calculator use until 7th grade.

If students need additional mental arithmetic practice, you may suggest Activities #8 and #9 in the Chem I activities.

# # # # #

AP Mental Arithmetic #2: Fractions and Exponentials

On this sheet, do NOT use a calculator.

1. Convert each term to a whole number power of 10 (such as 10^{-4}), then simplify. Write your final answer as a whole number power of 10.

   a. $\dfrac{100 \times 0.10}{0.0001 \times 0.010} = \underline{\qquad\qquad\qquad} =$

   b. $\dfrac{1}{1{,}000 \times 0.010} = \underline{\qquad\qquad\qquad} =$

   c. $\dfrac{10 \times 0.0010}{10{,}000 \times 0.010} =$

   d. $\dfrac{0.10 \times 0.010}{1{,}000 \times 100{,}000} =$

2. Calculate, then convert the final answer to scientific notation with 3 digits in the significand.

   a. $\dfrac{3 \times 10^{-5}}{4 \times 10^{-2}} =$

   b. $\dfrac{2 \times 10^{9}}{8 \times 10^{-2}} =$

   c. $\dfrac{1}{80 \times 10^{-2}} =$

   d. $\dfrac{3 \times 0.0010}{5 \times 0.010} =$

3. Zeros *before* the decimal but *after* all other numbers can "cancel on the top and bottom."

   Example: $\dfrac{60 \times 4{,}000}{800} = \dfrac{6\cancel{0} \times 4{,}00\cancel{0}}{8\cancel{0}\cancel{0}} = \dfrac{2400}{8} = \mathbf{300}$

   Below, cancel zeros top and bottom, then simplify using mental arithmetic. Write the answer as a fixed decimal number.

   a. $\dfrac{600 \times 40}{10 \times 30} =$

   b. $\dfrac{7500 \times 90}{30 \times 25} =$

   c. $\dfrac{160 \times 300}{3200 \times 60} =$

4. Fractions with zeros in the denominator *before* the decimal but *after* all other numbers can be separated into two parts and converted to exponential notation.

   Example: $\frac{3}{500} = \frac{3}{5 \times 100} = \frac{3}{5} \times \frac{1}{100} = 0.60 \times 10^{-2} = 6.0 \times 10^{-3}$

   Separate these into two parts, then simplify. Write the final answer in scientific notation with two digits in the significand.

   a. $\frac{64}{160} =$

   b. $\frac{144}{1200} =$

   c. $\frac{63}{7{,}000} =$

5. Convert these to fixed decimal values in the form 0.XXX

   a. $\frac{7}{28 \times 2} =$

   b. $\frac{70}{2 \times 50} =$

   c. $\frac{4 \times 45}{30 \times 9} =$

   d. $\frac{400}{20 \times 60} =$

6. Re-write each of the two quantities to scientific notation, multiply or divide, then convert to scientific notation with a 2-digit significand.

   a. $(7{,}000 \times 10^{-2})\ (0.080 \times 10^{-11}) =$

   b. $(0.090 \times 10^{9})\ (0.0070 \times 10^{-8}) =$

   c. $\frac{8 \times 10^{-3}}{200 \times 10^{-2}} =$ ________________ =

   d. $\frac{72 \times 10^{-3}}{900 \times 10^{7}} =$ ________________ =

Answers: 1a. 10^{7} 1b. 10^{-1} 1c. 10^{-4} 1d. 10^{-11} 2a. 7.50×10^{-4} 2b. 2.50×10^{10} 2c. 1.25×10^{0} 2d. 6.00×10^{-2} 3a. 80 3b. 900 3c. 0.25 4a. 4×10^{-1} 4b. 2b. 1.2×10^{-1} 4c. 9.0×10^{-3} 5a. 0.125 5b. 0.700 5c. 0.667 5d. 0.333 6a. 5.6×10^{-11} 6b. 6.3×10^{-4} 6c. 4.0×10^{-3} 6d. 8.0×10^{-12}

Activity #5

AP Mental Arithmetic #3: Fractions, Estimates, and Exponentials

To the Instructor

Activity #5 can be started in class at any time after both Activity #4 and tutorial Chapter 1 have been completed.

On this sheet, problems under each question are grouped with several of each type in a row. To cover each type, you might ask students to complete every 2nd or 3rd problem, then complete a similar part in the question if a particular type of problem gives them difficulty.

AP Mental Arithmetic #3: Fractions, Estimation, and Exponentials

On this sheet, do NOT use a calculator.

1. Re-write each of the two quantities to scientific notation, multiply or divide, and then convert your final answer to scientific notation with a 2-digit significand.

   a. $\frac{200 \times 10^{12}}{0.40 \times 10^{4}}$ = ________________ =

   b. $\frac{0.010 \times 10^{3}}{0.50 \times 10^{-7}}$ = ________________ =

   c. $\frac{0.10}{0.004}$ = ________________ =

   d. $\frac{0.020}{5{,}000}$ = ________________ =

   e. $\frac{0.048}{0.008}$ = ________________ =

2. Round these value, then *estimate* to an answer with one non-zero digit.

   a. $\frac{183}{21 \times 2}$ =

   b. $\frac{24}{5 \times 53}$ =

   c. $\frac{4 \times 27}{525}$ =

3. Solve these in any way you choose. Convert your final answer to scientific notation with a 2-digit significand.

   a. $\frac{0.00062}{0.20}$ =

   b. $(4.5 \times 10^{-4})\ (0.020 \ \times 10^{7})$ =

   c. $\frac{96 \times 10^{-3}}{120 \times 10^{-1}}$ =

   d. $\frac{75 \times 10^{16}}{0.025 \times 10^{-4}}$ =

Answers:

1a. 5.0×10^{10} 1b. 2.0×10^{8} 1c. 2.5×10^{1} 1d. 4.0×10^{-6} 1e. 6.0×10^{0}

2a. Between 3 and 6 2b. Close to 0.10 2c. Close to 0.2

3a. 3.1×10^{-3} 3b. 9.0×10^{1} 3c. 8.0×10^{-3} 3d. 3.0×10^{23}

For Honors/Pre-AP/Chem I Chemistry

Activity #6 – *The Mental Math Fluency Quiz*

To the Instructor

A first course in chemistry assumes students have had nine or more years of extensive practice in calculations involving arithmetic, fractions, and algebra (including exponential and logarithmic calculations). But is that assumption accurate for your students?

The fluency quiz in Activity #1 will help to find out. Questions 1-12 all involve math students are assumed to know as preparation for a first course in chemistry. The fluency quiz will help to identify what portion of that math may need review prior to when it is needed in Chem I.

In a course prior to AP, the last two questions should be omitted.

If Questions 1-8 on the fluency quiz identify "less than mastery" of mental arithmetic and exponential operations, you may want to consider Activities #7 and #10 for homework and #8 and #9 for classroom use.

For fluency quiz access and follow-up questions, see Activity #1

# # # # #

Activity #7 – *The Numeracy Tutorial*

To the Instructor

Activity #7 is a 9 page tutorial homework assignment which can printed for students or accessed online. The two lessons cover math facts, standard algorithms, decimal equivalents for fractions, using mental math to simplify fractions – and how to study chemistry. Lecture notes, practice problems, and worked-out answers are included.

The tutorial content can be viewed on PDF pages 5 to 13 at this link:
http://www.ChemReview.net/PrepChemFree.pdf (click and check your downloads).

Timing

The tutorial is available for free access at all times. It can be assigned at any point where you begin the "math topics" of chemistry to be completed by the 2nd or 3rd class thereafter.

For Chem I/Honors/Pre-AP sections, the Numeracy Tutorial could be homework assigned on the first day of class,

Assignment Options

An assignment to students could be

> Numeracy Homework:
>
> Go to this link: www.ChemReview.Net/Chem1Assignment.html
>
> Follow the instructions and complete Chapter 1 Lessons **1.1 and 1.2**.
>
> Be ready for a quiz on the content on (date).

For students without reliable computer access, the lessons can be printed from http://www.ChemReview.net/PrepChemFree.pdf and handed out: Print PDF pages 5 to 13, plus answers on page 25.

The quiz on this assignment is part of the multiple Chapter 1 quizzes provided. A quiz on the numeracy content alone could be constructed by modifying one of those quiz versions.

# # # # #

Activity #8 – *Using Mental Arithmetic to Simplify Fractions*

To the Instructor

Activity #8 is practice with the numeric simplification operations that are useful both during calculations and when estimating to check a calculator answer.

Activities #8 and #9 are “Practice Sheets” intended to be worked in class that are similar to the problems in the homework tutorials. The assumption is that in intro chem, students will benefit from both lecture and homework reinforcement.

You may want to use the sheets to introduce the topics in class and provide guidance and feedback as students work the problems a few at a time. Some problems can be left to complete at the end of a block, or as homework, or as a warmup review at the start of the next class.

This activity is recommended before students begin work on calculations involving exponential notation in Activity #10. The operations in this exercise will help with “exponential calculations without a calculator.”

# # # # #

Using Mental Arithmetic to Simplify Fractions

WithOUT a calculator, use your mental arithmetic skills to reduce these fractions to a one or two digit whole number. Show your work on this paper. Check your answers at the bottom.

Each problem may have multiple ways to cancel and solve. Any way to a correct answer works.

1. Example: $\frac{8 \times 15 \times 3}{72} = \frac{\cancel{8} \times 15 \times 3}{\cancel{72}\ \mathbf{9}} = \frac{\cancel{8} \times 15 \times \cancel{3}}{\cancel{72}\ \cancel{\mathbf{9}}\ \mathbf{3}} = \frac{15}{3} = \mathbf{5}$

(When doing multiple cancellations, you may want to re-write at some point, as in the "next to last" step above, to keep your progress clear.)

Hint: It usually helps to try to reduce the larger numbers on both the top and bottom first.

2. $\frac{49 \times 2 \times 3}{4 \times 7} =$

3. $\frac{42 \times 36 \times 5}{2 \times 6 \times 7} =$

4. $\frac{63 \times 4 \times 42}{6 \times 7 \times 9} =$

5. $\frac{48 \times 6 \times 11}{4 \times 18} =$

6. $\frac{35 \times 2 \times 8}{40 \times 14} =$

7. $\frac{72 \times 4 \times 36}{8 \times 9} =$

8. $\frac{8 \times 12 \times 7}{2 \times 96} =$

9. $\frac{10 \times 18 \times 56}{8 \times 2 \times 30} =$

10. $\frac{8 \times 27 \times 56}{7 \times 9 \times 32} =$

11. $\frac{28 \times 60}{12 \times 7 \times 2} =$

12. Double these: 42 17 36 45 16 24 32 48

13. Cut these values in half: 44 98 86 38 46 78 56

Answers: 2. 12 3. 50 4. 28 5. 44 6. 1 7. 50 8. 7 9. 21 10. 6

11. 10 12. 84 34 72 90 32 48 64 96 13. 22 49 43 19 23 39 28

Activity #9 -- *Multi-digit Multiplication and Division*

To the Instructor:

The worksheet below reviews the standard algorithms for multiplication and for simple long division. This activity is recommended *if* mental arithmetic gaps were identified in the fluency quiz.

Using the multiplication "standard algorithm" requires practicing recall of multiplication and addition. The division algorithm requires practicing multiplication, division and subtraction fact recall.

The benefits of requiring students to occasionally perform these types of calculations include

- They are an easy way to practice the "overlearning" of fundamentals that science says is necessary to understand explanations of quantitative relationships;
- Problems like these can be put on the board at the start of a class throughout the term for productive student work while you tend to administrative necessities.

The explanation of the two algorithms is the same as that in Lesson 1.2 in the homework tutorials, but the problems have different numbers. This sheet will supply additional practice.

The Common Core math standards require teaching both of these standard algorithms, but until 2014, under "K-12 math standards" in some states, students were not taught long division.

To start, you may want to assign one problem each of multiplication and division, then glance at a few papers to get an idea of what background your students have in these procedures.

# # # # #

Multi-digit Multiplication and Division

To understand the numeric relationships in science, you need to be able to do arithmetic quickly "in your head." One way to keep mental math skills sharp is to occasionally solve simple multi-digit multiplication and division without a calculator. To do this without overwhelming "working memory" (where you think), you need to apply a "standard algorithm."

1. The multiplication algorithm usually taught in the US includes these steps. For 76 × 42 = ?

Step 1:

$$\begin{array}{r} {}^{1}76 \\ \times\ \underline{42} \\ 152 \end{array}$$

Steps 2 and 3:

$$\begin{array}{r} {}^{2}76 \\ \times\ \underline{42} \\ 152 \\ \underline{304\ \ } \\ \mathbf{3192} \end{array}$$

←(putting a **0** after the 4 is an option)

With*out* a calculator, working on this paper, multiply these:

a. $\begin{array}{r} 95 \\ \times\ \underline{16} \end{array}$ b. $\begin{array}{r} 84 \\ \times\ \underline{73} \end{array}$ c. $\begin{array}{r} 39 \\ \times\ \underline{62} \end{array}$ d. $\begin{array}{r} 57 \\ \times\ \underline{48} \end{array}$

2. The "long division" algorithm usually taught in US education includes these steps:

For 2048 ÷ 8 =

$$\begin{array}{r} \underline{\ \ 2\ \ \ \ } \\ 8\,)\,2\,0\,4\,8 \\ \underline{1\,6\ \ } \\ 4\,4\ \end{array} \qquad \begin{array}{r} \underline{\ \ 2\,5\,6} \\ 8\,)\,2\,0\,4\,8 \\ \underline{1\,6\ \ } \\ 4\,4\ \\ \underline{4\,0\ } \\ 4\,8 \\ \underline{4\,8} \end{array} \qquad = \quad \mathbf{256}$$

With*out* a calculator, try these "evenly divisible" cases (the answer will be a multi-digit whole number -- no decimals or remainders).

a. $6\,\overline{)\,5\,1\,6}$ b. $9\,\overline{)\,2\,1\,8\,7}$ c. $8\,\overline{)\,5\,5\,6\,0}$

Activity #10 – *The Exponential Notation Tutorial*

To the Instructor

Activity #10 is a 11 page tutorial homework assignment which can printed for students or accessed online. The three lessons cover exponential notation, converting to scientific notation, and calculations that include powers of 10.

The tutorial content can be viewed on PDF pages 13 to 25 at this link: http://www.ChemReview.net/PrepChemFree.pdf (click and check your downloads).

Timing

The Exponential Notation tutorial is available for free access at all times. It can be assigned at any time after the Numeracy Tutorial (Activity #7) is completed.

Assignment

An assignment to students could be

> Exponential Notation Homework:
>
> Go to this link: www.ChemReview.Net/Chem1Assignment.html
>
> Follow the instructions and complete Chapter 1 Lessons **1.3, 1.4, 1.5**, and the **Review Quiz**.
>
> Be ready for a quiz on the content on (date).

For students without reliable computer access, the lessons can be printed from this file and handed out: http://www.ChemReview.net/PrepChemFree.pdf Print PDF pages 13 to 27.

Quizzes

Quizzes are available to instructors on the content of Chapter One (the Numeracy and Exponential Notation tutorials). A "practice quiz" is included which can be completed in class on the day before the quiz that counts.

To request the quizzes, click here.

# # # # #

For Instructors

Activity #11 – *Other Mental Math Resources*

To the Instructor

The tutorials are taken from the first two chapters of the supplementary textbook *Calculations in Chemistry - An Introduction*, available from W. W. Norton. The publisher has granted the authors of the text permission to post the first two chapters for free use by students and instructors at all times during the school year.

All **AP** and **first-year** instructors may request a free examination copy of all 24 chapters of the eBook. To receive a copy, click here.

The text includes the following lessons which review math both with and without a calculator:

Chapter 3	Significant Figures
Chapter 4	Dimensional Analysis
Chapter 5	Word Problem Strategies
Lesson 12.1	Solving for Ratio Units
Lessons 12.3	Fraction and Percentage Calculations
Lesson 16.3	Cancellation of Complex Units
Lesson 17.1	Choosing Consistent Units
Lesson 17.4	Choosing the Right Equation
Lesson 21.1	Powers and Roots of Exponential Notation
Lesson 22.1	Acid-Base Math -- Review
Lesson 23.1	Base 10 Logarithms
Lesson 24.3	Natural Logarithms

These lessons may provide ideas for math review lessons if you prefer to write your own.

For High Schools, a license for the full 24 chapters of the eBook is available for $6 per year if purchased for a 6-year adoption ($36 per six year license). Details are here .

Lessons in *Calculations* may be assigned at points in AP for review of Chem I fundamentals or as homework for topics throughout Chem I.

# # # # #

Activity #12 – *How the Brain Solves Problems*

To the Instructor

This section is a summary of the scientific research on

The New Science

With the arrival of inexpensive calculators in about 1975, curriculum writers began to assume that memorizing math facts to use in calculations would no longer be needed. The well-intended hope was to spare students the hard work of memorizing math facts.

Similarly, after the arrival of the internet in 1995, memorization of other facts and procedures was assumed to be less necessary for problem solving.

The assumption of these reforms was that the brain, during reasoning, could apply both memorized and non-memorized information with equal facility. Unfortunately, this assumption turned out to be mistaken.

Working Memory

What cognitive studies between 2000 and 2010 discovered and confirmed was that the "working memory" where the brain solves problems can use all information that can quickly be recalled from long-term memory (LTM), but very limited information that has not been well-memorized.

Award-winning cognitive scientist Susan Gathercole writes that for information that is not-well-memorized,

> "the capacity of working memory [where the brain reasons] is limited, and the imposition of either excess storage or processing demands in the course of an on-going cognitive activity will lead to catastrophic loss of information from this temporary memory system."

Which means fundamentals that are used often in problem solving, such as math facts – and symbols for elements and ion formulas -- must be well memorized.

The Importance of Fluency

How can we help students learn to solve scientific calculations? Here's what the experts say instructors need to know.

In a U.S. Presidential Commission report, five of the nation's leading cognitive experts wrote:

> "[T]here are several ways to improve the functional capacity of working memory. The most central of these is the achievement of automaticity, that is, the fast, implicit, and automatic retrieval of a fact or a procedure from long-term memory….
>
> [T]o obtain the maximal benefits of automaticity in support of complex problem solving, arithmetic facts and fundamental algorithms should be thoroughly mastered, and indeed, over-learned, rather than merely learned to a moderate degree of proficiency (Geary et al. 2008).

"Overlearning" means practicing recall *beyond* mastery: using "retrieval" strategies such as flashcards, mnemonics, or sequence recitation (methane, ethane …) to the point of mastery, and doing so repeatedly (Willingham 2004).

Why Makes Math and Science Different?

To learn math and science, why is such intense study required? For many types of learning, summary ("gist") memory is sufficient, and a species brain built for speech comprehension is good at summarizing meaning (Pinker 1994). But the relationships of math and science often require exact (verbatim) memory (6 times 7 is not "about 40" and phosphate ion isn't "PO something"), which the brain finds more difficult to store (Geary et al. 2008).

What Else Is Needed?

Initial memorization of fundamental relationships, though necessary, is *not* sufficient. Elements of knowledge are stored in the neurons of long-term memory. Neural links among those neurons on a variety of characteristics must be constructed and weighted by solving problems in different contexts, so that elements can be fluently recalled when appropriate (Anderson et al. 2004, Willingham 2008). Demonstrations, discussions, guided inquiry, and other forms of "active learning" can provide visual, spatial, auditory, and sequential associations for new knowledge.

However, neural connections cannot form until *after* the elements being connected are stored in and recallable from LTM.

To Summarize

According to science, to learn both math and science efficiently and effectively, students must *begin* each topic by "automating" (via "overlearning") their recall of the fundamental relationships for the topic. This new stored information must then be applied to solving problems in a variety of distinctive contexts.

Resources

Additional articles on how instructors can help students learn science and prepare for STEM majors include

1. *"Do I Need to Memorize That?" or Cognitive Science for Chemists* (2015), posted at www.ChemReview.Net/CogSciForChemists.pdf .
2. *Automaticity in Computation and Student Success in Introductory Physical Science Courses* (2016) at http://arxiv.org/abs/1608.05006
3. *Addressing Math Deficits With Cognitive Science* (2017) at https://confchem.ccce.divched.org/content/2017fallconfchemp8

References for the summary above:

Geary, D., et al.: Chapter 4 - Report of the Task Group on Learning Processes, pp. 4-2 to 4-11. (2008) https://www2.ed.gov/about/bdscomm/list/mathpanel/report/learning-processes.pdf

Willingham, D.: Practice makes perfect—but only if you practice beyond the point of perfection. *Am. Educator* 28(1), 31-33 (2004) at: http://www.aft.org/newspubs/periodicals/ae/spring2004/willingham.cfm

Pinker, S.: The Language Instinct: How the Mind Creates Language. Wm. Morrow, New York (1994)

Gathercole, S. E., Lamont, E., & Alloway, T. P. (2006). Working memory in the classroom. *Working memory and education*, 219-240.

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., Qin, Y.: An integrated theory of the mind. *Psychological Review* 111(4) 1036 (2004)

Willingham, D.: What will improve a student's memory? *Am. Educ*. 32(4), 17-25 (2008) at http://www.aft.org/pdfs/americaneducator/winter0809/willingham.pdf

Feedback

These materials are from www.ChemReview.Net/MentalMath.PDF .

Check back on occasion for updates. Version dates are noted at the top of the file.

Feedback on this material is appreciated! ChemReviewTeam@ChemReview.Net .

(End of packet)