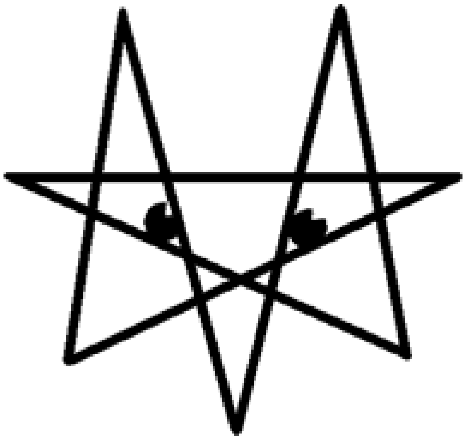

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Basic chemistry help is available here for high school or college students. Chemtutor begins with the fundamentals and gives expert help with the most difficult phases of understanding your first course in chemistry. Chemtutor is not necessarily a complete text for your course or a complete outline, but we are proud to offer some insightful help in the parts of primary chemistry that have been, from our experience, the hardest for students to grasp.

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Chemtutor is a work in progress. We are over half finished with the primary chemistry program. Pretty is not our aim, but there is a lot of good information here. Chemtutor can be a course of study for independent students, a resource for chemistry teachers, a review, or a tutoring program for students taking high school or basic college chemistry.

If you like what you see here, use it, tell your friends, and especially tell your chemistry instructor.
If you can help us with constructive advice, email info@chemtutor.com

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- Heuristics - How to learn
- Numbers and Math - The math you need for chemistry
- Units and Measures - Units and dimensions of measurements
- Atomic Structure - The inner workings of atoms
- Elements - A description of some selected common elements
- Periodic Table - An organized look at elements
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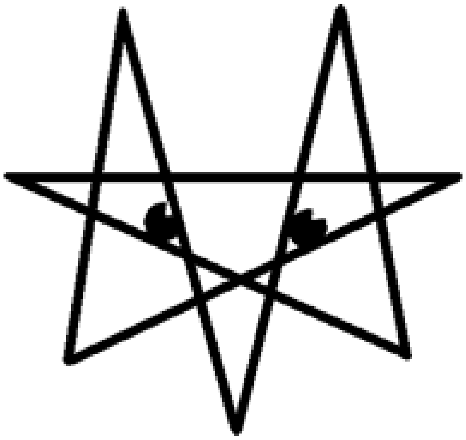

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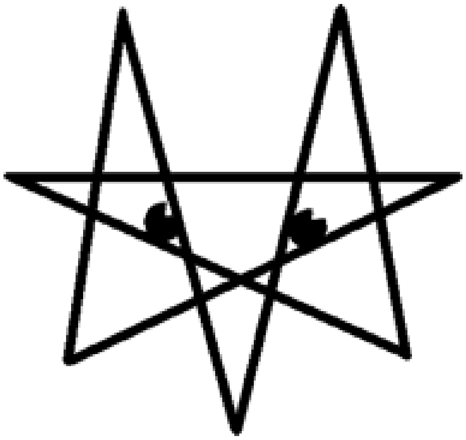

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HEURISTICS

HOW TO SURVIVE BASIC CHEMISTRY

In many high schools and colleges the basic chemistry course is the one that causes most concern among students. With everything going right, chemistry can be a fun but challenging course. Under poor conditions, your first chemistry course can be a real spittin’, cussin’ nightmare. The study of chemistry may be different from anything else you have ever done. In fact, there are several different topics in chemistry THAT MAY NEED TYPES OF STUDYING TAILORED TO THE TOPIC. Basic chemistry is a survey course in chemistry (That is, it covers a little bit of everything.) with emphasis on common chemicals and study techniques. The aim is to give you some chemical and general scientific literacy rather than train you to be a chemist. This outline is to: (a) tell you what to expect in most courses, (b) show you some methods of study for the course, and (c) show you some directions you can turn to for help, if you should need it.

The most useful advice is to stay up with or ahead of the class. As the Red Queen said to Alice, “Now, *here*, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!” If you fall significantly behind in basic chemistry, it is hard to catch up, but catching up is the only way to continue. The material "snowballs" in this course. By that I mean that the basic facts that need to be learned or memorized at the beginning are going to be used later in the course. Fluency in the basic material is necessary for you to be able to understand and learn the more complex ideas in the course. Chemtutor can help you keep up by showing you study methods, explanations, and other ways to learn the material.

We have found that students do better by having a quiz over a small amount of material. Act as if you will have a quiz every class period. These quizzes would either ask you to memorize some basic material or to use some of the material in a math process or a basic idea about chemistry. Designing and giving yourself quizzes to help you schedule your studying will prepare you for the major tests. Chemtutor usually has a Quickquiz or some math problems available to you to help you. If you are studying with someone, teach it to each other. The teacher always learns more than the student. (If you have it together sufficiently well to present it to someone else, you know it a lot better.)

Many students find studying with others from the same class is a lot of help. If you get together in a group of three or four, you will always have someone to study with. If you study with other students, it is easier to call them for missed assignments if you must be out.

Back to the beginning of Heuristics.

LEARNING STYLE MANAGEMENT

Learning is easy for some people. They can read something or hear something and understand it. For others the number of useful learning methods are more limited. Just because a person has a limited way to easily learn

DOES NOT MEAN THE PERSON IS STUPID OR UNEDUCABLE. The term LD (learning disability) indicates that a person has a difficult time acquiring and learning information by one source or another. It is truly unfortunate that a small number of students have used the idea of a learning disorder to attempt to cover for laziness. Most of the students who have a learning disorder would dearly love to be like other students, but they have experienced disappointment after disappointment.

If you have a learning disorder, you must analyze (or have analyzed) exactly what it is and learn your best way to compensate for it. Anyone teaching for any time has seen the student who will obey a spoken request, but when asked to read the request will appear to let it go in one eye and out the other. For some people the written word just does not register in the right way. For this type of learning disorder a student might find that reading the assignment aloud from the book will help. For others, copying the words in the book works best. For students who have a rough time understanding oral lectures, (Ask the teacher first.) bring a tape recorder to school and tape the lecture. At home, speak the lecture after the teacher or transcribe the lecture. Whatever works is best for you.

If you have a problem with learning, YOU CAN USE THIS CLASS AS AN EXPERIMENTAL PLACE to find some ways you can adapt to learning this type of material. Particularly the students who want to go into any type of scientific work will see this type of material again along with the need to grasp great amounts of it quickly. So the basic chemistry course makes a good practice ground for whether you can adapt yourself to this type of study. You know yourself best, so the person to help you with learning problems best is yourself. You need to vary your learning techniques UNTIL YOU FIND SOMETHING THAT WORKS for you for each type of studying. Try a number of methods. Use varying techniques. If teaching chemistry to your little sister works for you, do it. If you do not seem to find a way that you can use, consult a counselor who is willing to help you get professional assistance.

Back to the beginning of Heuristics.

HOW TO STUDY FOR TESTS

The type of test you can expect will, to a certain extent, determine what kind of studying you must do for it. Most instructors will tell you what style of test they will give you.

Objective tests (fill-in-the-blank or multiple choice) likely have the most obvious study methods. Flash card and association techniques are old standards for this type of work. Students working in pairs can quiz each other on this type of material. Make lists when you need to. Be sure you understand definitions rather than just memorizing them.

Math tests require the information of the objective tests and the practice in working problems. Historically in this class, the majority of trouble with math comes not from the math itself, but with background information that is lacking. Much of the background comes from the material Chemtutor suggests you know. If you have a problem with the math, first go back and learn the background well enough to use it. If the math itself is a problem, you need to ASK FOR HELP from a student or instructor. There is some help in math for you in Chemtutor, but if you have live help who can emphasize the points your instructor is requiring, that can be as useful. Many times your instructor will suggest a problem solving technique to you. Learn it and use it. If your instructor does not suggest a problem solving technique, Chemtutor has several approaches you can use.

Essay questions require yet another set of skills. The questions contain words like “explain” or “describe” or “compare”, and you will be expected to write an essay on the subject at the test. The first requirement, of course, is that you be able to write in the English language. Without intending to be unfriendly or mean, I do know that there may be some who have difficulty with that. The best I can tell you for a problem with the English language is that practice definitely shows.

Some students are used to writing a large amount of FILLER on essay tests. Most instructors can easily see through that and do not grade it, except downward if it becomes excessive. Most instructors look for content when they grade an essay test. Essay answers may be expected to contain information from the book and/or from lecture. To study for essay tests, you should: (a) consider some of the likely questions you might have, (b) collect information, (c) organize the information into an answer, (d) compare your answer to some of the answers of your classmates, and (e) practice answering the questions at home as if you were at the test. You should memorize important items you need to mention (“key words”), but usually efforts to memorize whole answers word-for-word do not work well.

Chemtutor can help you keep up with the class. If you still need help, other students in your class may be able to help you. If you do not get the help you need from students, call or visit your instructor. If the other students can not help you, maybe they also need some help. Most instructors would be glad to help you on an individual or group basis. ASK. Get help **far** before you find yourself close to failing. Many instructors understandably feel uncomfortable about helping students with their work only a few hours or minutes before a test. Usually they have test materials to get together at that time and feel a panicky student is not likely to learn much at short notice.

Back to the beginning of Heuristics.

CLASS MANAGEMENT

Chemtutor can be of significant help to you in the general material of the course, but each course and instructor is somewhat different. Your instructor should give you a course syllabus, a description of the course with information on what you need to do to pass the course. Keep your course syllabus as the first page of your class notebook. This may sound somewhat compulsive, but a well-kept notebook can be a great help to you. Keep all your notes in a three-ring or other insertable binder. Everything pertaining to the course should go into the notebook, preferably in date order.

Taking class notes is another important art. You must be able to judge what is important enough to write in your notes. If you are too busy writing notes, you may miss something useful. If you have trouble taking notes, you should compare your notes with the notes of other students in the same class as soon after the class as you can.

If you need help or information (notes or assignments) in the course, your first questions should go to the members of your lab or study group. Next, ask other students in the class. Get the name and phone number or email address of the members of your lab group and other students in the class. Keep these in your notebook. CALL them when you need guidance about course requirements.

Some colleges and universities allow you to drop a course before the end of it to preserve your grade average. If for some reason you need to drop out of the course, give your instructor the courtesy of the opportunity to talk with you. There are some good reasons for wanting to drop out; you don't feel you have the background, you don't have the time to devote to the work, you have other turmoil in your life and can't expend the emotional or mental effort, your work schedule conflicts with your school, etc.

Back to the beginning of Heuristics.

SOME POINTERS ON GENERAL STUDYING FOR CHEMISTRY:

- Keep up with the course. Catch up as quickly as you can if you fall behind.
- Know all rote material perfectly.
- Understand all concepts before going on.
- Thoroughly memorize all background material you are assigned.You will need it later.
- Keep a close watch on the assignments for the course. Call other students if you must.
- Find a good place to study. It must be comfortable, quiet, well-lit, and have all the things you need.
- Find a good consistent time for studying chemistry.
- Review lectures as soon afterward as you can.
- Determine which study methods are best for you.

- Study with others if it helps you. Choose study partners who are serious about learning.

Back to the beginning of Heuristics.

PROBLEM SOLVING SKILLS IN CHEMISTRY

In general, ACCURACY needs to increase rather than speed. Any technical literature is concentrated, and any form of “speed reading” is a waste of time on informationally dense material. Instead, devices to increase comprehension are necessary, such as mental models, finger counting, lip movement, figure drawing, or reading aloud to another person.

Intelligence may be defined as the ability to do abstract reasoning. Weaker students jumble abstract reasoning from lack of ability to grasp the entire problem at “one shot”. The next step for a weaker student is to give up for lack of a way to even get started. The best students support abstraction with concrete ideas. It is not the ability of the better student to fully grasp the complete abstraction that sets them apart, BUT THE ABILITY TO ORGANIZE A PROBLEM SO THAT NO PART OF IT IS TOO DIFFICULT. The idea behind the abstraction becomes more apparent as the idea is used. Another way to put that is that the better student does not usually have more efficient mental “hardware” but better “software”.

One tool for the development of better methods of problem solving is to take a short standard intelligence test and later analyze the results. The number of correct answers is not the most important data, but the analysis of how to “concrete” each question and how to spot potential errors on a case-by-case basis can help students see some ways to improve their personal analytical reasoning ability.

The use of a standardized test will give an ability to see a broad general group of problems that are each “informationally neutral”, that is, having no need for a body of background information other than the very rudimentary, such as the number system, the alphabet, and the ability to define words. Indeed, on any IQ test some questions require just word definition knowledge. In coursework, though, a body of knowledge is needed to interpret the questions. In chemistry some of this material may have to be known by rote in order to most efficiently perform on tests. Some examples of material that should be know by rote are the symbols of elements, polyatomic ions, some valences, measurements and the conversion factors among them, dimensions and the symbols for them, and some common names for materials. There are several ways to learn rote material, to include flashcards, pair quizzing, mnemonic devices, and reading aloud. Class time is poorly spent on rote material, but it is the teacher's responsibility to point out which material is a candidate for rote learning. There is, unfortunately, no way to “pour” this information into a student. That basic maturity of recognizing something that must be done and DOING it is necessary as a prerequisite.

We say that the math is difficult for the students, but they can do the arithmetic very well on the calculators they have. The real stumbling blocks are difficulties organizing the problem and a lack of background rote information. The problem-solving technique needs to be practiced first with trivial problems and then with increasingly difficult problems. “Practice makes perfect” seems to be true; the best way to learn what can go wrong in a problem is to make the mistake yourself, find the mistake, and learn from your mistake. Again, from the initial observations, any problem that can not be thought out completely in the head needs an overall ‘roadmap’ toward a solution and an orderly implementation of the pathway in which each step is demonstrable. For some good ideas on solving problems that are not the “formal” type of chemistry homework problem, see Polya's book, “How to Solve It.” For chemistry problems involving a formula, one pathway is the W5P method to be introduced later. For most conversion problems (many of the chemistry problems), the Dimensional Analysis system, also to be introduced later, is a splendid framework. The point is that with a good framework in which to think of the problem, a complicated problem is merely a series of simple problems.

Back to the beginning of Heuristics.

SOME POSSIBLY USEFUL POINTERS ON PROBLEM SOLVING:

- Read the problem carefully, moving your lips if necessary.
- Find the best way to think of the problem in the most concrete terms.
- Draw the problem, if possible.
- List the important information items in the problem. (GIVEN AND FIND)
- Know the background material for the problems.
- Follow the problem-solving method your teacher gives you, if one is given.
- Understand and use the units of quantities.
- Know your own weakest points so you can be wary of them.
- Go back and check your work. Use the units of the measurements to check your work. If the answer does not make sense, something is wrong.

Back to the beginning of Heuristics.

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Thermochemistry

A mnemonic device is a memory trick for memorizing information, such as HOMES as a memory jogger for the Great Lakes; Huron, Ontario, Michigan, Erie, and Superior. Medical students use menmonic devices to remember the cranial nerves such as, "On Old Olympus' Towering Tops A Finn And German Viewed Some Hopps," and some other less likely and more scatological sayings.

There was a cartoon in the New Yorker magazine some years back in which a neurosurgeon had a patient on the operating table with the top of the head off. The surgeon was stepping back pensively reciting the, "On Old Olympus'....." mnemonic device, with the obvious caution that there is a limit to the utility of such mnemonic devices. There comes a time when the information must be a little more fluent.

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NUMBERS AND MATH OPERATIONS

Back to the beginning of Numbers and Math Operations.

MEASURED vs EXACT NUMBERS

Exact numbers are numbers that are exact by definition, such as;

1 inch = 2.54 cm   or

1 gallon = 231 cubic inches   or

1 foot = 12 inches

or

numbers that come in integers and are not likely to be available in amounts smaller than integers. When you ask for seating in a restaurant, the number of people is an integer, an exact number.

Measured numbers are an estimated amount, measured to a certain number of significant figures without the benefit of any natural unit **or** a number that comes from a mathematical operation such as averaging. You would get a measured number from using a meterstick to find the length of a board or using a graduated cylinder to find the volume of a liquid. Average numbers of people would make a measured number, even though people naturally come only in integers. The average family in the U.S. has 2.37 children.

Back to the beginning of Numbers and Math Operations.

SCIENTIFIC NOTATION

There are many very large and very small numbers in scientific studies. How would you like have to calculate with:

1 mol = 602,200,000,000,000,000,000,000 atoms
or

1 Dalton = 0.000,000,000,000,000,000,000,00165 g?

You can streamline large or small numbers with scientific notation. The standard is that you place the decimal point after the first significant digit and adjust the exponent of ten so that there is no change in the value of the number. Think of the change as creating a new number with two parts, a digit part and an exponent part, from the old number. To put the decimal point behind the first digit, you must divide or multiply the original number by some integer power of ten. Then you must do the opposite (inverse) to the exponent part of the new expression so that there is no change in the value of the number.

$$(0.000{,}000{,}000{,}000{,}000{,}000{,}000{,}00165 \text{ x } 10^{24}) \text{ x } 1/10^{24} = 1.65 \text{ x } 10^{-24} \text{ or } 1.65 \text{ E-24}$$

$$(602{,}200{,}000{,}000{,}000{,}000{,}000{,}000/10^{23}) \text{ x } 10^{23} = 6.022 \text{ x } 10^{23} \text{ or } 6.022 \text{ E23}$$

The original numbers have the same value as the exponential forms, but the exponential forms have the decimal point in the right place. The 'right place' is to the right of the first digit. The ‘E’ in the number stands for exponent. Your scientific calculator will use the numbers in the shortened form, usually best represented by the ‘E’ form. Don’t get caught making too much of this. You have seen it before. The number ‘five point two million’ is the same as 5.2 E6. The number of the power of ten only indicates how many places you need to move the decimal to get the long form of the number back. The only question you might have trouble with is WHICH WAY to move the decimal. The easy way to remember that is: numbers that are less than one have negative exponent numbers in the scientific notation form, and numbers that are larger than one have positive exponent numbers. Very often Chemistry professors will tell you they want answers in scientific notation if the number is larger than one thousand or smaller than one thousandth. Keep your professor happy. Find out exactly what is required in your course and follow the instructions to the letter. Get some practice with scientific notation in the Chemtutor Quickquiz.

The table shows the fully written out number, the way we say the number in English, and the way to write the number in scientific notation. The numbers in scientific notation are to two significant digits.

Full number	Words for number	Sci. notation styles
5,000,000,000	five billion (USA)	5.0 x 10^{9} or 5.0 E9
500,000,000	five hundred million	5.0 x 10^{8} or 5.0 E8
50,000,000	fifty million	5.0 x 10^{7} or 5.0 E7
5,000,000	five million	5.0 x 10^{6} or 5.0 E6
500,000	five hundred thousand	5.0 x 10^{5} or 5.0 E5
50,000	fifty thousand	5.0 x 10^{4} or 5.0 E4
5,000	five thousand	5.0 x 10^{3} or 5.0 E3
500	five hundred	5.0 x 10^{2} or 5.0 E2
50	fifty	5.0 x 10^{1} or 5.0 E1
5	five	5.0 x 10^{0} or 5.0 E0

0.5	five tenths	5.0×10^{-1} or 5.0 E-1
0.05	five hundredths	5.0×10^{-2} or 5.0 E-2
0.005	five thousandths	5.0×10^{-3} or 5.0 E-3
0.000,5	five ten-thousandths	5.0×10^{-4} or 5.0 E-4
0.000,05	five hundred-thousandths	5.0×10^{-5} or 5.0 E-5
0.000,005	five millionths	5.0×10^{-6} or 5.0 E-6
0.000,000,5	five ten-millionths	5.0×10^{-7} or 5.0 E-7
0.000,000,05	five hundred-millionths	5.0×10^{-8} or 5.0 E-8
0.000,000,005	five billionths	5.0×10^{-9} or 5.0 E-9

Back to the beginning of Numbers and Math Operations.

SIGNIFICANCE AND ROUNDING

All the numbers in the above table have only two significant digits. Only the five and zero in each number has any numerical meaning other than place-holding. Let’s say that Delhi, India has five million people. We have expressed that number in one significant digit. That might be sufficient for such a number. Are we considering just people within the city limits? How about people who live outside the city and come in only for business? What year are we specifying? Let’s say we have enough information to number the population of Delhi at 5.1 million. That is now more a more accurate number that claims a two digit significance. What if we were to go absolutely wild and say that Delhi has 5.1376504×10^{6} people? That is the same number, isn’t it? First, it ridiculously claims eight significant digits. Even worse, that figures to 5,137,650.4 people, and people just don’t come in four-tenths of a person. Yes, you can claim to be far too accurate. With that in mind, here are the rules for considering the number of significant digits:

1. All non-zero digits are significant. Every 1, 2, 3, 4, 5, 6, 7, 8, and 9 claims significance.
2. All leading and following zeros that are only place-holders are not significant. The two numbers given as examples have a large number of merely magnitude-indicating zeros.
3. All zeros between two other digits are significant. The number 6.023 has a significant zero for a total of four significant digits.
4. All zeros to the right of the decimal and to the right of other digits are significant. For instance, the number 43.500 has five significant digits, two of which are zeros.

You may hear the phrases significant digit, significant numeral, or significant figure to describe this idea. Chemtutor will sometimes shorten it to "sig figs."

We can round numbers to the proper number of significant digits by lopping off all digits past the number

needed if less than five and rounding up the last needed digit if the following digit is five or more. For examples, here rounding to three significant digits:
3.4848 becomes 3.48;
4.1550 becomes 4.16;
5,786,899 becomes 5,790,000; and
0.000,347,00 becomes 0.000,347.

How do you know when you need to round? In multiplication and division, the answer cannot have more significant digits than the number with the smallest number of significant digits used to calculate the answer. So a four significant digit number multiplied or divided by an eight significant digit number will result in a number that can only claim four significant digits. Wisconsin has 379 cities with about 5.1 thousand people in it. How many people live in all these small towns? 379 x 5.1 E3 = 1.9329 E6, but the answer can only claim two significant digits. The answer must be 1.9 E6 people because the number 5.1 E3 only has two significant digits.

How do you know where to round in actual measurements? The last digit is the one we get by estimation. For instance, if you have a graduated cylinder marked in milliliters and tenths of a milliliter, you should be able to estimate between the lines (interpolate) of tenths of milliliters and measure hundredths of milliliters.

The allowed significance works differently with adding and subtracting. The addition of a family of four to a city of three million does not significantly change the population of the city. If you have 1,578,000 chickens and you add 2,717 chickens to them, you have 1,581,000 chickens. Align these numbers one on top of the other so you can more easily see the reasoning behind this. No answer in subtraction or addition can have significant digits in COLUMNS in which on the right there is not a significant digit in each participant number.

It is just as important to know WHEN to round as HOW to round. In any math problem you should wait until the end to round; Only the final answer should be rounded. Carry as many significant digits as you can throughout the problem. On a calculator, the most efficient way to carry the maximum is to do all the calculation on the calculator. Arrange the problem so that you do not have to copy an intermediate answer only to re-enter it into the calculator. If you do find yourself needing to save numbers outside the calculator, copy several more significant digits than you think you need.

For help in significant digits and scientific notation, ask Chemtutor for the Quickquiz. For a good scientific calculator on the web, click here.

Back to the beginning of Numbers and Math Operations.

DIMENSIONAL ANALYSIS

Dimensional analysis is a system of using the units of quantities to guide the mathematical operations. There are other names for the very same idea, for instance, unit conversion or factor label or factor-unit system. Here we will abbreviate it to DA. It can be used for conversions, to check work done with formulas, or, in uncomplicated problems, instead of formulas. As we will use it, DA can do much of the mathematical work of chemistry. We will also be doing some more complex math problems for which the use of formulas is necessary. The general rule for whether to use DA or W5P is: if the answer is the same dimension as the given units, you will likely use DA, but a formula best accounts for any change in dimension. (W5P method. See below.) To use the DA system for conversions, you should check to see that the unit given and the unit into which you want to change are the same dimension. To someone unfamiliar with that idea, the prospect of finding out how many feet are in 2.5 acres almost seems a reasonable one.

Begin with the KNOWN QUANTITY. Place all the known quantity in the numerator of the beginning fraction if there is no denominator. To use DA, one must know the dimensions of units and conversion factors. Definitions, such as those found in the metric prefix and unit sheet can serve as conversion factors by dividing one side of an equation by the other, thus: since 1 mile = 5280 ft.

$$\left(\frac{1\text{ mile}}{1\text{ mile}}\right)=\left(\frac{5280\text{ ft.}}{1\text{ mile}}\right)\quad\text{so}\quad\left(\frac{5280\text{ ft.}}{1\text{ mile}}\right)=1\quad\text{and}\quad\left(\frac{1\text{ mile}}{5280\text{ ft.}}\right)=1$$

We can multiply any quantity by anything equal to 1 without changing the value of the quantity. Therefore, 5280 ft/mile or 1 mile/5280 ft is a conversion factor for length. These conversion factors can change 6.20 miles to a number of meters in serial fashion thus:

$$\left(\frac{6.20\ \cancel{\text{miles}}}{1}\right)\left(\frac{5280\ \cancel{\text{ft.}}}{1\ \cancel{\text{mile}}}\right)\left(\frac{12\ \cancel{\text{in}}}{\cancel{\text{foot}}}\right)\left(\frac{2.54\ \cancel{\text{cm}}}{\cancel{\text{inch}}}\right)\left(\frac{1\text{meter}}{100\ \cancel{\text{cm}}}\right)=\boxed{9978\text{ meters}}$$

Notice you can visualize the definitions you know from the units-and-definitions section in each one of the conversion factors. The definition 1 mile = 5280 ft can convert miles to feet. We want to cancel out the miles, so we place 1 mile under the 5280 ft. Now the mile units can cancel with one in the denominator and the other in the numerator. If we were to stop at this point, the answer would be in units of feet. Similarly, use 1 foot = 12 in. to go from feet to inches, placing the foot unit in the denominator to cancel with the foot unit in the numerator. The definitions and conversions in the units and measures and definitions chapter become very convenient for use as conversion factors. It is necessary to know them by rote to be able to easily use the system. If you know the definitions well, not only will you escape having to look up the right definition, but you will much more easily spot the best way to convert the numbers. The metric system definitions come from the powers of ten of the metric prefixes. The metric ‘staircase’ method allows for changes from any magnitude to another in one conversion step by ‘counting the steps up or down the staircase.’

We can use the density of a material as a conversion factor between mass and volume rather than a formula in this manner: The density of mercury is 13.6 g/cc. What is the mass of two liters of mercury?

$$\overset{\text{GIVEN}}{\left(\frac{2.00\ \cancel{\text{liters}}}{1}\right)}\ \overset{\text{DACF}}{\left(\frac{1000\ \cancel{\text{cc}}}{\cancel{\text{liter}}}\right)}\ \overset{\text{DENSITY}}{\left(\frac{13.6\text{ g}}{\cancel{\text{cc}}}\right)}=\overset{\text{RAW ANSWER}}{27200\,\cancel{\text{g}}}\ \overset{\text{DACF}}{\left(\frac{\text{kg}}{1000\,\cancel{\text{g}}}\right)}=\overset{\text{ANSWER}}{\boxed{27.2\text{ kg}}}$$

This math could have been done without stopping to calculate the intermediate answer of 27200 g, but the math always works, no matter in what order it is done. In both cases we carefully accounted for the units by canceling. A stepwise orderly progression of easily remembered changes can convert units to anything you need. The metric system is particularly easy to use with DA. The definitions are multiples of ten and need scrupulous care to stay untangled. Here is a way to think of it using a change from Kilometers to millimeters. Kilometers being the larger unit, begin with one of the larger unit. The number of smaller units, (mm) is the power of ten that is the number of steps up the metric staircase. This process keeps the exponent positive.

$$1\ \text{km} = 1\text{x } 10^{6}\ \text{mm} \quad \text{or} \quad 1\ \text{km} = \text{E6 mm}$$

Problems that involve many substances or a lot of addition and subtraction can become difficult with DA, but for conversions within a dimension or simple multiplication or division problems, even in serial fashion, it is a powerful tool. We can use DA when working formula problems by consistently using and canceling the appropriate units. The answer must come out in the proper dimension according to the units, or you should suspect something wrong. You may then easily convert the answer to units you want by using simple definitions as conversion factors. As you may have suspected, DA has many uses in the study of chemistry. Many common daily-living problems could be helped by thinking in DA.

Back to the beginning of Numbers and Math Operations.

PROBLEM SOLVING TECHNIQUES - THE W5P METHOD

One of the really difficult things to learn or teach in any science is the way to do word problems. For some students, there seems to be a mental block about it. Chemtutor teaches a method that may work for you, but the success of the method depends upon the background knowledge of the student in the units, dimensions, and formulas.

W5P METHOD (WILD & WONDERFUL WAY TO WORK WORD PROBLEMS)

GIVEN **-** List all pertinent information with dimension symbol, number and unit.

FIND **-** List the dimension of the quantity requested in problem.

FORMULA **-** With the dimensions in GIVEN and FIND, list the formula of formulas that fit.

SOLVE **-** Solve the formula for what you are looking for (FIND), substitute the number values in GIVEN, and perform the math on both the units and the numbers.

ANSWER **-** Check the answer for likeliness, make sure the units are appropriate, express the answer in scientific notation and to the accuracy required, and draw a box around it so it is obvious which number your answer is.

Here is a sample problem using W5P method. Lead is 11.3 g/cc. What is the volume of 24.5 kg of lead? If you recognize the units of density, you can immediately spot that D = 11.3 g/cc. The symbol of the dimension, density, is D. We show the number and units of the density with the symbol. The mass is 24.5 kg. (m = 24.5 kg.) Find the volume (V). The formula that has all the dimensions needed is the density formula from the formula list. We write it here in its original (memorized!) form. Solve for what you are looking for (volume here) using just a little bit of good old basic algebra. You would like to get the equation in the condition where you have V on one side all by itself. Do the algebra as stepwise as you need to in order to show yourself you have actually done it right. Next, substitute the measurements for the dimension symbols. Note that the kilogram and cc and gram units cancel, along with the number one thousand in the math. All we have left is to do the division and processing of the answer. The answer calls for three significant digits. The number does not need scientific notation because the number is less than one thousand and more than one thousandth.

GIVEN: $D = 11.3\ \text{g/cc}$ $\quad m = 42.5\ \text{kg}$ $\qquad$ **FIND:** V

ORIGINAL FORMULA $\qquad$ **STEPS IN SOLVING FOR "V"** $\qquad$ **SOLVED FORMULA**

$$D = \frac{m}{V} \qquad D(V) = \frac{m\cancel{(V)}}{\cancel{V}} \qquad \frac{\cancel{D}V}{\cancel{(D)}} = \frac{m}{(D)} \qquad V = \frac{m}{D}$$

SUBSTITUTE $\qquad$ **D A TO CLEAN UP** $\qquad$ **RAW ANSWER** $\qquad$ **ANSWER**

$$V = \frac{24.5\ \cancel{\text{kg}}}{11.3\ \cancel{\text{g}}/\cancel{\text{cc}}} \quad \frac{1000\ \cancel{\text{g}}}{\cancel{\text{kg}}} \quad \frac{\text{liter}}{1000\ \cancel{\text{cc}}} = 2.168\ \text{L} = \boxed{2.17\ \text{L}}$$

Notice that the "GIVEN" section includes the symbol for the dimension of the information, the number and unit. "FIND" shows the dimension of the information requested. The formula is not labeled as such, but it is the relationship that has the requested information among the dimensions and all other dimensions in the formula are known. (Here we are looking for V and we know D and m.) The next step is to solve the formula for the dimension we need. Then substitute the given quantities for the known dimensions and process the answer.

Here is an opportunity to show you a small but useful way to save yourself some grief. Consider the unit g/cc in the above math. The unit is a fraction in the denominator. It is easier to think of as cc/g in the numerator. (The rules of math permit you to move a fraction from the denominator to the numerator if you invert the fraction.)

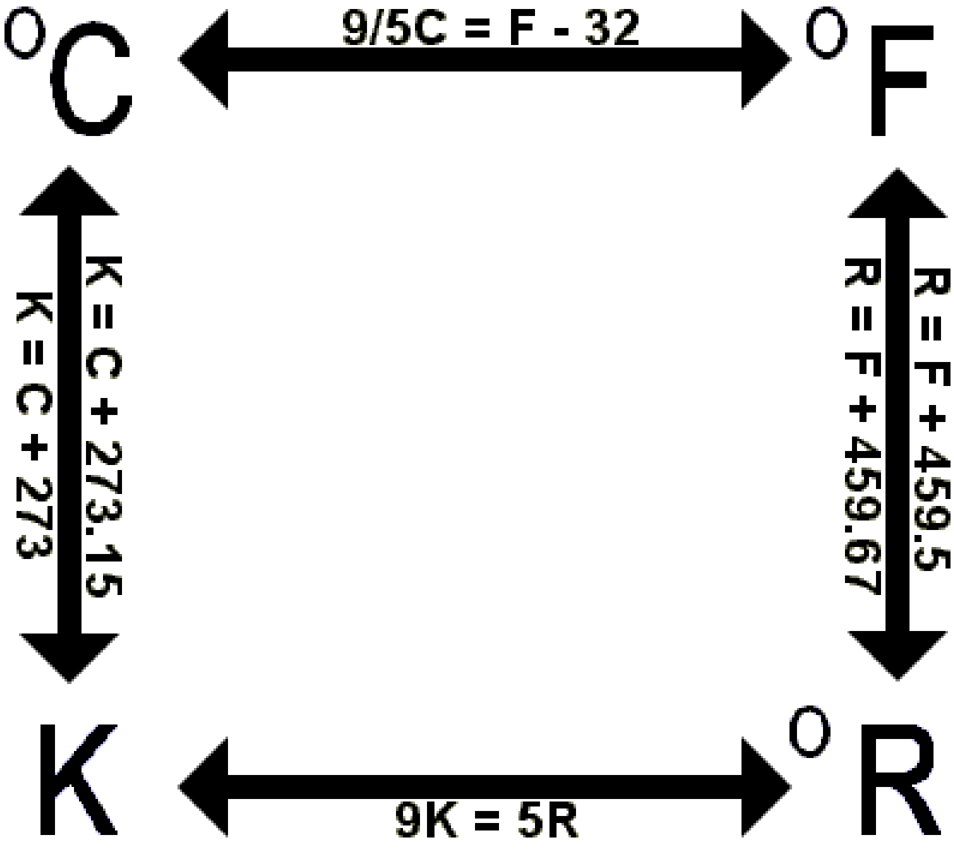
$$\overset{\textbf{A}}{\frac{24.5\ \text{kg}}{11.3\ \left(\frac{\text{g}}{\text{cc}}\right)}} = \overset{\textbf{B}}{\frac{24.5\ \text{kg}\left(\frac{\text{cc}}{\text{g}}\right)}{11.3}} = \overset{\textbf{C}}{\frac{24.5\ \text{k}\cancel{\text{g}}\ (\text{cc})}{11.3\ \quad (\cancel{\text{g}})}} = \overset{\textbf{D}}{\frac{24.5(\text{k})\text{cc}}{11.3}} = \overset{\textbf{E}}{\frac{24.5\,\text{liters}}{11.3}}$$

Fraction A comes from the original substitution of the numbers and units into the solved equation. Fraction B shows the inversion of the fractional unit into the numerator. This is a really useful way to simplify fractions that seem complex. Fraction C shows the same fractional unit integrated into the whole fraction and cancels the unit of gram. Step C is not needed if you want to cancel the gram unit in the numerator. Fraction D shows what happens when you cancel a unit without its metric prefix. The k is just one thousand now, so k (cc) is the same as one thousand times cc which is a liter. Fraction E shows the final unit. Many students make math mistakes by failing to simplify fractions in the denominator.

Back to the beginning of Numbers and Math Operations.

THE TEMPERATURE BOX

There are two types of common conversion that are not easily fit for calculation by DA because they require formulas among the different units. Temperature conversions are among the units Celsius, Kelvin, Fahrenheit, and Rankine. Acidity units are pH, hydrogen ion concentration, hydroxide ion concentration, and pOH. A conversion box is a fine teaching device for this type of unit association group.



(For going around the box, use K = C + 273.15 and
R = F + 459.67 to get more accurate results.)

SOME COMMON TEMPERATURES in all four scales to the nearest whole degree

Material Point	Kelvin	Celsius	Fahrenheit	Rankine
copper m.p.	1356	1083	1981	2441
gold melt pt	1336	1063	1945	2405
aluminum m.p.	933	660	1219	1680
lead melt pt	601	327	621	1081
H_2O bp1atm	373	100	212	672
chicken body	313	40	104	564
human body	310	37	98.6	558
room temp.	293	20	68	528
H_2O m.p.	273	0	32	492
zero °F	292	-19	0	460
mercury m.p.	234	-39	-38	422
°C = °F	233	-40	-40	420
absolute zero	0	-273	-460	0

There are only three temperature measurement scales commonly used. The Kelvin, Fahrenheit, and Celsius or Centigrade scales all have common uses. The Rankine scale is not commonly used, but it is needed here for the learning experience. Consider four identical liquid-type thermometers side-by-side with different markings on them. This is a good mental image because These four scales measure exactly the same thing. The small superscript ‘zero’ before the symbol means ‘degree.’ Some people make a big issue of omitting the degree sign before Kelvin. They say ‘Kelvins’ instead of ‘degrees Kelvin.’

The Kelvin and Rankine scales are both absolute temperature scales. Since temperature is a measure of the average velocity of the atoms or molecules in a material, it makes sense that there is a temperature that represents the condition of no molecular motion. That temperature is called ‘absolute zero.’ Both Kelvin and Rankine scales are absolute scales. The zero mark on these scales is at absolute zero. There are no negative temperatures on either scale. Since they have the same zero point, the relationship between them is a simple proportion. You will remember the formula as the Dog Equation - - Canine equals Arf-ive. Yes, K 9 = R 5 or, as you more commonly see it, 9 K = 5 R. No applause, please.

The size of the Celsius degree is the same as the size of the Kelvin degree. The Celsius scale just has its zero at the freezing point (or melting point, for they are the same) of water, 273.15 K. The size of the Fahrenheit degree is the same as the size of the Rankine degree. To calculate the temperature in Rankine, add 459.67 to the Fahrenheit temperature. For instance, the freezing point of water is 32 °F or 491.67 °R.

The easy way to be sure to know the conversion between Fahrenheit and Celsius is as follows: (a) Only remember one formula. (b) From the Dog Equation the proportion of Celsius and Fahrenheit is nine to five. 9/5 C must be the right proportion, and (c) Fahrenheit zero is 32 degrees below the freezing point of water. Therefore, the equation is:

$$\boxed{9/5\ C = F - 32}$$

KNOW THIS

This is the only equation you will need or want. Some texts will ask you to memorize two equations, one solved for Fahrenheit and the other solved for Celsius. To get Celsius temperature from Fahrenheit, you must solve for 'C,' but, for the convenience of remembering only one easily related equation, the price is cheap.

The temperature box is a device that can give you as much practice as you need. Here is how to use it. Choose a temperature, for instance, 37 °C, normal human body temperature. Calculate around the box either clockwise or counter-clockwise. You should return to the same Celsius temperature. For rough one-time calculations, you can use the more generally quoted change between Celsius and Fahrenheit and between Fahrenheit and Rankine. For going around the temperature box, you should use the more exact numbers in the parentheses.

Back to the beginning of Numbers and Math Operations.

PERCENTAGE CALCULATIONS

Converting raw numbers to percentages is easy once the parts are defined. A percentage is the target over the total multiplied by one hundred percent.

$$\frac{\text{TARGET}}{\text{TOTAL}} \text{ X } 100\% = \text{PERCENT}$$

There are thirty people in the classroom. Of them, seventeen are male. What percentage of males are in the classroom? 'Seventeen males' is the target we have defined. 'Thirty people' is the total. Seventeen divided by thirty times one hundred is 56.66667 to seven significant digits or 56.7 to three significant digits. Males are people, so we cancel the units. The answer is 56.7 percent.

$$\frac{17 \text{ males}}{30 \text{ people}} \times 100\% = 56.66667\% = 56.7\%$$

In many cases, the most difficult part of using percentages is identifying the target and the total. Percentages do not have any other unit attached to them other than the percent. After dividing one unit by the same type of unit and cancelling the units, that makes sense.

Back to the beginning of Numbers and Math Operations.

BASIC ALGEBRA

Algebra operations can be performed on equations with symbols, numbers, or measurements. An equation states that the right side of the equation is equal to the left side. The rules of manipulation of the two sides of an equation without changing the equation are: (a) you can multiply or divide both sides by the same thing, (b) you can add or subtract the same thing from both sides, (c) you can raise both sides to the same power, you can change both sides to or from any exponent. Also, you can substitute anything in an equation for something of equal value.

One of the really big mistakes many novice calculators make is attempting to do too much between the ears before enough practice has been done. The best advice is that calculating with a pencil (or writing implement of any type) is much more reliable than calculating mentally. You may have heard if ‘back- of- the- envelope’ calculations by scientists or engineers. Most people of science or technology understand that even something scratched on the back of an envelope is more reliable than mental calculation. Show your work, if not to your teacher, to yourself. Show the addition of the same thing to both sides. Show the cancellation of units. Show the stepwise conversion of what you know to what you need. Except for log and antilog work for pH calculations, the use of more complex algibraic operations in basic chemistry course is rare. The use of quadratics or complex factoring is rare.

Back to the beginning of Numbers and Math Operations.

PROPORTIONALITY - DIRECT PROPORTION

A boy and a girl are in the back seat of the car on a long trip through the countryside. Their mother suggests that they count the cows on their side of the car to keep them occupied. The boy sees a large number of cows on his side and begins furiously counting, “1, 2, 3, 4, 5,….” It is obvious from his disappointment that he did not get a chance to count all his cows. Then a much larger herd appears on the girl’s side. She looks at the herd and proudly announces, “Six hundred and seventy seven cows.” The boy angrily says, “Oh, you couldn’t have counted that many so quickly.” She retorts, “It’s easy. All you have to do is count the legs and divide by four.”

Mathematically, of course, she is correct. The number of cows is proportional to the number of legs; as the number of cows increases, the number of legs increases and visa-versa. This could be expressed mathematically as:

$$\text{number of cows} \propto \text{number of cow legs}$$

You would read the proportionality as: "The number of cows is proportional to the number of cow legs."

An example in chemistry of proportionality is the relationship of the pressure and temperature of the same gas at a constant volume. When the temperature increases, the pressure increases. When the temperature decreases, the pressure decreases. The formula for that can be expressed:

$$\frac{T_1}{T_2} = \frac{P_1}{P_2}$$

PROPORTIONALITY - INVERSE PROPORTION

Consider the table of hydrogen ion concentrations versus hydroxide concentrations. As the [H$^+$] increases, the [OH$^-$] decreases. As the [H$^+$] decreases, the [OH$^-$] increases. This relationship is inverse proportionality.

It is something of a joke in corporate circles that the importance of a person is inversely proportional to the number of keys carried. The CEO of the company (of 'infinite importance') does not have to keep any keys because all doors are opened for the CEO. The janitor (lowest in importance) has a large ring of keys. This can be shown in the proportion manner by:

$$\text{importance} \propto \frac{1}{\text{number of keys}}$$

Using the pressure and volume of the same gas at constant temperature, inverse proportionality can be expressed mathematically by:

$$P_1V_1 = P_2V_2$$

HOW FORMULAS SHOW DIRECT AND INVERSE PROPORTION

It is easy to spot proportionalities in mathematical formulas. Let’s use the universal gas law, $PV = nRT$, as an example. If the two variables are both in the numerator (or both in the denominator) on opposite sides of the equation, as P and T in the universal gas law, they are proportional. It two variables are on the same side of an equation, they are inversely proportional, as in P and V in the same equation.

Back to the beginning of Numbers and Math Operations.

FOR AN EXPLANATION AND DISCUSSION OF EACH PROBLEM, CLICK ON THE QUESTION MARK FOLLOWING THE QUESTION. A SET OF ANSWERS FOLLOW EACH PROBLEM SET.

These problems may not have much to do directly with chemistry, but they are designed to help you understand the methods of thinking about and solving problems in chemistry.

PROBLEM SET # 1 - CONVERSIONS USING DA

DO THESE CONVERSIONS IN THE DIMENSIONAL ANALYSIS STYLE. ANSWER IN SCIENTIFIC NOTATION IF > E3 or < E-3.

1. What is 1.50 mm in km ?

2. How many nanoseconds are in 1.50 days?

3. How many floz. of water do you have in exactly half of a ten gallon can?

4. A car is going 60.0 MPH. How fast is that in ft/sec?

5. A car is going 62.0 MPH. How fast is that in KPH?

6. How many mm^2 are there in one square kilometer?

7. How many in^2 are there in an acre?

8. How many mm^2 are there in 0.550 acre?

9. A car goes 0 to 60.0 MPH in 5.00 sec. Write that acceleration in $m/_{sec^2}$?
(Start with (60 mi)/(hr.)(5 sec))

10. Light travels at 3.00 E8 m/sec. How fast is that in MPH?

11. An elephront has a mass of 1.80 tonnes. What is its weight in ounces?

12. Mercury has a density of 13.6 g/cc. What is that in #/gal?

13. A light year is the distance that light goes in a year. Using data from #10, how long is a light year in miles ? (Rate times time = distance)

ANSWERS TO PROBLEM SET #1

1. 1.5 E-6 km
2. 1.30 E14 nsec
3. 640 Floz.
4. 88.0 ft/sec
5. 99.8 KPH
6. E12 mm2
7. 6.27E6 in2
8. 2.23 E9 mm2
9. 5.36 m/sec
10. 6.71E8 MPH
11. 6.34 E4 Oz.
12. 113 #/gal
13. 5.88 E12 mi

Back to the beginning of Numbers and Math Operations.

PROBLEM SET #2 - PRACTICE WITH W5P METHOD

1. How deep would the water in a trench three inches wide and sixteen feet long have to be to contain 24.0 cubic feet of water?

2. Cloth is four feet wide as it comes on the bolt. What length of cloth would you need to cover a surface of 58.0 square yards?

3. It is 762 miles from here to Chicago. An obese Chemistry teacher jogs at a rate of one mile every twenty minutes. How long would it take him to jog to Chicago if he jogged continuously and REALLY wanted to get there?

4. The density of lead is 11.4 g/cc. What is the mass of a block of lead two cm by ten cm by four cm?

5. How many liters of water could you fit into a container measuring 10.0 ft by 13.0 ft by 8.00 ft?

6. A box of qrtpsdfgh measures 24.0 x 4.00 x 12.0 inches. It has a density of 38.0 pounds per cubic foot. What is the weight of qrtpsdfgh in the box? (Notice the English system density!)

7. My basement was flooded after a big rain. The basement is rectangular 12.0 ft by 17.0 ft. The water was measured as it drained out at 51.0 cubic feet. How deep was the water in the basement?

8. A standard expressway lane is 11.0 ft wide. How long would a four lane expressway be if it had a square mile of pavement?

9. The density of gasoline is 720 g per liter. What is the mass of a jar of gasoline three cm by four cm by five cm?

10. How many liters of water could you fit into a hot tub that measures 1.50m deep and three meters in diameter? How many people? (1 cubic meter = 1000 L)

11. Mr. Richland has a swimming pool 10.0 ft by 20.0 ft. He had a wild party and they threw his son's Volkswagen into the pool. The VW has a volume of 10 cubic feet. It was sealed up, but it sank because of all the lead bricks (?!?!?*?*?) in it. (a) What is the area of the pool? (b) How much did the VW raise the water level?

12. How long is a string?

ANSWERS TO PROBLEM SET #2

1. 72 in (6 ft)
2. 43.5 yd
3. 254 hours
4. 912 g
5. 2.94 E4 L
6. 25 1/3 #
7. 0.25 ft
8. 120 miles
9. 43.2 g
10. 1.06 E4 L
11a. 200 sq.ft.
11b. 0.6 in or 1/20 ft.
12. yes

Back to the beginning of Numbers and Math Operations.

PROBLEM SET #3 - W5P AND DA REVIEW PROBLEMS

1. How many ounces is 45.0 tonnes?

2. How many liters are in 8.55 cubic miles of ocean water?

3. Water has a density of one gram (1.00g) per cubic centimeter. What is that in pounds per gallon?

4. A roadsign posts a 50.0 MPH limit. What is that in KPH?

5. How large in square feet is a 525 square meter house?

6. How many square yards of paint are needed on the ceiling of a room that is 24.0 feet wide, 51.0 feet long and ten feet high?

7. Gasoline has a density of 5.83 pounds per gallon. What volume tank would you need to store three tons of gasoline?

8. The bathtub in the residential suite of the White House had to be enlarged for Warren G. Harding. He weighed 370 pounds. (Burp.) The bathtub is four feet wide, six feet long and three feet high. How many gallons of water are needed to fill the WGH Memorial Bathtub? (1 gal = 231 cu.in.)

9. The density of water is 8.3 #/gal. What weight of water is needed to fill the WGH Memorial Bathtub?

10. Mercury is 13.6 kg/liter. What mass of mercury is needed to fill the WGH Memorial Bathtub?

11. The velocity of light is 186,000 mi/sec. It takes radio signals 17.6 minutes to go from Earth to Jupiter at their closest approach. How far apart are the two planets at that time?

12. A car takes on 22.7 L of gasoline. How many Floz is that?

13. Osmium metal is 22.0 g/mL. What's the volume of 2.50 kg of it?

14. Concentrated sulfuric acid is 1.84 kg/L. What is the mass of 500 mL of it?

15. A man is 5 ft. 11 inches tall. How many meters is that?

16. Why is a duck?

ANSWERS TO PROBLEM SET #3

1. 1.59 E6 Oz.
2. 3.56 E13 L
3. 8.30 #/gal
4. 80.5 KPH
5. 5.65 E3 ft^2
6. 136 sq.yd.
7. 1.03 E3 gal
8. 539 gal
9. 4.49 E3 #
10. 2.76 E4 kg
11. 1.96 E8 mi
12. 770 Floz
13. 114 mL
14. 0.920 kg
15. 1.80 m
16. because

Back to the beginning of Numbers and Math

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Elements
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UNITS, MEASURES, & DIMENSIONS

MEASUREMENTS

Measurement is the most useful form of description in science. Often the most useful measurements are those that have a number and a unit, such as ‘12.7 inches.' Here '12.7' is the number and 'inches' is the unit. This unit of inches in the example is one of the common units in the dimension of length. A number, then, is an expression in numerals. A unit is a recognized way to divide the essence of a dimension for measurement, and a dimension is a measurable physical idea. Here is a bit of advice you can overlook only at your peril: To become fluent in the subject you should memorize the basic background of information. The following units, dimensions, and measures are so basic to the study of Chemistry that you could always help yourself by memorizing these. Chemtutor offers a Quickquiz on this table along with the metric prefixes. The real test of whether you know this well enough is to recognize the dimensions of any measurement and know its symbol and magnitude from the unit alone. Chemtutor Quickquiz will help you with that.

Back to the beginning of Units and Measures.

DIMENSIONS, UNITS, AND SYMBOLS

Notice the symbols of the dimensions as they would be used in formulas. The basic metric symbol or the symbol of the most used metric unit is listed after the metric units.

DIMENSION	**SYMBOL**	**METRIC UNITS**	**SYMBOL**	**“ENGLISH” UNITS**
LENGTH	S, l, d, r	meter (+m.p.)	m	Ft, in,Yd, mi, etc.
AREA	A	sq.meter, etc,hectare	m^2	sq.Ft, etc., acre
VOLUME	V	cu.meter, etc., liter	m^3, L	cu.Ft,cu.in,etc.,gal,Floz.
TIME	t	sec (+m.p.) sec,min,hr,day,yr,etc.(both metric & English)		
MASS	m	Kilogram (+ m.p.), AMU	kg	(slug, rarely used)
FORCE (weight)	F, F_w	Newton (+ m.p.)	N	Pound (#), Oz, etc.
VELOCITY	v	meter/sec,KPH,etc	m/sec	Ft/sec, MPH, etc.
ACCELERATION	a	meter/sec.sq., etc.	m/sec2.	Ft/sec sq., etc.
PRESSURE	P	N/sq.m, atm.,Pa	atm,Pa*	#/sq.in (PSI), inHg, etc.
DENSITY	D	g/cc, Kg/liter, etc.	g/cc	#/cu.Ft, #/gal, etc.
TEMPERATURE	T	Celsius or Kelvin	°C	Fahrenheit or Rankine
ENERGY	E	Joule (+ m.p.)	J	foot-pound
HEAT	Q	calorie (+ m.p.)	cal	BTU (British Thermal Unit)
CONCENTRATION	C**	gram/L, mol/L, Molar	M	(#/gal or #/cu.ft, **rare**)

Abbreviations: Ft = foot, in = inch, AMU = atomic mass unit, KPH = kilometers per hour, MPH = miles per hour, gal = gallon, PSI = pounds per square inch, cc = cubic centimeter, inHg = inches of mercury, Pa = Pascal m.p. = metric prefixes, cu. = cubic, sq. = square, atm = atmosphere.

*The unit Pa, for Pascal, is a unit of pressure that is the standard unit for the SI system, the MKS system in the metric measurements. The unit of Pascal, however, is rarely used in chemistry. Instead, the unit "atm," for "atmosphere," is still most used in chemistry.
**The symbol "B" is now the official symbol for concentration in the SI, but there are still chemistry texts using the "C" as is shown here."

The table above lists almost all the dimensions you will need in this course, the symbol for each dimension as it will be used in common formulas, and the units of each dimension. Notice Chemtutor has two systems of measurement displayed that you should know. There are really two commonly used metric subsystems. Most chemistry texts will use the MKS system (meter, kilogram, second) rather than the less-used CGS (centimeter, gram, second) system. A *system* is defined by its basic measure of distance, mass, and time.We will use the MKS system, also called the S.I., or International System. The symbol for only the basic unit of each dimension in the metric system is on the list.

Back to the beginning of Units and Measures.

METRIC SYSTEM vs. "ENGLISH SYSTEM"

The metric system typically uses only one root word for any basic dimension such as for length, the meter. All the metric units of length use the root word 'meter' with the metric prefixes in the next table. Our common system in the United States is not really a system, but is a thrown-together mess of measurements with no overriding order. Chemtutor, as does most of the United States, calls this group of measurements the “English system.” While calling it that is a considerable slander on the English people, the United States and Liberia are the only nations on earth to still cling to it. Chemtutor thinks that the English system makes a fine learning tool, along with being wonderfully poetic. You will want to know how to relate the English System to the metric system. Particularly notice the large number of units of length in the English system. This is only a small number of the common ones. We regularly use fathoms to measure depth in water and furlongs to measure distance in horse racing. There are many little-used English length units such as the barleycorn (one third of an inch) that may be picturesque, but are not used today. Notice that we define the barleycorn as a third of an inch. The way to relate one English unit to another is by definition. Length is the most common measurement. As a result, it has not only the largest number of words to describe it, but it also has the largest number of symbols to represent it in formulas. The English language also uses distance, long, width, height, radius, displacement, offset, and other words for length, sometimes in specialized applications.

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LENGTH

A meter is a little longer than a yard, so a meterstick that has inches on the back of it will has just a bit over thirty-nine inches on the English side. Typically, on the English side, the inches are broken into halves, fourths, eighths, and perhaps sixteenths. On the metric side one meter breaks down into ten decimeters, one hundred centimeters, and a thousand millimeters.

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AREA

An area is a length multiplied by a length. (A= l l as in the formula list.) An area is an amount of surface. Almost all area units are length units squared, such as: square meter (m^2), square centimeter (cm^2), square inch (in^2), etc. The acre and hectare, units of land measurement, are the only units commonly used that are not in the ‘distance squared’ area unit format. An acre is defined as 43,560 square feet, so in using the unit 'acre' in dimensional analysis, the definition can be used to relate the acre to other units. Notice the squaring of a unit of length. A meter multiplied by a meter is a square meter. A foot by a foot is a square foot, etc.

Back to the beginning of Units and Measures.

VOLUME

Volume is length multiplied by length multiplied by length. You may have heard that volume is length times height times width, but it means the same thing. (V= l l l) You may think of a volume as the space inside a rectangular (block-shaped) fish tank. Volume is the measure of an amount of space in three dimensions. Because volume is such a common type of measurement, it is unique in that it has two types of commonly used root word in both metric and English systems. The metric roots are liter and cubic meter. The English system also uses cubic length and an extensive array of units that are not in the cubed length format. Again, analagously to area measurements, a cubic meter is a meter multiplied by a meter multiplied by a meter, and a cubic foot is a foot by a foot by a foot.

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TIME

Time is also a bit odd in its units. In both systems the units of less than a second are in the metric style with prefixes before the second. Time units of more than a year are in a type of metric configuration because they are in multiples of ten. (Decades, centuries, millennia, etc.) The dimension of time is messy for good reason. The more commonly used time units from day to year are all dependent upon the movement of the earth. The unit of 'month,' particularly if it is directly related to the moon, is useless as an accurate unit because it does not come out even in anything. Having sixty seconds in an hour and twenty-four hours in a day come about from the ease of producing mechanical clocks. (Is it time to switch to metric time? How would you like, say, ten hours in a day, one hundred minutes in an hour, and one hundred seconds in a minute. It would come out to almost the same length of second.)

Back to the beginning of Units and Measures.

MASS

Mass is an amount of matter. Mass has inertia, which is the tendency of matter to stay where it is if it is not moving, or to keep moving at the same rate and direction if it is already moving. You could measure mass by an inertial massometer. Visualize a metal strip held tightly on one end and “twanged," or given a push to make it vibrate on the other end. It has a natural pitch to vibrate. If you were to put a mass on the end of that strip, you would change the pitch of the vibration. The change of pitch would make it possible to calculate the mass of the added object. This measurement of mass is completely independent of gravity, the way we often weigh a mass by comparing the push or force of the mass on a surface. Mass is a more accurate way of thinking of amount of matter compared to weight. The metric system is mass-based whereas the English system thinks in weight. Consider that an astronaut in near earth orbit has no weight because the gravitational attraction cancels inertia, but the mass of the astronaut remains the same. The metric root word of mass is the gram. Notice the difference between the ‘root word,’ gram, which is the basis for adding metric prefixes, and the system base of kilogram, the mass unit of the S.I. metric system.

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FORCE

A force is a push or a pull. Those simple words are the best definition of a force under our limited experience. A force can not be seen or heard directly, so it is a bit of a difficult concept beyond the simple definition. Having basic metric units like 'kilogram-meter per second squared' make the idea of force hard to think about using that tool also. It is shameful to give you this in the same manner as a British sex education, but until a better way comes about, that's all there is to be said about it.

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WEIGHT

Weight is a downward force due to the mass of an object and the acceleration of gravity. The English system can conveniently use the idea of weight to measure amount of material because there is very little difference in the acceleration of gravity over the surface of the earth. There are certainly other forces besides gravity. Magnetism produces a force. Electric charge produces a force.

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VELOCITY

Velocity is a complex dimension. The unit of velocity is a combination of more than one type of basic dimension. A velocity is a distance per time. The word 'per' here means 'divided by,' and distance divided by time is not only the definition of velocity, but it is the easy way to remember the velocity formula, $v = d/t$. Velocity also has the name of rate. You might know the same formula as, ‘rate times time equals distance.’ Here’s where we could start complicating the math by using calculus, but we won’t. If you are taking a course that requires calculus, the math is only slightly different, but the basic ideas behind it are the same.

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ACCELERATION

An acceleration is just another step down the same road as velocity, that is, acceleration is a distance per time per time, or, another way to see it, distance per time squared. An acceleration is a time rate of change of velocity. If something changes its velocity, it has an acceleration. An acceleration causes an increase or decrease in speed or a change in direction. Newton and Einstein identified gravity as an acceleration. Gravity has a fairly consistent amount of acceleration on the surface of the earth, that is 32 ft./sec^2 or 9.8 m/sec^2. As you can see, the acceleration of gravity, ‘g,’ can substitute for the ‘a’ of acceleration in the formulas below when the acceleration is due to gravity.

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PRESSURE

A pressure is a force per area. You can almost see the pressure of the wind on a sail. The pressure of the wind is the same, so the larger the area of the sail, the greater the force of the wind on the ship. Pressure unit definitions that we need for this course revolve around the unit ‘atmosphere’ because historically the pressure was first measured for weather.

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DENSITY

Density is mass per volume, weight per volume, or specific gravity, which is the density of a material per the density of water. Metric system densities are usually in the units of mass per volume, such as kg/L (kilogram per liter) or g/cm^3 (gram per cubic centimeter). English densities are usually in weight per volume, such as #/gal. (pounds per gallon) or #/ft3 (pound per cubic foot). Specific gravity has no units (!) because it is a comparative measurement. Specific gravity is the density of a material compared to the density of water.

Expressing density as specific gravity shows neither system.

We can have fun in a density demonstration by passing a large-grapefruit-sized ball of lead around the class. That size of lead ball weighs about 35 pounds. People do not expect something that compact to weigh so much. One way to think of density is, ‘How much mass is packed into a volume.’

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TEMPERATURE

Temperature is a bit more subtle dimension. What we really measure is the average velocity of the atoms or molecules in the material. One way to measure it is by the expansion of a liquid in a very small tube. This is the shape of a liquid (usually mercury or alcohol) in a thermometer. The Fahrenheit scale is still not a bad one for use with weather. Scientists are more likely to use the Celsius or Centigrade scale. Gas law calculations require the Kelvin scale because it is an absolute scale. The other absolute scale, Rankine (pronounced “rank-in”), is useful for teaching purposes, but is not in common use.

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ENERGY

Energy is the ability to do work. A Joule, the metric unit of energy is a kilogram- meter- square- per- second-square. Both of those ideas can be difficult to wrap your mind around. The easier way to think of energy is perhaps by its various types. You should have an intuitive feeling that a fifty pound rock held above your head has more energy of position in a gravitational field than the same fifty pound rock by your feet. A rubber band pulled back has more spring energy than a lax one. A speeding train has more energy of movement than a still one. We usually value petroleum not for its beauty, but for its chemical energy content. Energy is transferable from one type to another, but is not lost or gained in changes.

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HEAT

Heat is a form of energy. It is the energy of the motion of molecules. Even though heat and energy are fundamentally the same dimension, we measure and calculate them differently. We define a calorie (note the lower-case 'c') as the amount of heat that increases the temperature of a gram of liquid water one degree C. The BTU, the English unit of heat, is the amount of heat that increases the temperature of a pound of liquid water one degree F. A food Calorie (note upper case 'C') is one thousand heat calories of usable food energy. That is, the food Calorie reflects the type of living thing eating AND USING the energy. So the food Calorie depends on the type of (animal) eating it. A cow or a termite could get much more food value from a head of lettuce than a human being can, so what is a Calorie for us would be different for them.

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CONCENTRATION

Concentration is amount of material in a volume. In this course, we will stay mostly with measuring the amount of solute in a solution. There is more on this in the chapter on solutions, and we really need to explain the idea of mol or mole before a thorough explanation of concentration can mean much.

Notice the formulas in the table below. Some of the simple ones we use in this course only for practice with problem-solving techniques and for defining the units and dimensions. There are a few items in the formulas that have not been mentioned yet, such as c, the specific heat; n, the number of mols; and R, the universal gas constant. These we will consider in context as we use them.

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FORMULAS

$A = l\,l$	$V = l\,l\,l$	$V = A\,l$	$v\,t = d$	$F = m\,a$ ($Fw = m\,g$)
$a = v/t$	$a = d/t^2$	$P = F/A$	$C\,V = n$	$D = m/V$ ($D = Fw/V$)

$P V = n R T$ $Q = m c \Delta T$ Circle Area, $A_c = \pi r^2$ · Cylinder Volume = $V_c = A_c l = \pi r^2 l$

Chemtutor offers a Quickquiz on the formulas.

A formula is a relationship among dimensions. The symbols for the dimensions in the formula list are in the dimension list. Note the capitalization or lack of it in the symbols, for instance, V = volume and v = velocity; C = concentration and c = specific heat, etc. Also, there are some letters written after and slightly under a symbol called a subscript. Subscripts indicate a special case of the symbol, as you see above with the area of a circle being represented by the A for area and a subscript c for circle.

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DEFINITIONS TO CHANGE UNITS

There are three types of definitions you should know for changing units, English system definitions, metric system definitions, and changeover definitions between the two systems.

There are a small number of English system definitions listed below in Table C that you should know by rote. Notice that we take the same approach here with one of the larger unit being stated first and then some number greater than one of the smaller unit. All of these English definitions are exact definitions except for the cubic feet-to-gallons relationship. Take a look at any edition of the Chemical Rubber Company (CRC) Handbook of Physics and Chemistry and you will see the incredible number of non-metric units.

bookseller.base.org - Mail-order chemistry books for sale, including the CRC Handbook.

Back to the beginning of Units and Measures.

ENGLISH SYSTEM DEFINITIONS YOU SHOULD KNOW BY ROTE

1 ft. = 12 in.
1 mi. = 5280 ft.
1 cup = 8 Floz.
1 pint = 2 cups
1 qt. = 2 pints
1 gal. = 4 qts.
1 # = 16 Oz.
1 ton = 2000 #
1 acre = 43560 ft^2
*1 ft^3 = 7.48 gal.

1 gal. = 231 in^3 *not an exact def.

Back to the beginning of Units and Measures.

METRIC PREFIXES AS FACTORS OF TEN

FACTOR	PREFIX	SYMBOL
+18	exa	E
+15	peta	P
+12	tera	T
+9	giga	G
+6	mega	M
+3	kilo	k
+2	hecto	h
+1	deka	da
0	*ROOT WORD ONLY*	
-1	deci	d
-2	centi	c
-3	milli	m
-6	micro	µ
-9	nano	n
-12	pico	p
-15	femto	f
-18	atto	a

The above table includes only the commonly used metric prefixes. There have been some metric prefixes suggested for some of the exponents of ten not listed here, but they are not in common use, or are in use by only a small number of people for limited use. The prefix "myria-" (my or ma) as E4 is a good example. The word "myriad" means ten-thousand, so the prefix is well documented in language. (Thanks to Van Isaac Anderson for the thought.)

A FEW ODD METRIC DEFINITIONS

1 metric tonne = E3 kg	1 mL. = 1 cc = 1 cm3
1 Ångstrom = E-10 m	1 cubic meter = 1000 L

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THE METRIC STAIRCASE

The metric staircase below is a graphic way of showing how metric prefixes interact. It is the same thing as the chart above, but in a more visual representation. Each step is a multiple of ten of the lower step. For instance, 'centi' is on the next step above 'milli,' so a centimeter is ten times larger than a millimeter. Centigram is ten times larger than milligram. There are no common metric prefixes for some powers of ten such as +4,+5,-7, etc.

```
| peta +15
    |__
        |__
            | tera +12
                |__
                    |__
                        | giga +9
                            |__
                                |__
                                    | mega +6
                                        |__
                                            |__
                                                | kilo +3
                                                    | hecto +2
                                                        | deka +1
                                                            | ROOT WORD
                                                                | deci -1
                                                                    | centi -2
                                                                        | milli -3
                                                                            |__
                                                                                |__
                                                                                    | micro -6
                                                                                        |__
                                                                                            |__
                                                                                                | nano -9
                                                                                                    |__
                                                                                                        |__
                                                                                                            | pico -12
                                                                                                                |__
                                                                                                                    |__
                                                                                                                        |femto-15
                                                                                                                            | _
```

METRIC SYSTEM DEFINITIONS

Metric system definitions are relationships between units with the same rootword that, is, only the prefix changes. The Metric Staircase is just a way to visualize the relationships among the metric prefixes. We make a metric system definition in the following way, using the units kilometer and millimeter as an example:

1.Pick the largest metric prefix. Begin the metric definition with **one** of the larger units, e.g. 1 km = (some number of) millimeters.

2. Count the number of 'steps' down the metric staircase between the two metric prefixes. For instance, kilo- to milli- is six steps.

3. The number of the smaller unit is ten to the power of the number of steps between the metric prefixes. In our example
1 km = 106 mm. Another way to think of it is that the number of zeros of the smaller unit is the number of steps, so
1 km = 1,000,000 mm.

The reason for stating the metric system definitions this way is to make calculations easier and make the sense of the definition more obvious. It is easier to use 1 km = E6 mm than 1 mm = 1/1,000,000 km in math, even though they are both correct.

Here is more information on the metric units, their origins and uses. This chart emphasizes the point of view of computer use.

There are some times you will need to convert between systems. The following few conversion definitions are all you should need to memorize to convert almost anything. Notice we show a “bridge” between the systems in length, volume, and mass to weight.

Back to the beginning of Units and Measures.

COMMONLY USED CONVERSIONS FROM METRIC TO ENGLISH

1 in. = 2.54 cm. 1 L = 1.06 qt
1 kg = 2.2 # (at “g”) or 1 # (at 'g') = 453 grams (Use either of these two.)

These three conversions are all you will need in this course. The DA (dimensional analysis) system will use these to convert more complex units. See the DA problems at the end of Numbers and Math for more understanding as to how these conversion factors work. As you need them for whatever you might do on a regular basis, you might need to find conversions that are more useful to you. A cook might want a conversion factor between cups and liters. A doctor or pharmacist might want a conversion factor between grains and grams. The conversion between inches and centimeters is an exact one by definition, but the others are not. The conversion from metric mass to English weight must be done assuming the acceleration of gravity is one g.

Particularly in the section on gases you will need the following pressure units:

1 atm = 760 mmHg = 33.9 ftH2O = 14.7 PSI = 30 inHg

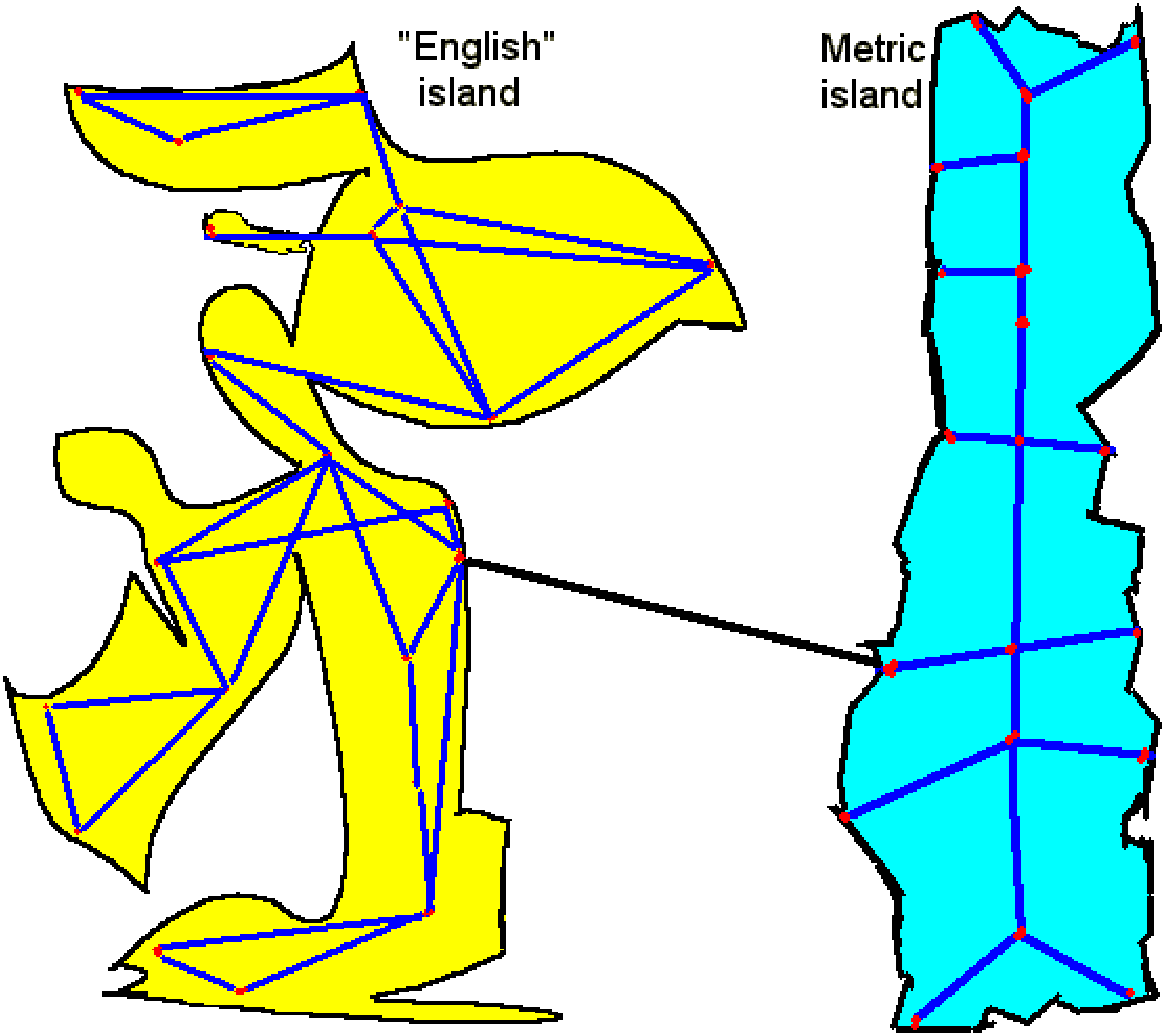
Abbreviations: atm = atmosphere, mmHg = millimeters of mercury, PSI = pounds per square inch, ftH2O = feet of water, inHg = inches of mercury. The unit ‘feet of water’ is not common, but included because it can be useful. For every hundred feet below the surface of water the pressure increases about three atmospheres. The running equation above (It just keeps going!) shows the common pressure units. You can use it to change between any two of the units, for example:

760 mmHg = 14.7 PSI.

The official SI unit of pressure, the Pascal, Pa, is not often used in chemistry because it is such a small unit. One atmosphere is about equal to 100,000 Pascals, or you could say that one atmosphere is approximately equal to 100 kPa.

More exactly, 1 atm = 1.01325 E5 Pa = 101.325 kPa

ISLAND SYSTEMS



Here is one way to think of the metric and "English" systems. The metric system is the metric island with an orderly set of towns and an orderly and simple and fast road system. The "English" island has every town connected as well as they can (by definitions) to other neighboring towns. The "English" system of transportation is not too efficient.

There only has to be one good solid bridge (changeover definition) between the two islands. You can get anywhere from one system to the other by first coming to the bridge town, crossing, and then taking the new system to wherever you want to go.

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Metric prefix humor (?) exa-ray exa-rated peta-cat tera-dactyl giga-low tera-bull pico-nose deci-mate tera-piece-of-paper peta-greed tara-rism pico-peach deca-cards atto-mobile micro-phone nano-pudding milli-mouse milli-cent pico-card peta-gogue peta-ful pico-nick ba-nano pico-low centi-mental exa-lint atto-miser milli-tent pico-boo atto-whack tera-pin kilo-bug deca-ration centi-fold tera-torialism

THERE'S MORE *
1 million microphones = 1 megaphone
2000 mockingbirds = two kilomockingbirds
10 cards = 1 decacards
1 millionth of a fish = 1 microfiche
453.6 graham crackers = 1 pound cake
1 trillion pins = 1 terrapin
10 rations = 1 decoration
100 rations = 1 C-ration
10 millipedes = 1 centipede
3 1/3 tridents = 1 decadent
AND EVEN MORE
2 monograms = 1 diagram
8 nickels = 2 paradigms
2 wharves = 1 paradox

* Thanks to Ellen Averill

email Chemtutor at info@chemtutor.com to add to this nonsense.

Back to the beginning of Units and Measures.

Heuristics
Numbers and Math
Atomic Structure
Elements
Periodic Table
States of Matter
Compounds
Reactions
Mols, Stoichiometry, and Percents
Oxidation and Reduction Reactions
Gases
Solutions
Acids and bases
Kinetics
Thermochemistry

A BRITISH SEX EDUCATION

The father calls his ten-year-old boy into his study. After the boy sits down, the father, clearly uncomfortable, blurts, "Young lad, do you know what the stags do in the Autumn?"

The young fellow feels as out of place as his father and, wishing to please, mutters, "Yes, sir."

Whereupon the father, visibly relieved, says, "I thought you did. That's all. Good afternoon."

Back to Force.

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ATOMIC STRUCTURE

AND YOU THOUGHT YOU WERE STRANGE

Here is an outrageous thought: All the matter around you is made of atoms, and all atoms are made of only three types of subatomic particle, protons, electrons, and neutrons. Furthermore, all protons are exactly the same, all neutrons are exactly the same, and all electrons are exactly the same. Protons and neutrons have almost exactly the same mass. Electrons have a mass that is about 1/1835 the mass of a proton. Electrons have a unit negative charge. Protons each have a positive charge. These charges are genuine electrical charges. Neutrons do not have any charge.

Even more outrageous is the shape of the atoms with the three subatomic particles. The neutrons and protons are in the center of the atom in a nucleus. The electrons are outside the nucleus in electron shells that are in different shapes at different distances from the nucleus. The atom is mostly empty space. Ernest Rutherford shot subatomic particles at a very thin piece of gold. Most of the particles went straight through the gold. It was like shooting a rifle into a thin line of trees. Some of the particles bounced off, some stuck inside, but the major portion of them passed through the gold foil. By Rutherford's calculations, the nucleus in an atom is like a B-B in a boxcar. That is a genuinely outrageous idea. Almost all the mass of an atom is concentrated in the tiny nucleus. The mass of a proton or neutron is 1.66 E -24 grams or one AMU, atomic mass unit. The mass of an electron is 9.05 E -28 grams. This number is a billionth of a billionth of a billionth of a gram. It is not possible for anyone or any machine that uses light to actually see a proton using visible light. The wavelength of light is too large to be able to detect anything that small.

Back to the beginning of Atomic Structure.

ATOMIC WEIGHTS AND ATOMIC NUMBERS

The integer that you find in each box of the Periodic Chart is the atomic number. The atomic number is the number of protons in the nucleus of each atom. Another number that you can often find in the box with the symbol of the element is not an integer. It is oversimplifying only a little to say that this number is the number of protons plus the average number of neutrons in that element. The number is called the atomic weight or atomic mass.

How can it be that an element must have an averaged atomic weight? The number of protons defines the type of element. If an atom has six protons, it is carbon. If it has 92 protons, it is uranium. The number of neutrons in the nucleus of an element can be different, though. Carbon 12 is the commonest type of carbon. Carbon 12 has six protons (naturally, otherwise it wouldn't be carbon) and six neutrons. The mass of the electrons is negligible. Carbon 12 has a mass of twelve. Carbon 13 has six protons and seven neutrons. Carbon 14 has six protons and eight neutrons. Carbon 14 is radioactive because, as other atoms with the wrong percentage of neutrons to protons, it is unstable. The nucleus tends to pop apart. The proper ratio of protons to neutrons is about one to one for small elements and about one proton to one and a half neutrons for the larger elements. Types of an element in which every atom has the same number of protons and the same number of neutrons are called isotopes. Carbon 14 is a radioactive isotope of carbon. Any carbon 14 that was made at the time the earth was formed is now almost all gone. Carbon 14 is continuously made from high energy electromagnetic radiation hitting nitrogen atoms in the ozone layer of the earth. This carbon 14 when taken into plants as CO_2 will also be taken into animals. We can find out how much carbon 14 that normally is in a living plant or animal and from there we can find the actual amount of carbon 14 left in a plant or animal long dead. We can get a very good idea of how long ago that plant or animal was living from the amount of carbon 14 remaining in the dead body. This process is called 'carbon dating.' The stable, non-radioactive isotopes of carbon play no part in this. As a whole element, carbon has a more or less fixed proportion of the various carbon isotopes. For this reason, we can determine a weighted average of the isotopes for all elements. On a periodic chart you may see some atomic weights that are integers or in parentheses. These are usually on the very large or very rare or very radioactive elements. That is not really an integer atomic weight, but the atomic weight has been estimated to the nearest integer.

Back to the beginning of Atomic Structure.

FORMULA WEIGHT OR MOLECULAR WEIGHT OR FORMULA MASS OR MOLAR MASS

Now with the atomic weight information we can consider matching up atoms on a mass-to-mass basis. Let's take hydrogen chloride, HCl. One hydrogen atom is attached to one chlorine atom, but they have different masses. A hydrogen atom has a mass of 1.008 AMU and a chlorine atom has a mass of 35.453 AMU. Practically speaking, one AMU is far too small a mass for us to weigh in the lab. We could weigh 1.008 grams of hydrogen and 35.453 grams of chlorine, and they would match up exactly right. There would be the same number of hydrogen atoms as chlorine atoms. They could join together to make HCl with no hydrogen or chlorine left over. If we take one gram of a material for every AMU of mass in the atoms of just one of them, we will have a mol (or mole) of that material. One mol of any material, therefore, has the same number of particles of the material named, this number being Avogadro's number, 6.022 E 23.

The formula weight is the most general term that includes atomic weight and molecular weight. In the case of the HCl, we can add the atomic weights of the elements in the compound and get a molecular weight. The molecular weight of HCl is 36.461 g/mol, the sum of the atomic weights of hydrogen and chlorine. The unit of molecular weight is grams per mol. The way to calculate the molecular weight of any formula is to add up the atomic weights of all the atoms in the formula. $CuSO_4 \cdot 5H_2O$ is copper II sulfate pentahydrate. The formula has one copper atom, one sulfur atom, nine oxygen atoms, and ten hydrogen atoms. To get the formula weight of this compound we would add up the atomic weights. Copper II sulfate pentahydrate is not a molecule, strictly speaking, but you will hear the term ‘molecular weight’ used for it rather than the more proper ‘formula weight.' Since the unit of formula weight is grams per mol, it makes good sense to use the formula weight of a material as a conversion factor between the mass of a material and the number of mols of the material.

Back to the beginning of Atomic Structure.

ELECTRON CONFIGURATION

Protons have a positive charge and electrons have a negative charge. Free (unattached) uncharged atoms have the same number of electrons as protons to be electrically neutral. The protons are in the nucleus and do not change or vary except in some nuclear reactions. The electrons are in discrete pathways or shells around the nucleus. There is a ranking or heirarchy of the shells, usually with the shells further from the nucleus having a higher energy. As we consider the electron configuration of atoms, we will be describing the *ground state* position of the electrons. When electrons have higher energy, they may move up away from the nucleus into higher energy shells. As we consider the electron configuration, we will be describing the ground state positions of the electrons.

A hydrogen atom has only one proton and one electron. The electron of a hydrogen atom travels around the proton nucleus in a shell of a spherical shape. The two electrons of helium, element number two, are in the same spherical shape around the nucleus. The first shell only has one subshell, and that subshell has only one orbital, or pathway for electrons. Each orbital has a place for two electrons. The spherical shape of the lone orbital in the first energy level has given it the name ‘*s*’ orbital. Helium is the last element in the first period. Being an inert element, it indicates that that shell is full. Shell number one has only one *s* subshell and all *s* subshells have only one orbital. Each orbital only has room for two electrons. So the first shell, called the K shell, has only two electrons.

Beginning with lithium, the electrons do not have room in the first shell or energy level. Lithium has two electrons in the first shell and one electron in the next shell. The first shell fills first and the others more or less in order as the element size increases up the Periodic Chart, but the sequence is not immediately obvious. The second energy level has room for eight electrons. The second energy level has not only an *s* orbital, but also a *p* subshell with three orbitals. The *p* subshell can contain six electrons. The *p* subshell has a shape of three dumbbells at ninety degrees to each other, each dumbbell shape being one orbital. With the *s* and *p* subshells the second shell, the L shell, can hold a total of eight electrons. You can see this on the periodic chart. Lithium has one electron in the outside shell, the L shell. Beryllium has two electrons in the outside shell. The *s* subshell fills first, so all other electrons adding to this shell go into the *p* subshell. Boron has three outside electrons, carbon has four, nitrogen has five, oxygen has six, and fluorine has seven. Neon has a full shell of eight electrons in the outside shell, the L shell, meaning the neon is an inert element, the end of the period.

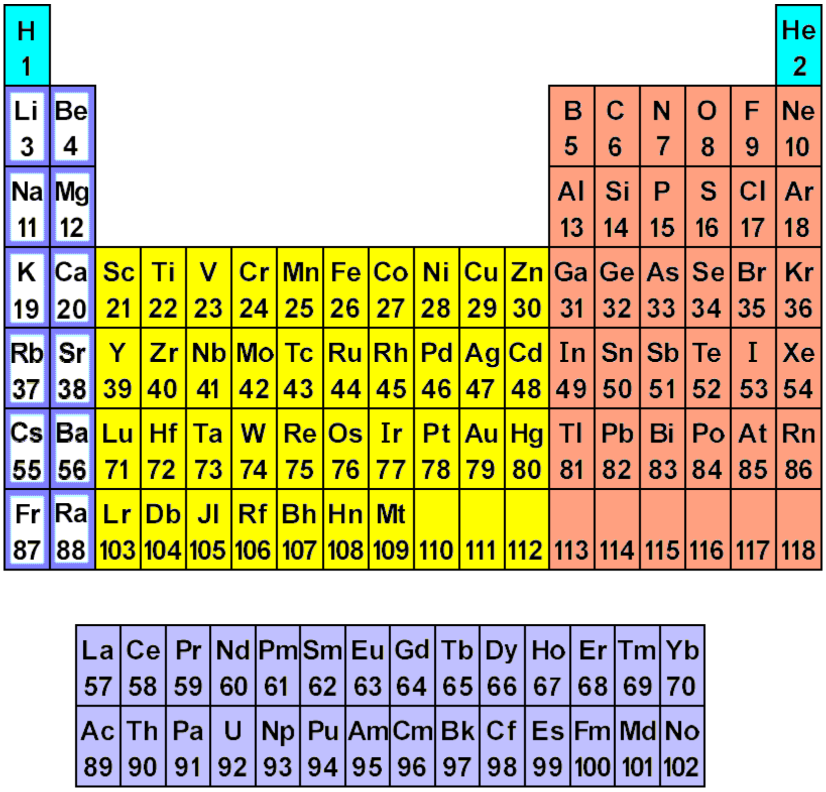
Beginning again at sodium with one electron in the outside shell, the M shell fills its *s* and *p* subshells with eight electrons. Argon, element eighteen, has two electrons in the K shell, eight in the L shell, and eight in the M shell. The fourth period begins again with potassium and calcium, but there is a difference here. After the addition of the **4***s* electrons and before the addition of the **4***p* electrons, the sequence goes back to the third energy level to insert electrons in a *d* shell.

The shells or energy levels are numbered or lettered, beginning with K. So K is one, L is two, M is three, N is four, O is five, P is six, and Q is seven. As the *s* shells can only have two electrons and the *p* shells can only have six electrons, the *d* shells can have only ten electrons and the *f* shells can have only fourteen electrons. The sequence of addition of the electrons as the atomic number increases is as follows with the first number being the shell number, the *s*, *p*, *d*, or *f* being the type of subshell, and the last number being the number of electrons in the subshell.

1*s*2 2*s*2 2*p*6 3*s*2 3*p*6 4*s*2 3*d*10 4*p*6 5*s*2 4*d*10 5*p*6 6*s*2 4*f*14 5*d*10 6*p*6 7*s*2 5*f*14 6*d*10 7*p*6

It is tempting to put an **8***s*2 at the end of the sequence, but we have no evidence of an R shell. One way to know this sequence is to memorize it. There is a bit of a pattern in it. The next way to know this sequence is to SEE IT ON THE PERIODIC CHART. As you go from hydrogen down the chart, the Groups 1 and 2 represent the filling of an *s* subshell. The filling of a *p* subshell is shown in Groups 3 through 8. The filling of a *d* subshell is represented by the transition elements (ten elements), and the filling of an *f*subshell is shown in the lanthanide and actinide series (fourteen elements).

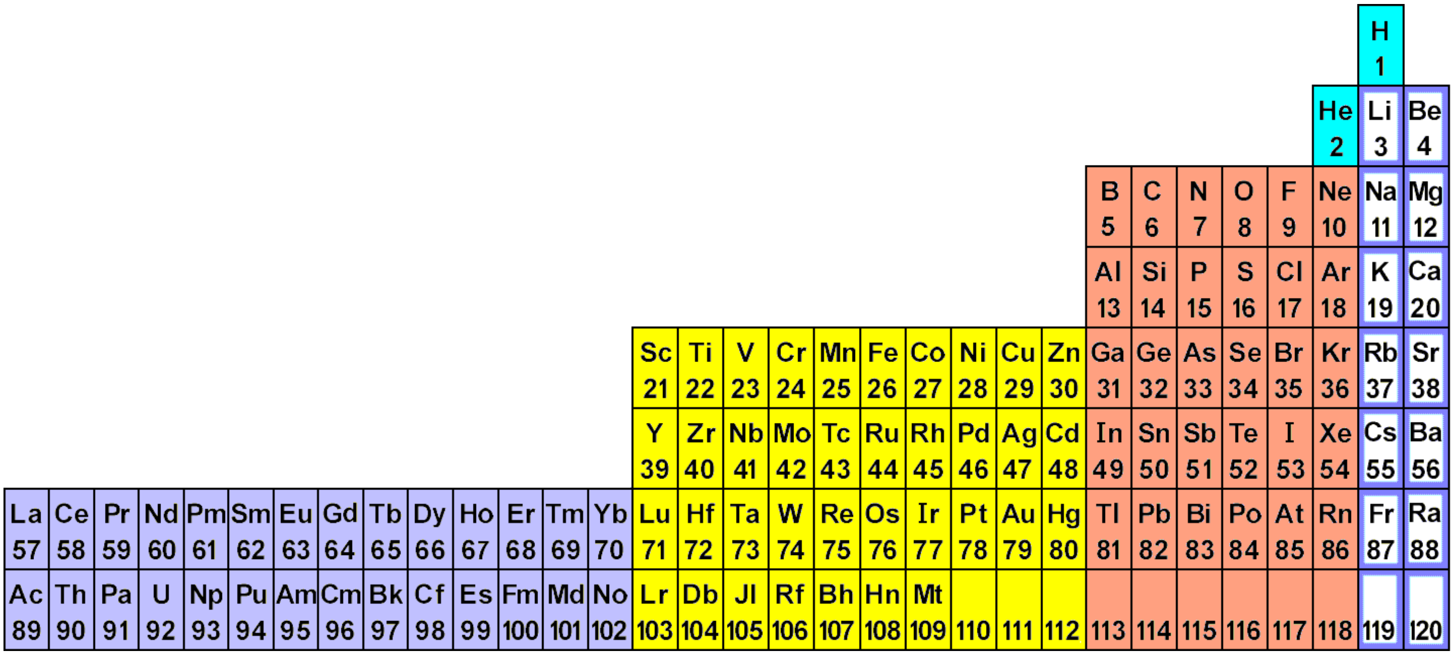
Here is a copy of the periodic chart as you have usually seen it.



H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Lr 103	Db 104	Jl 105	Rf 106	Bh 107	Hn 108	Mt 109	110	111	112	113	114	115	116	117	118

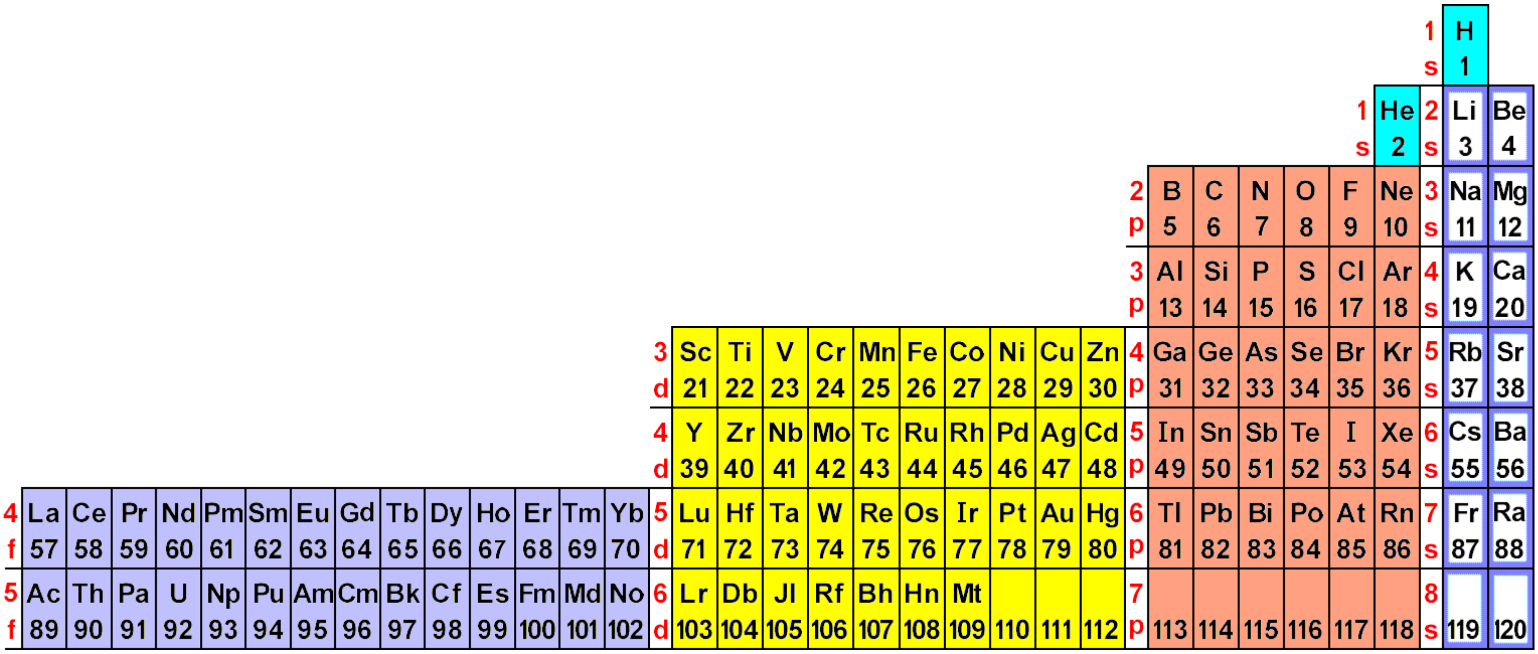
La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70
Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102

And here is the same chart re-arranged with the Lanthanides and Actinides in their right place and Group I and II afterward. Both of these charts are color coded so that the elements with the 2*s* subshell on the outside (H and He) are turquoise. All other elements with an *s* subshell on the outside (Groups I and II) are outlined in blue. Lanthanides and actinides are in grey. Other transition elements are in yellow, and all of the elements that have a *p* subshell as the last one on the outside are in salmon color.



																														H 1	
																													He 2	Li 3	Be 4
																								B 5	C 6	N 7	O 8	F 9	Ne 10	Na 11	Mg 12
																								Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	K 19	Ca 20
														Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	Rb 37	Sr 38
														Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54	Cs 55	Ba 56
La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86	Fr 87	Ra 88
Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103	Db 104	Jl 105	Rf 106	Bh 107	Hn 108	Mt 109	110	111	112	113	114	115	116	117	118	119	120

You may be able to see it better with the subshell areas labeled.



																																	1s	H 1	
																															1s	He 2	2s	Li 3	Be 4
																									2p	B 5	C 6	N 7	O 8	F 9	Ne 10	3s	Na 11	Mg 12
																									3p	Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	4s	K 19	Ca 20
															3d	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	4p	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	5s	Rb 37	Sr 38
															4d	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	5p	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54	6s	Cs 55	Ba 56
4f	La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	5d	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	6p	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86	7s	Fr 87	Ra 88
5f	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	6d	Lr 103	Db 104	Jl 105	Rf 106	Bh 107	Hn 108	Mt 109	110	111	112	7p	113	114	115	116	117	118	8s	119	120

There are several other schemes to help you remember the sequence.

The shape of the *s* subshells is spherical. The shape of the *p* subshells is the shape of three barbells at ninety degrees to each other. The shape of the *d* and *f* subshells is very complex.

Electron configuration is the "shape" of the electrons around an atom, that is, which energy level (shell) and what kind of orbital it is in. The shells were historically named for the chemists who found and calculated the existence of the first (inner) shells. Their names began with "K" for the first shell, then "L," then "M," so subsequent energy levels were continued up the alphabet. The numbers one through seven have since been substituted for the letters. Notice that I have included an "R" shell (#8) that is purely fantasy but makes the chart symmetrical.

The electron configuration is written out with the first (large) number as the shell number. The letter is the orbital type (either *s*, *p*, *d*, or *f*). The smaller superscript number is the number of electrons in that orbital.

Use this scheme as follows. You first must know the orbitals. An *s* orbital only has 2 electrons. A *p* orbital has six electrons. A *d* orbital has 10 electrons. An *f* orbital has 14 electrons. You can tell what type of orbital it is by the number on the chart. The only exception to that is that "8" on the chart is "2" plus "6," that is, an *s* and a *p* orbital. The chart reads from left-to-right and then down to the next line, just as English writing. Any element with over 20 electrons in the electrically neutral unattached atom will have all the electrons in the first row on the chart. For instance, scandium, element #21, will have all the electrons in the first row and one from the second. The electron configuration of scandium is: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^1$ Notice that the $2s^2\ 2p^6$ and $3s^2\ 3p^6$ came from the eights on the chart (2+6). Notice that the other electron must be taken from the next spot on the chart and that the next spot is the first spot on the left in the next row. It is a 3*d* spot due to the "10" there and only one more electron is needed, hence $3d^1$.

The totals on the right indicate using whole rows. If an element has an atomic number over thirty-eight, take all the first two rows and whatever more from the third row. Iodine is number fifty-three. For its electron configuration you would use all the electrons in the first two rows and fifteen more electrons. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2$ from the first two rows and $4d^{10}\ 5p^5$ from the third row. You can add up the totals for each shell at the bottom. Full shells would give you the totals on the bottom.

We have included an R shell (#8) even though there is no such thing yet proven to exist. The chart appears more symmetrical with that shell included. The two electrons from the R shell are in parentheses. We have not yet even made elements that have electrons in the *p* subshell of the Q shell.

Back to the beginning of Atomic Structure.

ELECTRON CONFIGURATION CHART

K	L	M	N	O	P	Q	R	
1	2	3	4	5	6	7	8	
s	*sp*	*spd*	*spdf*	*spdf*	*spd*	*sp*	*s*	
2	8	8	2					20
		10	6	2				38
			10	6	2			56
			14	10	6	2		88
				14	10	6	2	
------------	------------	------------	------------	------------	------------	-----------	------------	
2	8	18	32	32	18	8	2	TOTALS

Here is another way to consider the same scheme. The inert elements appear at the end of either the first two, an eight, a six. Wherever there is the six of a *p* subshell there is the two of an *s* subshell above it to make eight electrons in the outer full shell of a noble gas. The electron configuration for xenon is:

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6$

ELECTRON CONFIGURATION CHART

K	L	M	N	O	P	Q	R	
1	2	3	4	5	6	7	8	
s	*sp*	*spd*	*spdf*	*spdf*	*spd*	*sp*	*s*	
2 /HELIUM	8 /NEON	8 /ARGON	2					20
		10	6 /KRYPTON	2				38
			10	6 /XENON	2			56
			14	10	6 /RADON	2		88
				14	10	6 /UND	2	
------------	------------	------------	------------	------------	-----------	------------	------------	
2	8	18	32	32	18	8	2	TOTALS

“Und” is the undiscovered inert element that would be below radon on the periodic chart.

Another type of electron configuration chart is below. These are more commonly known schemes. All you have to do is follow the arrows through the points to find the sequence. Add up the number of electrons as you go, and stop when you have equaled or almost exceeded the number. There have been a large number of variations on this idea, but they all work the same. Arrange the subshells in a slanted order and go through the array in straight lines, as in the first scheme, or arrange the subshells in a straight line and go through the array in slanted lines, as in the second scheme. In these schemes the inert elements appear after the first *s* subshell and after every *p* subshell. As the other type, this scheme type has its advantages and disadvantages, but they all lead to the same sequence.

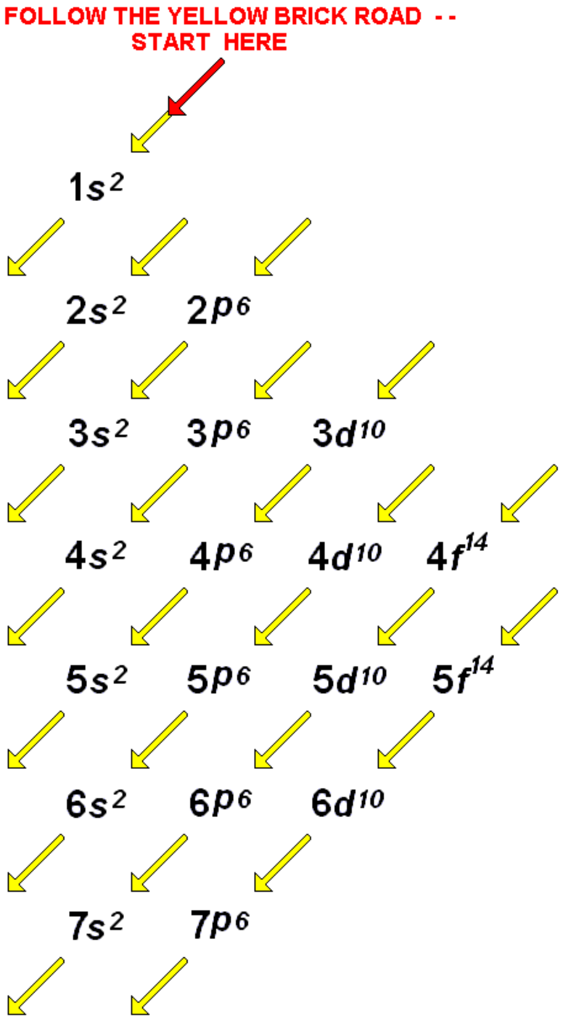
Back to the beginning of Atomic Structure.

COMMON ELECTRON CONFIGURATION SCHEME A

---»	1*s*2			
---»	2*s*2			
---»		2*p*6		
---»	3*s*2			
---»		3*p*6		
---»	4*s*2		3*d*10	
---»		4*p*6		
---»	5*s*2		4*d*10	
---»		5*p*6		
---»	6*s*2			4*f*14
---»			5*d*10	
---»		6*p*6		

---» 7*s*2 5*f*14
---» 6*d*10
---» 7*p*6

COMMON ELECTRON CONFIGURATION SCHEME B



Any of these schemes, if used correctly, will give you the same thing, the sequence of the addition of the electrons to the shells. This pattern is correct for all of the elements that are not Transitional Elements or Lanthanides or Actinides. Of the Transitional Elements and Lanthanides and Actinides about one third of the elements do not follow the pattern. The Periodic Chart below is arranged sideways to show the electron configuration by shell. As you work with the schemes for finding the electron configuration of elements, you can check to see if your answer is correct by adding the electrons in each shell (downwards in the first scheme) and comparing with the Sideways Periodic Chart. The elements that do not fit the pattern have an asterisk by them. In the Transition Elements that do not follow the scheme, only the *s* subshell of the outer shell and the *d* subshell of the next to last shell have some trading between them. In the Lanthanide and Actinide series any trading of electrons are between the *d* subshell of the next to last shell and the *f* subshell of the second to last shell, the one filling as the elements progress up that series.

Back to the beginning of Atomic Structure.

THE OCTET RULE AS SEEN ON THE PERIODIC CHART

The *octet rule* states that atoms are most stable when they have a full shell of electrons in the outside electron ring. The first shell has only two electrons in a single *s* subshell. Helium has a full shell, so it is stable, an inert element. Hydrogen, though, has only one electron. It can lose an electron to become H+, a hydrogen ion or it can gain an electron to become H-, a hydride ion. All the other shells have an *s* and a *p* subshell, giving them at least eight electrons on the outside. The *s* and *p* subshells often are the only valence electrons, thus the octet rule is named for the eight *s* and *p* electrons.

On the Periodic Chart with shell totals you can easily see the octet rule. A valence is a likely charge on an element ion. All of the Group 1 elements have one electron in the outside shell and they all have a valence of plus one. Group 1 elements will lose one and only one electron, that single outside electron to become a single positive ion with a full electron shell of eight electrons (an octet) in the *s* and *p* subshells under it.

Group 2 elements all have two electrons in the outer shell and all have a valence of plus two. Beryllium can be a bit different about this, but all other Group 2 elements can lose two electrons to become +2 ions. They do not lose only one electron, but two or none.

The Transition Elements, Lanthanides, and Actinides are all metals. Many of them have varying valences because they can trade around electrons from the outer shell to the inner *d* or *f* subshells that are not filled. For this reason they sometimes appear to violate the octet rule.

Group 3 elements have a valence of plus three. Boron is a bit of an exception to this because it is so small it tends to bond covalently. Aluminum has a valence of +3, but some of the larger Group 3 elements have more than one valence.

The smallest Group 4 elements, carbon and silicon, are non-metals because the four electrons are difficult to lose the entire four electrons in the outer shell. Small Group 4 elements tend to make only covalent bonds, sharing electrons. Larger Group 4 elements have more than one valence, usually including +4.

Small Group 5 elements, nitrogen and phosphorus, are non-metals. They tend to either gain three electrons to make an octet or bond covalently. The larger Group 5 elements have more metallic character.

Small Group 6 elements, oxygen and sulfur, tend to either gain two electrons or bond covalently. The larger Group 6 elements have more metallic character.

Group 7 elements all have seven electrons in the outer shell and either gain one electron to become a -1 ion or they make one covalent bond. The Group 7 elements are diatomic gases due to the strong tendency to bond to each other with a covalent bond.

All of the inert elements, the noble gases, have a full octet in the outside shell (or two in the first shell) and so do not naturally combine chemically with other elements.

Back to the beginning of Atomic Structure.

SIDEWAYS PERIODIC CHART WITH ELECTRON SHELL NUMBERS

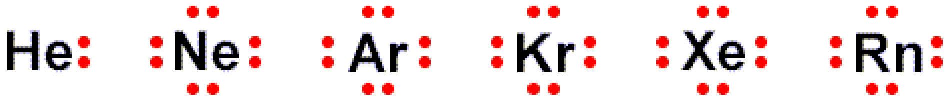
Fr #87	Cs #55	Rb #37	K #19	Na #11	Li #3	H #1

		2 8 18 32 18 8 1	2 8 18 18 8 1	2 8 18 8 1	2 8 8 1	2 8 1	2 1	1
		Ra #88 2 8 18 32 18 8 2	Ba #56 2 8 18 18 8 2	Sr #38 2 8 18 8 2	Ca #20 2 8 8 2	Mg #12 2 8 2	Be #4 2 2	
Ac #89 2 8 18 32 18 9 2*	La #57 2 8 18 18 9 2 *	Lr #103 2 8 18 32 32 9 2	Lu #71 2 8 18 32 9 2	Y #39 2 8 18 9 2	Sc #21 2 8 9 2			
Th #90 28 18 32 18 10 2*	Ce #58 2 8 18 19 9 2 *	Db #104 28 18 32 32 10 2	Hf #72 2 8 18 32 10 2	Zr #40 2 8 18 10 2	Ti #22 2 8 10 2			
Pa #91 2 8 18 32 20 9 2*	Pr #59 2 8 18 21 8 2	Jl #105 28 18 32 32 11 2	Ta #73 2 8 18 32 11 2	Nb #41 2 8 18 12 1 *	V #23 2 8 11 2			
U #92 2 8 18 32 21 9 2*	Nd #60 2 8 18 22 8 2	Rf #106 28 18 32 32 12 2	W #74 2 8 18 32 12 2	Mo #42 2 8 18 13 1 *	Cr #24 2 8 13 1 *			
Np #93 2 8 18 32 22 9 2*	Pm #61 2 8 18 23 8 2	Bh #107 28 18 32 32 13 2	Re #75 2 8 18 32 13 2	Tc #43 2 8 18 13 2	Mn #25 2 8 13 2			
Pu #94 2 8 18 32 24 8 2	Sm #62 2 8 18 24 8 2	Hn #108 2 8 18 32 32 14 2	Os #76 28 18 32 14 2	Ru #44 2 8 18 15 1 *	Fe #26 2 8 14 2			
Am #95 2 8 18 32 25 8 2	Eu #63 2 8 18 25 8 2	Mt #109 28 18 32 32 15 2	Ir #77 2 8 18 32 15 2	Rh #45 2 8 18 16 1 *	Co #27 2 8 15 2			
Cm #96 2 8 18 32 25 9 2*	Gd #64 2 8 18 25 9 2 *	#110	Pt #78 28 18 32 17 1 *	Pd #46 2 8 18 18 0 *	Ni #28 2 8 16 2			
Bk #97 2 8 18 32 26 9 2*	Tb #65 2 8 18 27 8 2	#111	Au #79 28 18 32 18 1 *	Ag #47 2 8 18 18 1 *	Cu #29 2 8 18 1 *			
Cf #98 2 8 18 32 28 8 2	Dy #66 2 8 18 28 8 2	#112	Hg #80 2 8 18 32 18 2	Cd #48 2 8 18 18 2	Zn #30 2 8 18 2			
Es #99 2 8 18 32 29 8 2	Ho #67 2 8 18 29 8 2	#113	Tl #81 2 8 18 32 18 3	In #49 2 8 18 18 3	Ga #31 2 8 18 3	Al #13 2 8 3	B #5 2 3	
Fm #100 2 8 18 32 30 8 2	Er #68 2 8 18 30 8 2	#114	Pb #82 2 8 18 32 18 4	Sn #50 2 8 18 18 4	Ge #32 2 8 18 4	Si #14 2 8 4	C #6 2 4	
Md #101 2 8 18 32 31 8 2	Tm #69 2 8 18 31 8 2	#115	Bi #83 2 8 18 32 18 5	Sb #51 2 8 18 18 5	As #33 2 8 18 5	P #15 2 8 5	N #7 2 5	
No #102 2 8 18 32 32 8 2	Yb #70 2 8 18 32 8 2	#116	Po #84 2 8 18 32 18 6	Te #52 2 8 18 18 6	Se #34 2 8 18 6	S #16 2 8 6	O #8 2 6	
		#117	At #85 2 8 18 32 18 7	I #53 2 8 18 18 7	Br #35 2 8 18 7	Cl #17 2 8 7	F #9 2 7	
		#118	Rn #86 2 8 18 32 18 8	Xe #54 2 8 18 18 8	Kr #36 2 8 18 8	Ar #18 2 8 8	Ne #10 2 8	He #2 2

Back to the beginning of Atomic Structure.

LEWIS STRUCTURES OF THE ELEMENTS

Examine the Sideways Periodic Chart With Electron Shell Numbers again. All of the Group I elements and hydrogen (the top row of the chart) have one and only one electron in the outside shell. That single electron is what gives these elements the distinctive character of the group. The Lewis structures are just an attempt to show these valence electrons in a graphic manner as they are used to combine with other elements. The element symbol is in the center and as many as four groups of two electrons are shown as dots above, below, to the right and left of the element symbol to show the valence electrons. All of the inert gases (noble gases) have all eight of the electrons around the element symbol, except for helium, which has only two electrons even with a full shell. Below is a demonstration of the noble gases written in Lewis structure. Notice the electrons are in red just to emphasize them.



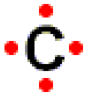
All the other elements have less than eight electrons in the outside shell. These electrons can be in the positions of the eight electrons of the noble gases, but there are some suggestions about where they belong. The Group I elements have only one electron in the outer shell, so it really does not matter where the electron dot is placed, over, under, right or left of the element symbol.

Group II elements have two electrons. Some authors will place the two electron dots together on any side of the element symbol because the electrons really are in an *s* subshell together.

Some authors will show the electrons separated from each other in any of the two positions with only one electron in each position. The reasoning behind that is that the electrons really do try to move as far away from each other as possible.

Boron and the elements below it on the periodic table all have three electrons in the outside shell. These electrons may be grouped as each electron alone in one of the positions around the element symbol or as a group of two (*s*) electrons in one position and one electron in another. Boron is usually shown with separate electrons because it bonds mostly covalently. Covalent bonds, we know from the shape of molecules, tend to blend the *s* and *p* subshells into *sp* orbitals with one *s* and one *p* orbital blended, *sp2* orbitals with one *s* and two *p* orbitals blended, or *sp3* orbitals, using the single *s* orbital with all three *p* orbitals. The *sp2* orbitals of boron tend to be flat trigonal shape, that is, the bonds are at 120 degrees from each other in a flat circle around the boron atom in the center. The Lewis structure of boron is any of the shapes below.

Carbon and the elements below it have four electrons in the outer shell. Carbon and silicon are usually shown in Lewis structures to have four separated electrons, again because these elements bond purely with covalent bonds. The *sp3* orbitals of carbon and silicon are tetrahedral in shape.



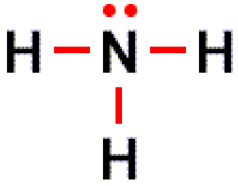
Nitrogen and the elements below it have five electrons in the valence shell, so they must be shown with one pair (anywhere) and three solitary electrons.

Oxygen and the elements below it have six valence electrons and so must have two pairs and two solitary electrons.

Elements in the halogen group, Group VII, all have seven electrons in the outer shell, so only there are three groups of two and a single electron in the last position.

The transition elements and the Lanthanide and Actinide series elements are not often used in the covalent bonds that the Lewis structures usually portray, but these metal elements can be portrayed in this manner using the number of electrons in the outer shell that corresponds with the valence of the element.

In using the Lewis structures to show covalent bonds, the pair of electrons that are in the bond are shown as a dashed line. For example, ammonia would be shown with the bonds from the nitrogen to the hydrogens and the unshared pair of electrons on the nitrogen.



The covalent bond dash is in red in the above sketch also. Notice that the electrons from all of the participants in this molecule are all accounted for.

There is more on Lewis structures in the compounds chapter in Chemtutor.

Back to the beginning of Atomic Structure.

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COMMON ELEMENTS ALPHABETICALLY

Chemtutor's fifty-or-so most useful elements to know

About the elements

- aluminum
- antimony
- argon
- arsenic
- astatine
- barium
- beryllium
- bismuth
- boron
- bromine
- cadmium
- calcium
- carbon
- cesium
- chlorine
- chromium
- copper
- deuterium
- fluorine
- francium
- germanium
- gold
- helium
- hydrogen
- iodine
- iron
- krypton
- lead
- lithium
- magnesium
- manganese
- mercury
- neon
- nickel
- nitrogen
- oxygen
- phosphorus
- platinum
- potassium
- radium
- radon
- rubidium
- silicon
- silver
- sodium
- strontium
- sulfur
- tin
- titanium
- tritium
- tungsten
- uranium
- xenon
- zinc

ABOUT THE ELEMENTS

There are only a few more than one hundred elements. Of those, only eighty-three are not naturally radioactive, and of those, only fifty or so are common enough to our experience to be useful in this course. These elements, though, are going to stay the same for a long time. You may have memorized the states and capitals of the United States. The elements will outlast any political entity. You have certainly memorized and internalized the English alphabet. The elements will be around long after the letters of any alphabet are gone. It would serve you well to know the elements. If you were to attempt to read anything without knowing your letters, you would be in trouble. Let's say you still have a hard time telling the difference between a 'b' and a 'd.' Your fluency in reading would be ruined by having to look up the difference every time you encountered one of those letters. Similarly, you should know your elements well enough so that if you read or hear about one of them, you instantly know what they are. Learn how to spell the names of the elements. Learn the symbols. Some of the symbols have one letter, some have two, but each element symbol has one and only one upper case letter in it. Chemtutor has a Quickquiz to help you learn the names and symbols of the elements.

COMMON ELEMENTS

You should know the name and symbol for the following elements. If you see the name, you should know the symbol. If you see the symbol, you should know the name. For the elements in the right-hand row there are other names for the element, sometimes Latin, from which the element symbol was derived or some other name that makes the element more recognizable. You do not need to know the names in parentheses.

Helium He
Boron B
Beryllium Be
Phosphorus P
Chlorine Cl
Bromine Br
Cobalt Co
Zinc Zn
Iodine I
Cesium Cs
Bismuth Bi
Radon Rn
Radium Ra

Lithium Li
Carbon C
Fluorine F
Nitrogen N
Argon Ar
Oxygen O
Nickel Ni
Krypton Kr
Platinum Pt
Barium Ba
Arsenic As
Xenon Xe
Uranium U

Hydrogen H
Silicon Si
Neon Ne
Aluminum Al
Magnesium Mg
Manganese Mn
Chromium Cr
Rubidium Rb
Cadmium Cd
Francium Fr
Strontium Sr
Polonium Po

Sodium (Natrium) Na
Calcium (Lime) Ca
Sulfur (Brimstone) S
Potassium (Kalium) K
Iron (Ferrum) Fe
Copper (Cuprum) Cu
Lead (Plumbum) Pb
Silver (Argentum) Ag
Tin (Stannum) Sn
Antimony(Stibium) Sb
Tungsten(Wolfram)W
Gold (Aurum) Au

Mercury (Hydrargyrum or Quicksilver) Hg

Back to the beginning of Elements

Aluminum. A very rare metal before the electrolytic process of producing it was discovered in 1886, Aluminum is a common metal to us. The melting point is 660 °C, so it can be melted on a common household stove unless it contains a lower boiling liquid, such as water. Aluminum’s silvery shine when new changes to a powdery gray in the air that gives it a protective coating against further oxidation. Aluminum is easily attacked by acids and bases. It is a good conductor of electricity, particularly on consideration of its weight. Due to the ease of the electrolytic process of refining it, aluminum is so cheap that small amounts of it are considered disposable. It is used for foil wrapping for foods

Back to the beginning of Elements

Antimony. On the Periodic Chart antimony appears on the line between metals and non-metals. Antimony is more brittle and less conductive of heat and electricity than most metals. Antimony is used in alloys, for instance mixing with lead to harden it. Antimony is also used in flame proofing compounds and in paints and pottery.

Back to the beginning of Elements

Argon. Argon is one of the inert gasses of Group 8 or 18, the noble gases. It does not combine with other elements. Argon is collected from the air by fractional distillation. It is used in the red colored electric fluorescent tubes popularly called ‘neon lights.’

Back to the beginning of Elements

Arsenic. It has been known for centuries that arsenic compounds are poisonous. Arsenic is a semi-metal (on the boundary between metals and non-metals) that is used in hardening metals, poisons as insecticides, and coloring materials in paints.

Back to the beginning of Elements

Astatine. Astatine is the only halogen (Group 7 or 17) element that is naturally radioactive.

Back to the beginning of Elements

Barium. A Group 2 element, barium is about as soft as lead. Compounds of barium make excellent absorbers of x-ray radiation, so are used to outline organs in medical radiology. White barium compounds are used in paints.

Back to the beginning of Elements

Beryllium. The least dense of the Group 2 elements, beryllium is a very hard, tough metal. Ores of beryllium are not very plentiful. Its soluble compounds taste sweet.

Back to the beginning of Elements

Bismuth. The element has been known for a long time, but it was often confused with tin or lead centuries ago. The pure metal has a slightly pink color to it on top of the usual metallic silvery shine. For a metal, bismuth has a low melting point and a low electrical conductivity. It is used in alloys for sprinkler systems and for metal casting.

Back to the beginning of Elements

Boron. Boron is familiar in its use as borax, a water softener, and in boric acid, a mild antiseptic. It is also used in ceramics. Boron is a non-metal element that is not found free in nature.

Back to the beginning of Elements

Bromine. Bromine is a halogen (Group 7 or 17 element). It is one of the few elements liquid at room temperature. Bromine has a melting point of -7 °C and a boiling point of 59 °C. A reddish-brown very irritating poisonous vapor comes from the liquid. The organic compounds of bromine are very important.

Back to the beginning of Elements

Cadmium. Cadmium is a soft bluish metal that is used in low-melting alloys, high friction-resistant alloys, and electroplating. Cadmium rods are used in control for atomic fission. Cadmium sulfide makes a yellow pigment.

Back to the beginning of Elements

Calcium. The word ‘lime’ has been used with calcium compounds for many years. Calcium is a Group 2 element that is very abundant in the earth’s crust in compounds, but never seen in nature as the free metal element. It is an essential element for living things, especially in muscles, leaves, bones, teeth, and shells. Calcium is found in limestone. It is used in Portland cement, mortar, plaster, and antacids. Lime, $Ca(OH)_2$, is used to mark off playing fields and for de-acidifying (‘sweetening’) agricultural fields. The element form of calcium, a soft metal, was not known until the early in the nineteenth century by electrolysis.

Back to the beginning of Elements

Carbon. There are three common forms of elemental carbon; carbon black (‘soot’ or ‘lamp black’), graphite, and diamond. More recently, various sizes of Bucky Balls have been found to be another allotropic form of carbon. Bucky Balls are geodesic dome-shaped balls of carbon atoms in discrete paterns named after Buckminster Fuller, the predictor of such arrangements. Carbon is not known to form ionic bonds, but only covalent bonds, of which it can make four single covalent bonds per atom. The four covalent bond arrangement gives carbon the geometrical capability to make an incredible number of compounds, called organic compounds, with carbon chains as the ‘backbone’ of a large molecule. One might say that the bonding of carbon makes possible the existence of living things as we know them.

Back to the beginning of Elements

Cesium. Cesium is a Group 1 element used in some photoelectric cells and as a catalyst in organic reactions. Cesium salts are important phosphors (glowing materials) on the front of phosphorescent color television recievers.

Back to the beginning of Elements

Chlorine. Elemental chlorine is a greenish dense gas that has been used in wartime as a poison gas. It is found in nature as the chloride, mostly of sodium. (Sodium chloride is ‘table salt.’) Chloride, the negative ion of chlorine dissolved in water, is one of the common electrolytes in living things. Elemental chlorine is released into water for drinking or swimming to control bacterial and fungal growth. Chlorine is used in bleaches and organic compounds. Chlorine is a non-metal element of the halogen group.

Back to the beginning of Elements

Chromium. The word ‘chrome’ is connotes ‘bright and shiny.’ In fact, chromium is used as an electroplated cover on many automobiles. Chromium is a metal element in many ways resembling iron. It is used in alloys, often with iron, to make harder metals and stainless alloys. The compounds of chromium have many brilliant varied colors, and so are used as pigments.

Back to the beginning of Elements

Copper. Evidence of copper mining and smelting goes back over five thousand years into human prehistory. The metal element is a characteristic golden-red. It is one of the best conductors of heat and electricity. The best copper for use in electric wires is the very pure copper that comes from using electrolysis as a final purification step. Copper was used in swords before brass and bronze, both alloys of copper that are harder and hold an edge better. Copper is about the easiest metal to smelt. Some distinctive blue-green rocks heated to a reasonable temperature are all the primitive metallurgist needs to get copper. The most important use we have for copper at this time is the conduction of electricity.

Back to the beginning of Elements

Deuterium. Deuterium is not an element, but one of only two named isotopes, both isotopes of hydrogen. Deuterium is called ‘heavy hydrogen’ because it has a neutron in the nucleus along with a single proton.

Back to the beginning of Elements

Fluorine. Pronounce ‘*flue ring*’ without the ‘g’ and it might be easier to remember the unusual spelling of fluorine. Fluorine is the least dense, the smallest element number, of the halogen group, Group 7 or 17. Element fluorine is a pale greenish-yellow gas that is extremely poisonous and extremely active chemically. Fluorine is used in hydrofluoric acid to etch glass. Sodium fluoride (say, ‘*flew ride*’) in very small quantities is used in drinking water to prevent dental decay. Many organic compounds containing fluorine are common useful materials such as Freon and Teflon.

Back to the beginning of Elements

Francium. The largest (highest element number) Group 1 (alkali metal) element, francium is radioactive. It is the most active of the alkali metals. It is a natural decay product of actinium.

Back to the beginning of Elements

Germanium. In making the primitive Periodic Chart, Mendeleev knew to skip a place for an element not yet found. By extrapolation from the chart, Mendeleev predicted the properties of Germanium. The melting point of 32 °C permits Germanium to be melted in a person’s hand. Germanium is used the manufacture of semiconductors.

Back to the beginning of Elements

Gold. Gold is likely the earliest metal known to humanity because it can be found in its native form and is easier to work (softer) than copper, which also is found in its native form. Gold is the least active of the metals. The gold of the ancient Incas buried many hundreds of years can be unearthed as shiny as it was when new. Gold is an excellent conductor of heat and electricity. It is used in electrical circuitry that is either exposed to weathering or must be reliable for many years. Gold is the most malleable material. It can be pounded into incredibly thin sheets. Pure gold is too soft a metal to make swords, but it is commonly used for jewelry. In the U.S. Most gold jewelry is 14 carat or about 58% gold in the alloy. The distinctive metallic yellow of gold is known and highly valued throughout the world.

Back to the beginning of Elements

Helium. The name helium refers to the sun because it was first detected in spectroscopic lines from sunlight. Helium is the lightest of the noble gasses, Group 18. Helium is difficult to acquire by fractional distillation of air because of its low boiling point, but it is available directly from the ground in helium wells in Texas, USA. It is used to inflate lighter-than-air balloons and airships and for artificial atmosphere for deep diving.

Back to the beginning of Elements

Hydrogen. The most famous mental picture of hydrogen is the burning of the zeppelin Hindenburg. There are some who claim that the fire that finished the Hindenburg was lit by the fabric that contained it rather than the explosive tendencies of the hydrogen itself, but a lot of hydrogen burned that day.

Hydrogen is the lightest (least dense) of the elements and the lightest of the gasses. The lift that the Hindenburg got from the elemental hydrogen in its gas bags was the best in the world -- with the one small flaw that hydrogen burns explosively with oxygen to make water. Airships today use another ‘lighter-than-air’ gas, helium, to get lift.

Almost all the hydrogen on earth is in the form of compounds, mostly water. Elemental hydrogen is one of the major components of stars. Large amounts of elemental hydrogen are used for fixing nitrogen for fertilizers and for hydrogenation of fats and oils. Hydrogen is a diatomic gas as an element. It usually appears at the top of Group 1 on the periodic chart, but hydrogen is not a member of Group 1. With only one proton, hydrogen has only one electron in a shell that can only contain two electrons. Hydrogen can lose one electron to become a positive ion, as in acid, or it can collect another electron to produce a hydride (H^-) ion with a full shell. In spite of a marked decrease in research funds, fusion power from hydrogen isotopes deuterium and/or tritium seems almost within the grasp of human technology at this writing (1999).

There are many people working on the possibility of using hydrogen as a fuel. The 'hydrogen economy' would require some changes in the way we do things, but may be the only way we have as our petroleum resources run out. Here are some references on the use of hydrogen as a fuel.

http://www.elsevier.nl/inca/publications/store/4/8/5/485.LE.shtml http://www.nrel.gov/lab/pao/hydrogen.html http://whyfiles.news.wisc.edu/069renew_energy/2.html

Back to the beginning of Elements

Iodine. The element looks like a dark gray brittle solid at room temperature, but it easily sublimes into a beautiful purple choking gas. It dissolves in water only slightly, but in alcohol fairly easily to make a purple solution. Iodine in alcohol solution is a commonly used antiseptic. Lack of iodine in human beings causes an enlargement of the thyroid gland called goiter. We don’t see much goiter in our culture because iodized table salt has a small amount of iodine added to it. Iodine is a halogen. As a gas it is a diatomic molecule.

Back to the beginning of Elements

Iron. Iron is the metal on which our civilization is built. It is usually not used as the pure element, but as the major component of a large number of alloys called steel. Carbon is one of the elements added to iron to make various alloys. In general, the more carbon in the mixture, the more brittle the iron alloy is. Pig iron, the material direct from the blast furnace, can be cast into shapes. The carbon content of pig iron can be about three percent. Other metals can be added to the iron to make alloys with much improved properties, such as stainless steel. Iron is magnetic and a decent conductor of electricity in its pure form.

Back to the beginning of Elements

Krypton. Krypton is an inert gas. As the other noble gases, it produces a bright line spectrum in fluorescent tubes. Krypton’s light output is a brilliant yellow-green. If you were a writer of fiction and wanted to describe a mineral with unlikely properties, you might claim that the mineral would be a compound of Krypton, since there are none.

Back to the beginning of Elements

Lead. With a melting temperature of 327 °C and a commonly available ore, lead is an easy metal to acquire and shape. Lead is malleable and fairly soft. Lead salts are poisonous. There is some suspicion that lead contributed to the downfall of the Roman Empire due to the use in water pipes and cups for warming mulled wine. There is some argument that the Roman upper classes having lead pipes and drinking mulled wine poisoned themselves. Lead is used in automotive electric batteries, solder for electronic devices, and pigments.

Lead was commonly used in making the pigments for house paint until the ninteen fifties. Many older houses now must bear the warning that very young children should not live in such places until the old paint is removed for fear of lead poisoning.

Back to the beginning of Elements

Lithium. As all the Group 1 elements, the alkali metals, Lithium reacts with water, so it is not found in nature. As a metal element it is as soft as cool butter. It burns in air to form the oxide. Industrially it is used in alloys to increase the tensile strength of the mixture. It emits a beautiful crimson flame test. Medically it is used in compounds to clear out uric acid and to relieve depression.

Back to the beginning of Elements

Magnesium. Magnesium is very common in the earth’s crust, but only in compounds. The metal is a light, strong, metal element that will burn in air with a bright blue-white flame. It is used in places where tough metal alloys are needed to be light weight, such as automobile wheels (mag wheels) and airplane and helicopter bodies.

Back to the beginning of Elements

Manganese. A magnetic metal with many of the properties of iron, manganese is more brittle than iron. It is used mainly in steel alloys to harden them. Potassium permanganate is one of the best-know of the compounds of manganese. Potassium permanganate is a beautiful purple compound that is an excellent oxidizing agent.

Back to the beginning of Elements

Mercury. The metal element is a liquid between -39 °C and 356 °C. It has a regular coefficient of expansion, so the most likely place for you to have seen elemental mercury is in a liquid thermometer. As a liquid conductor of electricity, mercury is used as the switch in thermostats. Mercury makes alloys called amalgams with many metals. For many years amalgams have been used as fillings for teeth. The name quicksilver, an old English name, means, alive metal, or lively metal due to the way the metal coheres to itself but does not wet many surfaces commonly wet by water. Liquid mercury has a fairly high vapor pressure, and the gas from it is a cumulative poison.

Back to the beginning of Elements

Neon. The gas that lends its name to the group of fluorescent lights made from inert gases itself only produces a red-orange color in the gas tubes. It is prepared by fractional distillation of liquid air. As an inert element, it does not combine with other elements to make compounds.

Back to the beginning of Elements

Nickel. Yes, there is some nickel in the USA five cent coin. Nickel is used for many alloys, generally making the alloy stronger and less chemically active. It is a metal element in the iron and cobalt group. Nickel with large surface area is used as a catalyst for the hydrogenation of edible oils. Nickel is used in some storage batteries.

Back to the beginning of Elements

Nitrogen. There is a lot of nitrogen in front of your face! About eighty percent of the atmosphere is elemental nitrogen. Nitrogen gas is a diatomic molecule with a triple (covalent) bond between the atoms. The strong bond makes the element somewhat inert. It is difficult to get atmospheric nitrogen into compound. Since many organic compounds require nitrogen, its availability is a limiting factor on biological growth. Thus, nitrogen compounds are included in many fertilizers. (See Phosphorus about fertilizers.) The process of combining nitrogen into compounds is called fixing. Ammonia is produced by the Haber process as one of the steps in producing nitrogen compounds. Nitrogen compounds may be somewhat unstable, therefore usable in explosives.

There is a wonderful article in the July 1997 issue of the SCIENTIFIC AMERICAN beginning on page 76, "Global Population and the Nitrogen Cycle," by Vaclav Smil. This is a part of the intriguing story of how chemistry and history and farming and ecology are all intertwined with the nitrogen cycle.

Back to the beginning of Elements

Oxygen. Just as nitrogen, oxygen is abundantly available in element form in the atmosphere. Oxygen as a diatomic molecule with double bonds between the atoms is about twenty percent of the air. Pure oxygen at atmospheric pressures can fully ignite a glowing wood splint, this being the classic test for the presence of oxygen. Every element except for the inert gases can chemically combine with oxygen, the metals in ionic bonds and the non- metals with covalent bonds. Oxygen is necessary for the respiration of all animals and almost all combustion.

Back to the beginning of Elements

Phosphorus. Along with nitrogen and potassium, phosphorus is also a limiting factor in the growth of living things. The standard notation for fertilizer is N P K. N is the percentage of nitrogen as nitrate. P is the percentage of phosphorus as phosphate, and K is the percentage of potassium. Phosphates in waste water pumped directly into streams will produce a proliferation of algae that clog waterways. Elemental phosphorus comes in three allotropes, the white or yellow phosphorus being the most common. White phosphorus can be changed to the red form by heating to 250 °C, just thirty degrees below the boiling point, and cooling. Red phosphorus does not spontaneously ignite in air and is not poisonous as is the white or yellow phosphorus.

Back to the beginning of Elements

Platinum. The free element platinum is a metal almost as inactive as gold. For this reason and its silvery beauty, platinum has been considered a precious metal. Most platinum is mined as a small by-product of nickel mining. Finely divided platinum can serve as a catalyst for several reactions.

Back to the beginning of Elements

Potassium. The word potash refers to potassium. That name may have come from the practice of leaching potassium (and sodium) hydroxide from the ashes of burnt wood. The lye (hydroxides) would be boiled with fat (from meats cooked on that same fire) to make soap. Potassium metal is a very soft metal that very quickly becomes tarnished in the air. The tarnishing can be slowed by storing the metal under kerosene. Potassium is a Group 1 element, an alkali metal. It reacts violently in water, burning with a bright blue-white flame. Potassium ions are not only not poisonous, but they are required by living things. (See Phosphorus about fertilizers.) Potassium chloride is often used as a table salt substitute for people who wish to limit the sodium intake.

Back to the beginning of Elements

Radium. Radium is the element that first made Madam Curie famous. She and a coworker were the first to isolate the element. Pierre and Marie Curie were both scientists working in turn-of-the-century Paris. Having an active social life, the Curies would throw parties at their home and show guests a test tube of the new material. The test tube would glow brightly, and the glow was visible even through closed eyelids! The Curies didn’t know that the rays from the radium were harmful. Marie Curie suffered from what we now would call radiation sickness. Her beautifully luminescent radium was the first element found to be radioactive. The strange fact of radium giving off light and spontaneously changing to another element forever altered our ideas of the structure of the atom. Radium is a Group 2 element, but because of its radioactivity, it is not usually found in basic chemistry labs.

Back to the beginning of Elements

Radon. The heaviest of the inert gases, radon is a radioactive gas. Unlike its lighter cousins, radon is not used in fluorescent lights. The radiation from radon has been shown to cause cancer in human beings in some buildings in which the radon seeps in from cracks in basement floors. Be careful to not confuse radon with radium, a radioactive metal element.

Back to the beginning of Elements

Rubidium. The name of rubidium comes from the deep red flame test it gives. As it is an alkali metal, Group 1, it makes similar compounds to sodium and potassium. A very soft metal element, it reacts violently with water.

Back to the beginning of Elements

Silicon. Pronounce the name to rhyme with '*kill-a-don*' to keep from confusing it with a class of its compounds, silicones, pronounced to rhyme with '*kill-a-phone*'. Elemental silicon in its most common allotropic form looks like a lump of very shiny coal. It is not malleable. Hit a lump of silicon and it shatters, spraying needle-sharp shards. It is a semi-conductor of electricity, a property that makes it valuable in electronic components. Silicon is the second most abundant element in the earth's crust, but it is never found in the native state. Chemically silicon is similar to carbon. It does not make ionic bonds, but makes four covalent bonds. Sand and other minerals are made of silicon dioxide. Silicones, organic compounds with silicon in placed of carbon, have been used to for an incredible number of biological tasks.

Back to the beginning of Elements

Silver. Known far before the Romans called it argentum, silver can be found in the native state and in compounds. Silver is the best of conductors of heat and electricity and almost the most malleable and ductile metal, second only to gold. Silver is harder than gold, but it reacts with some acids. The black tarnish on silver is silver sulfide, usually from combination with sulfur compounds in the air. Dilute silver nitrate is used as an antiseptic. Silver chlorides change on exposure to light, this reaction being the basis for black-and-white photography.

Back to the beginning of Elements

Sodium. Sodium is the most abundant of the alkali metals (Group 1) in the earth's crusts, but it is never found in the native state. Sodium chloride, table salt, is its most common compound. Sodium produces a pair of very strong lines close together in the yellow color region as an emission spectrum, giving the sodium flame test the characteristic yellow color. Free elemental sodium is a very soft metal that reacts quickly with the air. As with other alkali metals, storing it under kerosene decreases its availability to the moisture in the air. Almost all the salts of sodium are soluble in water. Baking soda is sodium bicarbonate. Soda lye, or caustic soda, is sodium hydroxide. Sodium ions are needed by most living things.

Back to the beginning of Elements

Strontium. The flame test for strontium is a brilliant dark red. This color is spectacularly shown in fireworks displays with strontium salts. Elemental strontium is a hard silvery metal of Group 2, very similar to calcium. Strontium 90, a radioactive isotope of strontium, can be in the fallout from nuclear explosions. It has been recorded that strontium 90 landing on vegetation eaten by dairy cattle can appear in the milk of those animals, similarly the usual calcium.

Back to the beginning of Elements

Sulfur. The brimstone of the Bible, sulfur was most likely encountered by prehistoric humankind near geothermal sources such as volcanoes and geysers. Sulfur’s two crystal forms, monoclinic and rhombic, both have a melting temperature just above the boiling point of water at one atmosphere. Under pressure, as under the earth, water temperature can exceed the melting temperature for sulfur. Since sulfur does not dissolve in water, the liquid sulfur immediately solidifies as it reaches the earth’s surface, leaving the distinctive non-metal pale yellow brittle solid. The Frasch process for mining sulfur does exactly the same as the geothermal process. Superheated water under pressure is pumped into the earth and retrieved with melted sulfur in it, mimicking the natural process for sulfur exposure. There is another non-crystalline form of elemental sulfur that can be made by melting crystalline sulfur, but the amorphous allotrope is unstable, reverting to one of the crystalline forms on standing. Sulfur burns in air (the stone that burns) to form sulfur dioxide. This is the first step in the manufacture of sulfuric acid, by far the most used compound of sulfur. It has been said that the amount of sulfuric acid made is a good measure of the level of industrialization of a country. Sulfur is one of the main ingredients in the vulcanization of rubber.

Back to the beginning of Elements

Tin. Tin was the secret ingredient in bronze that made it possible for the copper alloy to hold a minimal edge for swords. Tin is a metal element that has a characteristic tendency to form crystals in the solid metal. It does not react with mild acids or the normal constituents of the air, making it usable as a coating to cheaper metals.

Iron or steel coated with tin or zinc, called Galvanized, is used for ‘tin roofing,' ‘tin cans,' and ‘tin soldiers’ (perhaps even ‘tin woodmen’). It is easy to spot when tin is used to cover other metals because of the large crystals appearing on the surface. Pewter and solder are other important alloys of tin.

Back to the beginning of Elements

Titanium. The ores of titanium are not very common, but the metal is a very light, strong metal. Titanium is much stronger per mass than iron. Airplanes, bicycles, and ultracentrifuge rotors are some of the items that work best made of titanium because of its lightness (small density) and great tensile strength. Titanium oxide makes a beautiful white pigment.

Back to the beginning of Elements

Tritium. Tritium is the heaviest known isotope of hydrogen, having one proton and two neutrons. It is not an element. See 'deuterium'.

Back to the beginning of Elements

Tungsten. Having a melting point of almost six thousand degrees Celsius and good electrical conductivity, Tungsten makes a good light bulb filament. It is a hard, brittle metal. The great majority of tungsten is used to alloy with steel to make a hard, tough metal for uses like high speed drilling and cutting tools.

Back to the beginning of Elements

Uranium. The highest atomic number of the naturally occurring elements, uranium has a fissionable isotope. Some of the first ‘atomic bombs’ were fission devices with uranium. Some nuclear energy facilities use uranium as the fuel to make electricity. Some of the yellow or black compounds of uranium were used in ceramic glazes.

Back to the beginning of Elements

Xenon. The heaviest and the rarest of the naturally occurring inert gases in air, xenon produces a beautiful blue glow in fluorescent tubes. It has the highest boiling point of the natural inert gases at -107 °C. As the other inert gases, it makes no natural compounds.

Back to the beginning of Elements

Zinc. For many centuries zinc was included in the metals of brass without being recognized as an element. The element zinc is used to cover other metals to protect from oxidation and as one electrode in some electric cells. Elemental zinc is a bluish metal that has the surprising property of being slightly brittle at room temperature, but more malleable at or above 100 °C. Zinc metal is used to alloy with other metals. Zinc oxide is used as an antiseptic and as a white pigment.

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PERIODIC CHART

THE PERIODIC CHART OF THE ELEMENTS

The Periodic Chart of the Elements is just a way to arrange the elements to show a large amount of information and organization. As you read across the chart from right to left, a line of elements is a Period. As you read down the chart from top to bottom, a line of elements is a Group or Family. We number the elements, beginning with hydrogen, number one, in integers up to the largest number. The integer number in the box with the element symbol is the atomic number of the element and also the number of protons in each atom of the element.

Back to the beginning of Periodic Chart.

PROPERTIES OF MATTER

The Periodic Chart is based on the properties of matter. A property is a quality or trait or characteristic. We can describe, identify, separate, and classify by properties. How would you describe a person? A young man impressed with a young lady might describe her, “She has long dark hair that she keeps in a pony-tail, brown eyes, a long neck, and a very light complexion. She is about 180 centimeters tall and has pierced ears.” He has used some of her properties to describe her. You might be able to pick her out of a small group of people based on his description if it is not too inaccurate, too vague, or too biased. Similarly, you can collect a number of properties to describe an element or compound. The properties of the element or compound, though, are true for any amount of the material anywhere. South American gold is indistinguishable from South African gold by its properties.

There are two types of property of matter. Physical properties describe the material as it is. Chemical properties describe how a material reacts, with what it reacts, the amount of heat it produces as it reacts, or any other measurable trait that has to do with the combining power of the material. Properties might describe a comparative trait (denser than gold) or a measured trait (17.7 g/cc), a relative trait (17.7 specific gravity), or an entire table of measurements in a table or graph form (the density of the material through a range of temperatures).

Physical properties include such things as: color, brittleness, malleability, ductility, electrical conductivity, density, magnetism, hardness, atomic number, specific heat, heat of vaporization, heat of fusion, crystalline configuration, melting temperature, boiling temperature, heat conductivity, vapor pressure, or tendency to dissolve in various liquids. These are only a few of the possible measurable physical properties.

Chemical properties include: whether a material will react with another material, the rate of reaction with that material, the amount of heat produced by the reaction with the material, at what temperature it will react, in what proportion it reacts, and the valence of elements.

We can separate or purify materials based on the properties. We can separate wheat from chaff by throwing the mix into the wind. The less dense chaff is moved more by the wind than the denser wheat. We can separate a mixture of sand and iron filings by magnetism. The iron filings will stick to a magnet dragged through the mixture. We can separate ethyl alcohol (good old drinking alcohol) from water by boiling point. This process is called distillation. A mixture of water and insoluble material with alcohol mixed in it will release the alcohol as vapor at the boiling point of alcohol (78 °C). We can separate by solubility. A mixture of table salt and sand can be separated by adding water. The salt dissolves and the sand does not.

Back to the beginning of Periodic Chart.

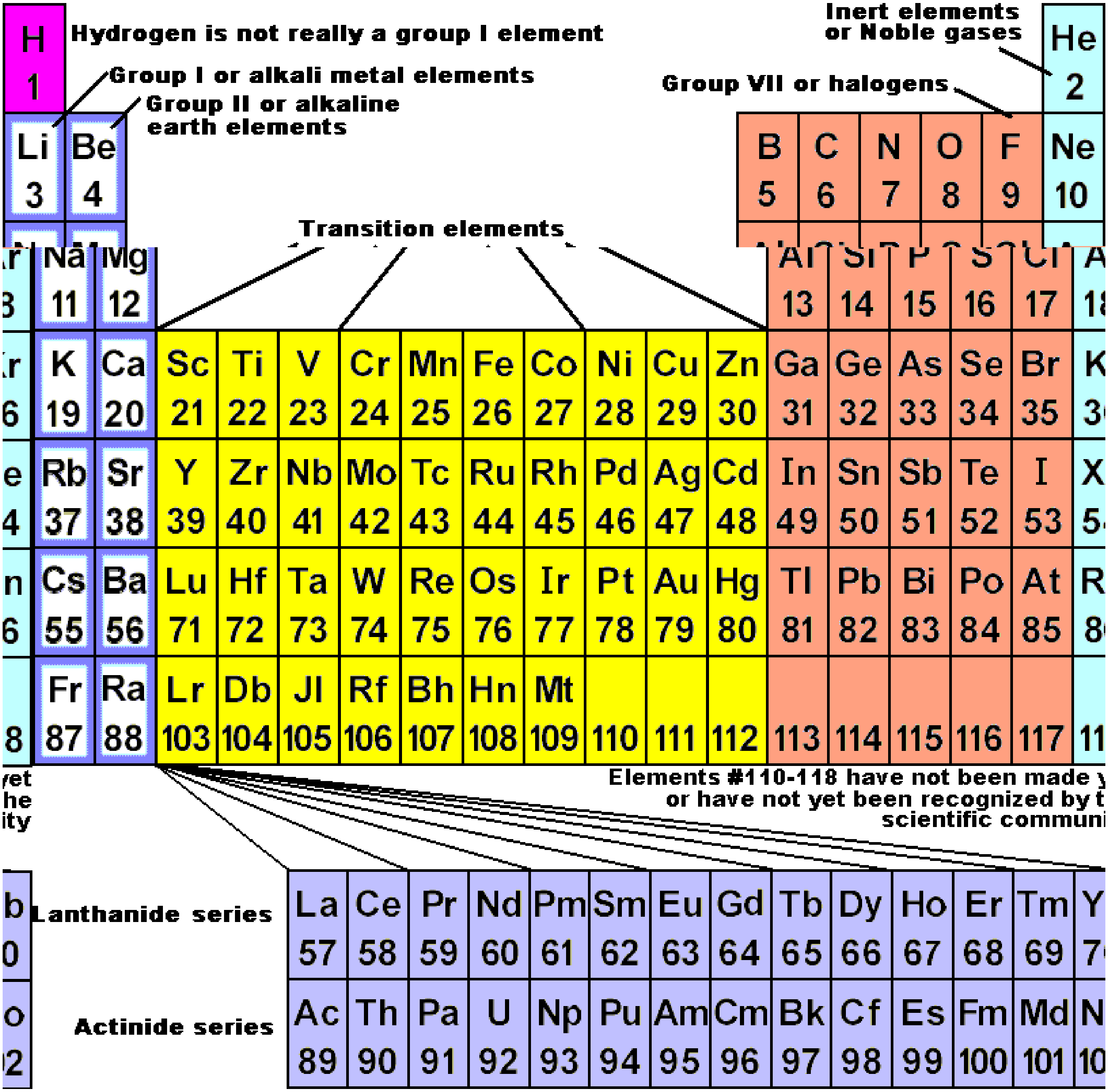
PERIODIC PROPERTIES

The periodic chart came about from the idea that we could arrange the elements, originally by atomic weight, in a scheme that would show similarity among groups. The original idea came from noticing how other elements combined with oxygen. Oxygen combines in some way with all the elements except the inert gases. Each atom of oxygen combines with two atoms of any element in Group 1, the elements in the row below lithium. Each atom of oxygen combines one-to-one with any element in Group 2, the elements in the row below beryllium. From here as we investigate the groups from left to right across the Periodic Chart, the story is not quite so clear, but the pattern is there. Group 3 is the group below boron. All of these elements combine with oxygen at the ratio of one-and-a- half to one oxygen. Group 4, beginning with carbon, combines two to one with oxygen. The group of transition elements (numbers 21-30 and 39-48 and 71-80 and 103 up) have never been adequately placed into the original scheme relating to oxygen. The transition elements vary in the ways they can attach to oxygen, but in a manner that is not so readily apparent by the simple scheme. Gallium, element number thirty-one, is the crowning glory of the Periodic Chart as first proposed by Mendeleev. Dmitri Ivanovich Mendeleev first proposed the idea that the elements could be arranged in a periodic fashion. He left a space for gallium below aluminum, naming it eka- aluminum, and predicting the properties of gallium fairly closely. The element was found some years later just as Mendeleev had predicted. Mendeleev also accurately predicted the properties of other elements.

Most Periodic Charts have two rows of fourteen elements below the main body of the chart. These two rows, the Lanthanides and Actinides really should be in the chart from numbers 57 - 70 and from 89 - 102. To show this, there would have to be a gulf of fourteen element spaces between numbers 20 - 21 and numbers 38 - 39. This would make the chart almost twice as long as it is now. The Lanthanides belong to Period 6, and the Actinides belong to Period 7. In basic Chemistry courses you will rarely find much use for any of the Lanthanides or Actinides, with the possible exception of Element #92, Uranium. No element greater than #92 is found in nature. They are all man-made elements, if you would like to call them that. None of the elements greater than #83 have any isotope that is completely stable. This means that all the elements larger than bismuth are naturally radioactive. The Lanthanide elements are so rare that you are not likely to run across them in most beginning chemistry classes. Another oddity of the Periodic Chart is that hydrogen does not really belong to Group I -- or any other group. Despite being over seventy percent of the atoms in the known universe, hydrogen is a unique element.

For more information on each of the elements, see the chapter on the elements alphabetically.

PERIODIC CHART OF THE ELEMENTS



H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	
Cs 55	Ba 56	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	
Fr 87	Ra 88	Lr 103	Db 104	Jl 105	Rf 106	Bh 107	Hn 108	Mt 109	110	111	112	113	114	115	116	117	

Lanthanide series	La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69
Actinide series	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101

Back to the beginning of Periodic Chart.

ELEMENT, ION, AND COMPOUND SYMBOLS

For every element there is one and only one upper case letter. There may or may not be a lower case letter with it. When written in chemical equations, we represent the elements by the symbol alone with no charge attached. The seven exceptions to that are the seven elements that are in gaseous form as a diatomic molecule, that is, two atoms of the same element attached to each other. The list of these elements is best memorized. They are: hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine. The chemical symbols for these diatomic gases are: H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2. Under some conditions oxygen makes a triatomic molecule, ozone, O_3. Ozone is not stable, so the oxygen atoms rearrange themselves into the more stable diatomic form.

Chemtutor highly recommends that a few short lists be well learned for immediate recognition. The diatomic gases (hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine), the Group one elements (lithium, sodium, potassium, rubidium, cesium, and francium), the Group two elements (beryllium, magnesium, calcium, strontium, barium, and radium), Group seven elements, the halogens, (fluorine, chlorine, bromine, iodine, and astatine), and the noble gases (helium, neon, argon, krypton, xenon, and radon). If nothing else, learning these as a litany will help you distinguish between radium, a Group 1 element, and radon, an inert gas.

Groups of two or more element symbols attached to each other without any charge on them indicate a compound. $CaCl_2$ is a compound with two chlorine atoms for each calcium atom. $CuSO_4 \cdot 5H_2O$, cupric sulfate pentahydrate, is also a compound. It has one copper atom and one sulfate ion consisting of a sulfur atom and four oxygen atoms attached to five molecules of water.

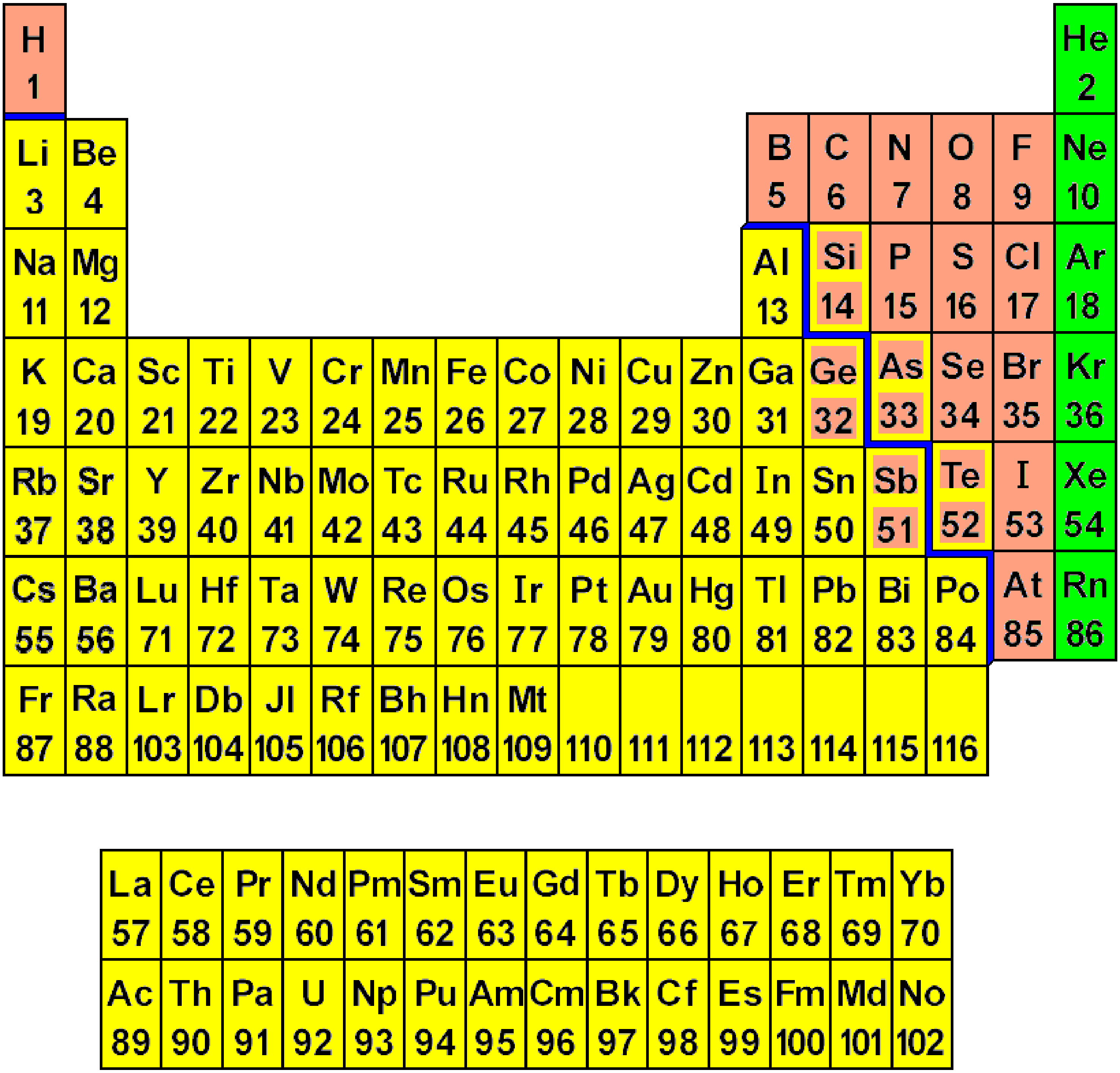
Charged particles, called ions, when written with symbols will have the charge, either positive (+) or negative (-), written to the right and superscripted to the chemical symbol. For instance, Na^+ is the symbol for the sodium ion. Atoms or polyatomic ions with charges of more than one, either positive or negative, have a number with the charge. For instance $(CO_3)^{2-}$ is the symbol for the carbonate ion. The carbonate ion has one carbon atom in it, three oxygen atoms, and a charge of negative two. Observe that the charge is outside the parentheses, indicating that the charge is from the polyatomic ion as a whole.

Back to the beginning of Periodic Chart.

CATEGORIES OF ELEMENTS

What Chemtutor calls 'categories of elements' include; metals, non-metals, semi-metals, noble gases, and hydrogen.

PERIODIC CHART OF THE ELEMENTS



H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Lr 103	Db 104	Jl 105	Rf 106	Bh 107	Hn 108	Mt 109	110	111	112	113	114	115	116		

La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70
Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102

Consider a staircase-shaped line on the Periodic Chart starting between boron and aluminum turns to be between aluminum and silicon then down between silicon and germanium, between germanium and arsenic, between arsenic and antimony, between antimony and tellurium, between tellurium and polonium, and between polonium and astatine. This is the line between metal and non-metal elements. Metal elements are to the left and down from the line and non-metal elements are to the right and up from the line. Well, that’s not exactly true. There is a line of non-metal elements, Group 8, or Group 18, or Group 0, whichever way you count them, the noble or inert gases that are really an entire Group and category to themselves. Hydrogen is a unique element, the only member of its own Group and category.

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NOBLE GASES

The noble gases, or inert gases, have the following properties: For the most part, they do not make chemical combinations with any elements. There have been some compounds made with the noble gases, but only with difficulty. There are certainly no natural compounds with this group. They are all gases at room temperature. They all have very low boiling and melting points. They all put out a color in the visible wavelengths when a low pressure of the gas is put into a tube and a high voltage current is run through the tube. This type of tube is called a neon light whether the tube has neon in it or not. The inert gases are non-metals because they are not metals, but they are significantly different from the other non-metals. As closely akin as all the noble gases are to each other, they should surely be considered a separate group.

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METALS

By far the largest category of elements on the Periodic Chart is the metal elements. Metals share a set of properties that are not as universal to them as the inert gases. Metal elements usually have the following properties: They have one, two, or three electrons on the outside electron shell. The outside electrons make it more likely that the metal will lose electrons, making positive ions. The ions of metals are usually plus one, plus two, or plus three in charge. Metals tend to lose electrons to become stable. They will attach to other elements with ionic bonds almost exclusively. When metal atoms are together in a group, there is a swarm of semi-loose electrons around the atoms. These electrons move about freely among the metal atoms making what is called an electron gas. The electron gas accounts for the shininess of metals. When there is a smooth surface on the metal it will reflect electromagnetic waves (to include visible light) in an organized manner. The shininess is also called metallic luster. The same electron gas accounts for the cohesive tendencies of metals. Cohesive means the material clings to itself. This property can be easily seen with mercury. Mercury atoms cling to other mercury atoms or other metal atoms with an incredible tenacity. This same cohesion of metals occurs in the solid state. Silver is very malleable. That means that if you hit it, the material would more likely change shape than shatter. At one time US half dollar coins were made of ninety percent silver. It is illegal to deface money, but school children would take a spoon and beat the sides of the silver half dollars until the edges curled inward.

When the center became the right size, it was taken out to make a silver ring beaten to fit your finger. Wire is made by pulling metals through a die. The metal coheres to itself so much that it will reshape itself to the shape of the die as it passes through the hole in the die. This property of being able to be pulled through a die to make wire is called ductility (from the Latin *ducere*, to pull). The presence of the electron gas makes metals good conductors of electricity. Again due to the cohesive property, metals have high melting and boiling points. Almost all metals are solids at room temperature. Metals are usually good conductors of heat. Active metals react with acids. Some very active metals will react with water. Metal elements tend to be denser than non-metals.

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NON-METALS

The properties of non-metals are not as universal to them as the metals; there is a great deal of variation among this group. Non-metals have the following properties: Non-metals usually have four, five, six, or seven electrons in the outer shell. When they join with other elements non-metals can either share electrons in a covalent bond or gain electrons to become a negative ion and make an ionic bond. When non-metal elements join by covalent bonds, it is usually to other non-metals. Non-metals can attach together with covalent bonds to make a group of (usually non-metal) elements with a common charge called a radical or polyatomic ion. Elemental non-metals often have a dull appearance. They are more likely to be brittle, or shatter when struck. Although not a constant rule, non- metals tend to have lower melting and boiling points than metals and the solids tend to be less dense. Non-metals are not as cohesive as metals and certainly not ductile. Non-metals are not usually good conductors of heat or electricity. Many non-metals form diatomic or polyatomic molecules with other atoms of the same element. Many non-metals have more than one form of the free element, called allotropes, that appear in different conditions. (The word free here means that the element is unattached to other types of atom, not that it has a monetary value of zero.)

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SEMI-METALS

We have pretended that there is a sharp dividing line between the metals and non-metals. This is not the case.

The staircase-shaped line between metals and non-metals has several elements on or near it that have properties somewhere between the two categories. By having three electrons in the outside shell, boron should be a metal element. It is not. Boron is more likely to form covalent bonds like a non-metal than donate electrons like aluminum, the next element down the chart in the same group. Aluminum is definitely a metal in most of its traits, but it has its own idiosyncrasy. Aluminum is amphoteric; it reacts with both acids and bases. Silicon, germanium, arsenic, antimony, and tellurium are on the line between metals and non-metals and exhibit some of the qualities of both. These elements do not really comprise a clear-cut category, but, due to the mix of properties they show, they are often lumped into a classification called semi-metals. Many of the elements on the line are semiconductors of electricity, meaning that they have the ability to conduct electricity somewhere between almost none and full conduction. This property is useful in the electronics industry.

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HYDROGEN

We have failed to include hydrogen in any of the categories, for good reasons. Hydrogen just does not match anything else. More than ninety-nine-point-nine percent of hydrogen is just one proton and one electron. A very small proportion (one atom in several thousand) of hydrogen is deuterium, one proton, one neutron, and one electron. An even smaller portion (one hundred atoms per million billion) of hydrogen is tritium, one proton, two neutrons, and one electron. When a hydrogen atom gains an electron, it becomes a negative ion. The negative hydrogen ion, called hydride ion, can be attached to metals, but it is not seen in nature because it is not stable in water. The positive hydrogen ion is what is responsible for acids. There really is no such thing as a (positive) hydrogen ion. Having only a proton and an electron, hydrogen becomes only a proton if it loses its electron. Loose protons attach themselves to a water molecule to make H_3O^+ ion, a hydronium ion. This hydronium is the real chemical that produces the properties of acids. Elemental hydrogen is a diatomic gas. Except for having a valence of +1, hydrogen has few other similarities with the Group 1 elements. Hydrogen makes covalent bonds between other hydrogen atoms or other non-metals. See hydrogen in the Elements chapter.

Back to the beginning of Periodic Chart.

GROUPS OR FAMILIES OF THE PERIODIC CHART

This section is not intended as an exhaustive study of the groups of the Periodic Chart, but a quick-and-dirty overview of the groups as a way to see the organization of the chart. Many texts and charts will label the groups with different names and numbers. Chemtutor will attempt to give some standard numbers and identify the elements in those groups so there is no question about which ones we are describing. It is a good idea to have a copy of the Periodic Chart available as you go through this section.

Group I (1) elements, lithium, sodium, potassium, rubidium, cesium, and francium, are also called the alkali metal elements. They are all very soft metals that are not found free in nature because they react with water. In the element form they must be stored under kerosene to keep them from reacting with the humidity in the air. They all have a valence of plus one because they have one and only one electron in the outside shell. All of the alkali metals show a distinctive color when their compounds are put into a flame. Spectroscopy (dividing up the spectrum so you can see the individual frequencies) of the colored light from the flame test shows strong emission lines from the elements. The lightest of them are the least reactive. Activity increases as the element is further down the Periodic Chart. Lithium reacts leisurely with water. Cesium reacts very violently. Very few of the salts of Group 1 elements are not soluble in water. The lightest of the alkali metals are very common in the earth’s crust. Francium is both rare and radioactive.

Group II (2) elements, beryllium, magnesium, calcium, strontium, barium, and radium, all have two electrons in the outside ring, and so have a valence of two. Also called the alkaline earth metals, Group 2 elements in the free form are slightly soft metals. Magnesium and calcium are common in the earth’s crust.

Group 3 elements, boron, aluminum, gallium, indium, and thallium, are a mixed group. Boron has mostly non-metal properties . Boron will bond covalently by preference. The rest of the group are metals. Aluminum is the only one common in the earth’s crust. Group 3 elements have three electrons in the outer shell, but the larger three elements have valences of both one and three.

Group 4 elements, carbon, silicon, germanium, tin, and lead, are not a coherent group either. Carbon and silicon bond almost exclusively with four covalent bonds. They both are common in the earth’s crust. Germanium is a rare semi-metal. Tin and lead are definitely metals, even though they have four electrons in the outside shell. Tin and lead have some differences in their properties from metal elements that suggest the short distance from the line between metals and non-metals (semi-metal weirdness). They both have more than one valence and are both somewhat common in the earth’s crust.

Group 5 is also split between metals and non-metals. Nitrogen and phosphorus are very definitely non-metals. Both are common in the earth’s crust. In the rare instances that nitrogen and phosphorus form ions, they form triple negative ions. Nitride (N^{-3}) and phosphide (P^{-3}) ions are unstable in water, and so are not found in nature. All of the Group 5 elements have five electrons in the outer shell. For the smaller elements it is easier to complete the shell to become stable, so they are non-metals. The larger elements in the group, antimony and bismuth, tend to be metals because it is easier for them to donate the five electrons than to attract three more. Arsenic, antimony and bismuth have valences of +3 or +5. Arsenic is very much a semi-metal, but all three of them show some semi-metal weirdness, such as brittleness as a free element.

Group VII (6 or 16) elements, oxygen, sulfur, selenium, and tellurium, have six electrons in the outside shell. We are not concerned with polonium as a Group 6 element. It is too rare, too radioactive, and too dangerous for us to even consider in a basic course. Tellurium is the only element in Group 6 that is a semi-metal. There are positive and negative ions of Tellurium. Oxygen, sulfur, and selenium are true non-metals. They have a valence of negative two as an ion, but they also bond covalently. Oxygen gas makes covalent double-bonded diatomic molecules. Oxygen and sulfur are common elements. Selenium has a property that may be from semi-metal weirdness; it conducts electricity much better when light is shining on it. Selenium is used in photocells for this property.

On some charts you will see hydrogen above fluorine in Group VII (7 or 17). Hydrogen does not belong there any more than it belongs above Group 1. Fluorine, chlorine, bromine, and iodine make up Group 7, the halogens. We can forget about astatine. It is too rare and radioactive to warrant any consideration here. Halogens have a valence of negative one when they make ions because they have seven electrons in the outer shell. They are all diatomic gases as free elements near room temperature. They are choking poisonous gases. Fluorine and chlorine are yellow-green, bromine is reddish, and iodine is purple as a gas. All can be found attached to organic molecules. Chlorine is common in the earth’s crust. Fluorine is the most active of them, and the activity decreases as the size of the halogen increases.

The inert gases or noble gases all have a complete outside shell of electrons. Helium is the only one that has only an ‘*s*’ subshell filled, having only two electrons in the outer and only shell. All the others, neon, argon, krypton, xenon, and radon, have eight electrons in the outer shell. Since the electron configuration is most stable in this shape, the inert gases do not form natural compounds with other elements. The group is variously numbered as Group VII, 8, 8A, 0, or 18. 'Group zero'seems to fit them nicely since it is easy to think of them as having a zero valence, that is no likely charge.

The Transition Elements make up a group between what Chemtutor has labeled Group 2 and Group 3. Transition elements are all metals. Very few of the transition elements have any non-metal properties. Within the transition elements many charts subdivide the elements into groups, but other than three horizontal groups, it is difficult to make meaningful distinctions among them. The horizontal groups are: iron, cobalt, and nickel; ruthenium, rhodium, and palladium; and osmium, iridium, and platinum.

Lanthanides, elements 57 through 70, are also called the rare earth elements. They are all metal elements very similar to each other, but may be divided into a cerium and a yttrium group. They are often found in the same ores with other elements of the group. None are found in any great quantity in the earth’s crust. Of the Actinides, elements 89 through 102, only the first three are naturally occurring, the rest being manufactured elements. Of the three naturally occurring ones, only uranium is likely to be referred to in any way in a basic chemistry course. Elements 103 through 109 have been manufactured, and they have been named by the IUPAC (International Union of Pure and Applied Chemistry), but they are not of much importance to this course.

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STATES OF MATTER

THE VIEW FROM ABOVE

One of the main reasons for the study of chemistry to be difficult has always been the difference in the way things seem to work from the point of view of the atom and the view from human being size. A human is usually between one and two meters tall. An atom is similarly usually between one and two Ångstroms in diameter. You might say that in one length dimension there is a difference in size of E10 (10^{10}) between humans and atoms. What if there were a creature that was E10 larger than humans? How would it look to us and how would it see us? Let’s call such a large thing a vrumschk because I don’t know of anything else called a vrumschk. (If you know of anything called a vrumschk, or, even worse, someone with a name anything like it, PLEASE tell me so I can change it.) Your average vrumschk is 1.5 E 10 meters across. This distance is one light minute, so it takes a whole minute for light to go from one side to the other of a vrumschk. At that size, it would have a mass of about the same as an average galaxy. (You could quibble about that mass. Don’t bother.) Eight vrumschks would fit between the earth and the sun. A vrumschk would just barely be able to put its finger between the earth and the moon.

One vrumschk says to another, “Hey, Snerbert! Drift over here! You won’t believe this, but I am getting signals from this little round grain of crud. I would be willing to bet there is something living on that little speck.”

“You’ve been inhaling comet dust," says Snerbert, "There is no way to see anything that small because the frequency of electromagnetic radiation we can detect is far too large to make a picture of anything that small. Do you have any evidence that they exist?”

“I’ve been watching it for a few billion years and it has changed since that time. I have recently picked up signals in an extraordinary high frequency of electromagnetic radiation. Some are interpreted as vibration only and some can be changed into a picture. Something about Ricky Ricardo having to get back to the club before Lucy finds out about ……”

Likewise, we have evidence of the atoms even if we can’t see them directly. We know what they do under some conditions. We can get electromagnetic radiation from them, if not I Love Lucy programs. We have plenty of evidence of what goes on at the atomic level. Our best tool is our imagination. We construct models of the likely configuration of things on that level and test the idea against the other observations we can make of the materials.

The result of years of careful study of matter shows that the ‘micro’ world of atoms and subatomic particles is very different from the ‘macro’ world we live in. The way it was deduced has been a marvelous construction of head work and careful observation. It takes a bit of a leap of faith to take in the theory of how the micro world works until the mounting weight of evidence, as you see how more and more of it fits together, makes it seem a little more likely as you study chemistry.

Back to the beginning of States of Matter.

KINETIC THEORY OF MATTER

The ***Kinetic Theory of Matter*** is the statement of how we believe atoms and molecules, particularly in gas form, behave and how it relates to the ways we have to look at the things around us. The Kinetic Theory is a good way to relate the 'micro world' with the 'macro world.'

A statement of the Kinetic Theory is:
1. All matter is made of atoms, the smallest bit of each element. A particle of a gas could be an atom or a group of atoms.
2. Atoms have an energy of motion that we feel as temperature. The motion of atoms or molecules can be in the form of linear motion of translation, the vibration of atoms or molecules against one another or pulling against a bond, and the rotation of individual atoms or groups of atoms.
3. There is a temperature to which we can extrapolate, absolute zero, at which, theoretically, the motion of the atoms and molecules would stop.
4. The pressure of a gas is due to the motion of the atoms or molecules of gas striking the object bearing that pressure. Against the side of the container and other particles of the gas, the collisions are elastic (with no friction).
5. There is a very large distance between the particles of a gas compared to the size of the particles such that the size of the particle can be considered negligible.

Since light, electromagnetic radiation, is required to see an object and light hitting an object gives it energy, as soon as one is able to see an object at absolute zero, it is not at absolute zero anymore from the new energy. Any other means of detection would add energy to the material at absolute zero. An object at absolute zero would be as hard to keep as a lump of antimatter. What would you keep it in? Practically, we can cool something down to temperatures approaching absolute zero, but we cannot get to that theoretical point, nor can we achieve temperatures below that point. There is no such thing as a temperature below absolute zero.

The Kinetic Theory of Matter does not, and is not intended to, take into account the energy of atoms due to excitation of electrons as you might see in glowing neon in a neon light or the bright redness of molten iron. In fact, objects cooler than molten iron and less excited than electrified neon will give off electromagnetic radiation, but that is another story.

In the view at this level, it is useful to look at atoms as if they were close to the hard little balls that Dalton considered. With this very mechanical view of atoms and molecules, we are losing some important facts to get an instructive thought on matter.

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SOLIDS

Solids are materials in which the atoms or molecules are set in place. In ionic solids such as table salt crystals, the ions are connected to their neighbors by electrical attraction. Covalently linked crystals such as diamonds produce the hardest materials. In other solids, each unit may have its own spot in which it fits (as in sugar crystals) or it may be just a jumble of molecules as in glass that have decreased energy. Crystalline solids have characteristic angles and can be cleaved along lines defined by the aligning of atoms or molecules of the crystal. Amorphous (without crystal shape) solids can be like carbon black or linked as in plastics. The common point about solids is that the atoms or molecules are in place. The temperature that can be shown by solid materials is due to the movement in place of the atoms or molecules. They have no independent linear motion of translation because they are attached to one another. Solids can have molecular energy due to vibration and rotation. Picture a class of second graders glued to their seat. Each student can jump up and down and sideways and turn the chair around, but they can’t move out of place. Another useful mental picture is a junkyard for springs. The springs have all been tied to each other in one enormous mass. Each spring can twist and vibrate, but it can’t get loose from its neighbor.

It is now necessary to change from being able to see and understand each atom or molecule to our larger world. Solids show a definite shape and a definite volume. Unless forces are used that are not commonly found near the earth’s surface, solids can not be compressed.

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LIQUIDS

Liquids are materials in which the atoms or molecules are as close to each other as solids, but the materials can slip over each other to change places. If you were only a few magnitudes larger than atoms, you might view liquids as B-B’s in a dump truck. Consider a large dump truck going fast down a very bumpy road. The B-B’s have some energy from the bumpy road. The top of the load is level. A few B-B’s are always in the process of getting enough energy to hop out of the dump truck. (This is a picture of vapor pressure of a liquid.) The B-B’s can be poured out of the dump truck. If there were a hole in the bottom of the dump truck, the B-B’s would leak out onto the ground. Like the B-B’s, liquids have no shape except for the shape of the container. B-B’s and liquids can not be compressed under common pressures. In a liquid the forces that hold the particles of liquid close to each other are greater than the forces due to motion that would force the particles away from each other.

The property of liquids of incompressibility is useful to us in hydraulic machines. A simple system of automobile hydraulic brakes are a good example of this. The brake pedal pushes a master cylinder. The travel (A description of distance (!) See Units and Measures.) of the brake petal is a few inches. The master cylinder pushes a small area of a liquid (hydraulic fluid) down a small tube (the brake lines) to the wheel cylinders. The wheel cylinders have a much larger area, but they go a shorter distance to push the brake pad against the drum or rotor, depending on what kind of brakes you have. The brake system cannot work correctly if there is any air (gas) in the system because the gas is compressible.

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GASES

Gas, or vapor, is the most energetic phase of matter commonly found here on earth. The particles of gas, either atoms or molecules, have too much energy to settle down attached to each other or to come close to other particles to be attracted by them. Material in the vapor phase have no shape of their own, that is, they take on the shape of the container. Gases have no given volume. A certain amount of gas at a pressure of one atmosphere and a volume of ten liters could become five liters if the pressure was increased or would become more than ten liters if the pressure was decreased.. The gas expands to fill the container. The Gas Law that covers the calculations of the pressure, volume, and temperature of gases is in a later chapter.

How can you picture the materials as a gas? A pool table is only in two dimensions, but what if the balls kept moving and the pool table were in three dimensions? Such a pool table would be like a gas. The rails of the 3-D pool table would be the sides of the container. The billiard balls would bounce off each other in completely elastic collisions and would bounce off the sides of the table to produce a constant pressure. The real hallmark of the gas is that the motion of the particles is so great that the forces of attraction between the particles are not able to hold any of them together.

Back to the beginning of States of Matter.

A WALK UP THE PHASE CHANGE GRAPH

On a piece of graph paper with the long side toward you, draw a graph with units of calories on the bottom from zero to nine hundred or a thousand calories and with temperature on the side, starting with minus twenty on the bottom and going up to about a hundred and twenty.

Let’s start with ice at minus twenty degrees Celsius. That is cold for a home refrigerator. Most home refrigerators don’t cool ice to below minus twenty. Usually a home freezer can get down to minus forty. The ice cube you take out of a freezer that cold will attract humidity out of the air and freeze it to the ice cube. It looks as if the ice cube is growing hair. This does not happen in completely dry air, but really dry air is not comfortable for people. The ice cube increases its temperature by cooling the surroundings. The surroundings lose the calories while the ice cube gains the same number of calories. Materials of different temperature will exchange heat until the two materials are the same temperature. It takes energy to separate temperatures, which is why it takes energy to run a refrigerator or an air conditioner.

The ice cube takes up about one half of a calorie for each gram of ice for each degree temperature increase. You can plot a slanted line from zero calories and minus twenty degrees Celsius to ten calories and zero degrees Celsius. This melting point of ice, zero degrees Celsius, is the end of the line for that process. The slope of the line indicates the specific heat of the ice, that is, the amount of heat that is necessary to increase the temperature of that material in that phase. Q is the heat in calories ice gains as it increases in temperature. m is the mass of ice in grams. c is the specific heat of ice, about 0.5 calorie per gram degree. T is the temperature of the ice. $(T_2 - T_1)$ or ΔT, pronounced 'delta tee' is the change in temperature as the ice accepts heat.

$Q = m\ c\ \Delta T$ is the equation that relates temperature change, specific heat, mass and heat of a material not changing phase, but changing temperature. Notice that the formula is the same for a downward change in temperature, but that the Q becomes negative for the ice as the temperature drops.

Once the ice cube reaches zero Celsius, there is a phase change. The ice changes from solid to liquid at the melting point. The same temperature is also the freezing point. To get the process of melting right, we are going to have to mix the materials well enough and do the heat changes slowly enough so that there are only very small changes of temperature throughout the container. The first drop of water from the ice cube has a temperature of zero degrees Celsius. The rest of the ice cube has the same temperature. As half of the ice has melted, the temperature of the water is zero degrees Celsius and so is the temperature of the ice. As the last little piece of ice is in the cup, the temperature of it is zero degrees Celsius and so is the water around it. THE PHASE CHANGE HAPPENS WITH NO CHANGE OF TEMPERATURE. The energy of the heat goes to increasing the molecular energy of motion of the water molecules.

As the ice melts, it takes about eighty calories (of heat) per gram (of ice) for the ice to melt. Continue the graph from the top of the line for the increase in temperature of ice for eighty degrees AT THE SAME TEMPERATURE. Go straight across the graph to show no change in temperature in a phase change. Q is the heat in calories gained by the ice. m is the mass of ice in grams. H_f is the “heat of fusion” of water, a measure of the amount of heat required to change the phase of one gram of ice (or water).

$Q = m\ H_f$ is the math formula for the phase change. Why is there no figure in this formula for a change in temperature?

When all the ice has melted, we have water at zero degrees Celsius. You know you can put water on a stove to accept more heat. As you increase the amount of heat the water accepts, the water increases in temperature by the slope of one calorie per gram degree. There is a considerable difference between the specific heat of water as a solid and water as a liquid. This is mainly due to the hydrogen bonding of water.

At the end of the eighty calorie straight line at zero degrees, begin the line for the warming of water as a liquid. The line goes up one hundred calories and goes up to one hundred degrees Celsius. You have seen this before. The water in the kettle increases in temperature as the heat from the stove is added to it.

The mathematical formula for the heating of water as a liquid is the same $Q = m\ c\ (T_2 - T_2)$ as for the heating of ice. This time, thought, the specific heat of water as a liquid, c, is one calorie per gram degree.

The boiling point of water is one hundred degrees Celsius at one atmosphere pressure. At this temperature we are going to have another phase change. Just as with the change from solid to liquid, the phase change will occur with no change in temperature. The temperature at which the phase change happens, though depends upon the gas pressure on the liquid. At one standard atmosphere the boiling point of water is one hundred degrees. This is just another way of saying that the vapor pressure of water at one hundred degrees is one atmosphere. The boiling point of a liquid is the temperature at which the vapor pressure equals the ambient pressure. (Ambient pressure is the pressure around the material. Ambient pressure in open containers is the atmospheric pressure.) An open pot of water boiling on the stove will be one hundred degrees when the water begins to boil. Regardless of how rapidly the water boils, it can not reach temperatures above the boiling point. The last few drops of water at a boil will be at one hundred degrees.

It takes 540 calories per gram to change liquid water into water vapor by boiling at one atmosphere pressure. This is an incredibly large heat of vaporization (H_v). From the top of the line for heating liquid water to the boiling point, extend the line straight across (no change in temperature) for 540 calories. The graph is a good way to see that the process of boiling water takes more than two and a half times the energy needed to bring the water up to temperature from minus forty degrees. The formula for the boiling away of water is similar to the formula for melting ice, but H_v, the heat of vaporization substitutes for H_f, the heat of fusion. $Q = m H_v$

The number of 540 calories per gram to vaporize water seems high. It is. You can confirm this for yourself by the following quick-and-dirty experiment. Measure the temperature of a pot of water at about room temperature. Put the pot with water in it on a gas cooking eye or onto a hot electric eye. Time (in seconds) how long it takes the water to come to a boil (with the top on the pot most of the time). With the top off the pot, time how long it takes to boil out all the water. Make sure the heating device is producing the same amount of heat all through the experiment. Take the pot off the eye immediately after the water boils out and cool the pot (under a stream of running water). If you started at twenty degrees Celsius, it takes eighty calories per gram to get to the boiling point (at sea level). You can proportionate the times and find how much heat it takes to boil out the same amount of water that you brought to a boil. This experiment is not really accurate due to the heat capacity of the pot, the uncontrolled evaporation of the water, and the lack of accurate heating, but it can give you the vital information that the heat of vaporization of water is very large.

Once water is in the form of steam, it must be contained in order to be heated further. In a pressure cooker or boiler or other pressure device the temperature of the gas can be increased with the addition of heat. The formula again is: $Q = m c (T_2 - T_1)$ and c, the specific heat is about one half of a calorie per gram degree.

There are a few things like free element iodine and carbon dioxide that go directly from a solid to a gas at normal atmospheric pressures. There are a number of materials that undergo chemical reactions at some temperature before they change phase, but most other materials go through the same type of phase changes as water, but with the numbers for melting point, boiling point, c, H_f, H_v, etc. that are properties of that material.

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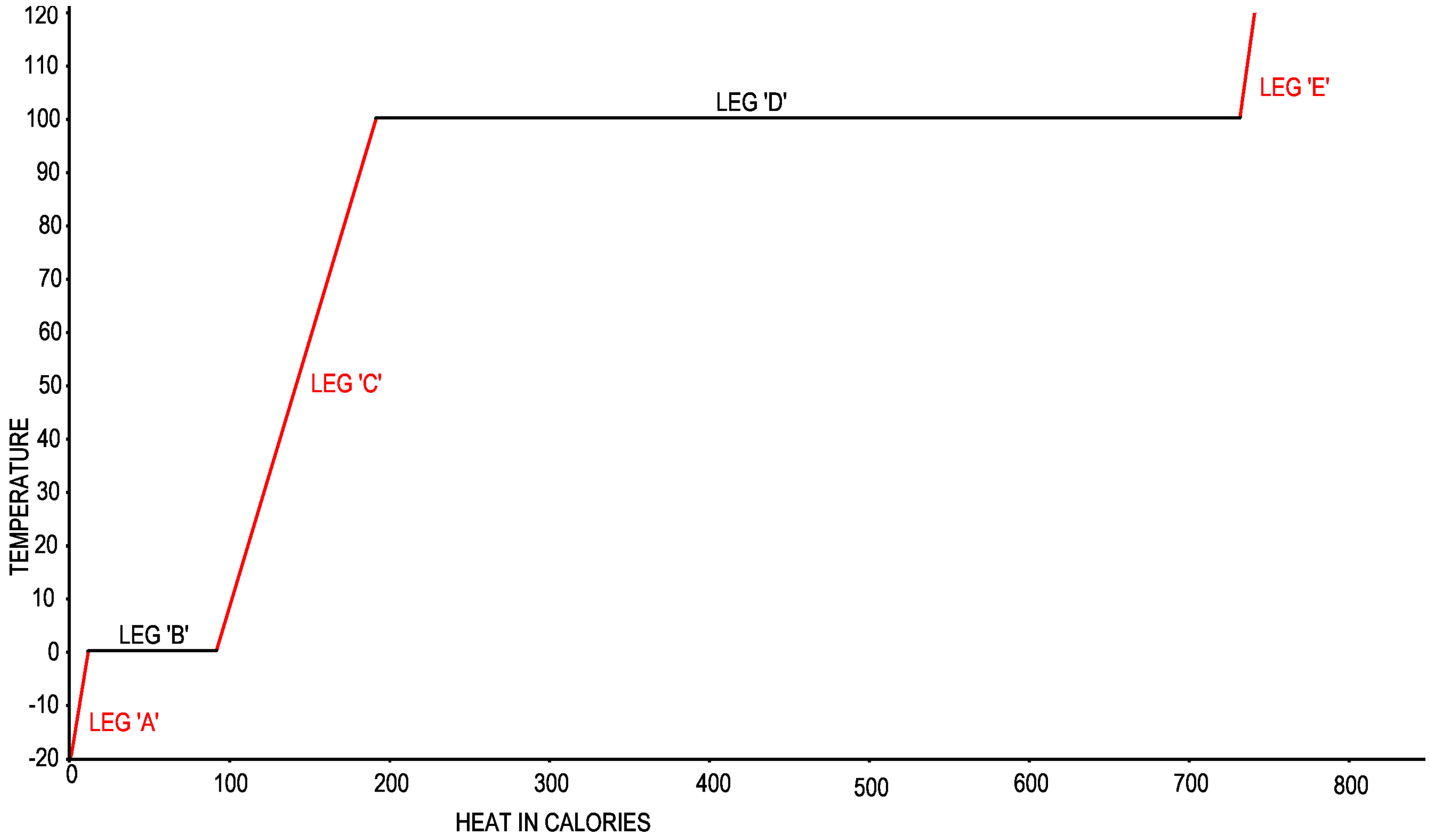
THE 'HEAT CURVE' FOR WATER



If you followed the instructions in the 'walk up the phase change pathway,' here is what you should have drawn. Leg 'A' is the warming of ice. Leg 'B' is the melting of ice. Leg 'C' is the warming of water. Leg 'D' is the boiling of water to steam. Leg 'E' is the warming of steam.

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LIVE STEAM

Live steam is the name given to water vapor at temperatures over the boiling point of water. The amount of energy required to change water into live steam can be reclaimed in the process of condensing the steam onto an object. Live steam is useful in pressing clothes, cleaning masonry or rugs, and very quick heating of water. The high efficiency of steam engines for trains and automobiles and the power they can produce is a testament to the great amount of energy in live steam. Live steam is extremely dangerous unless you have been given some training in how to use it. Many industrial accidents come from people using this primitive but powerful technology without proper training. High pressure boilers are used to make this readily accessible from many places in a site. In a hospital, for instance, the steam may be used to cook, to heat water, or to sterilize in different parts of the hospital. Not enough of the people using this powerful tool understand how dangerous it can be.

Just as the humidity in the air is not visible to the human eye, neither is live steam. You might think of a rapidly boiling kettle and remember the white plume coming out of the spout. That's not live steam. Look closer to the spout of the kettle. There is a short space just past the spout where there is none of the white fluffy material. THAT is the live steam. If you put your finger into the white fluffy material, it will get hot and wet. If you put your finger into the clear space just after the end of the spout, it will burn you very quickly. The white fluffy material is just a cloud with warm water droplets in it. The water in the cloud has already lost the heat of vaporization back to the air. Not that we are accustomed to doing so, but the live steam area is the place to put an envelope you might want to steam open.

Steam engines use live steam. The fire uses energy to heat up a boiler. The boiler is under pressure as the steam builds up in the boiler. The pressure of the steam is used to drive a reciprocating steam engine or a steam turbine. The use of steam for transportation is very efficient and the engines burn any combustable fuel. Some of the reasons we don't have very many steam automobiles are, (1) there is some popular fear about a boiler in a car, (2) it takes some time to heat up the boiler so the car can go, and (3) the increased weight and instability of the car from carrying around a large container of water.

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COOKING IN WATER

A lot of cooking is done in water. Boiling, poaching, and steaming have as lot of history in cooking. (After all, cooking is just some practical chemistry.) Cooking is just a matter of applying heat. The way the heat is applied, though, has a lot to do with how efficiently the heat is transferred, how evenly the heat is transferred, what other tastes and materials are taken on by the food in the process of heating, and how the amount of cooking is regulated. Boiling is a good way to efficiently transfer heat at a good, consistent temperature. It is easy to regulate how well an egg is to be cooked by timing the boiling of it. Boiling temperature varies with the altitude of the cooking and to a lesser extent with the small variations of the atmospheric pressure with the changes in weather. In Atlanta, Georgia with an elevation of one thousand feet above sea level, the boiling point of water averages about ninety-nine degrees Celsius, one degree lower than in Miami, Florida at sea level. In Denver, Colorado, the ‘mile high city,’ there is an even lower boiling point of water to an average of about ninety-five degrees Celsius. Since the cooking temperature is lower, the cooking time must be increased to get the same results.

Could you speed up cooking by keeping the heat all the way up on the stove? No, in an open pot cooking goes just as fast at a slow boil as at a vigorously rolling boil. Get the pot boiling and turn down the heat just enough to keep the pot boiling.

Could you speed up the cooking by increasing the pressure? Yes, pressure cookers work by increasing the pressure inside the cooker to increase the boiling temperature of water. Cooking with a pressure cooker requires enough water in the pot to increase the pressure by boiling water and trapping the vapor pressurized in a vessel. * * * * PRESSURE COOKERS CAN BE DANGEROUS. * * * * Follow the instructions carefully if you use a pressure cooker.

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TRIPLE POINT

You know that carbon dioxide is a gas at room temperatures. You may have seen 'dry ice,' solid carbon dioxide. The dry ice appears to go directly from the solid state to the vapor phase. What happened to liquid carbon dioxide?

There is no such thing as liquid carbon dioxide at only one atmosphere of pressure. If you increase the pressure to about 23 atmospheres at -40 degrees, you can see some liquid carbon dioxide.

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THERMODYNAMICS

What is the difference between chemistry and physics? In a physics course, the study of the phases of matter is a subchapter of the chapter on thermodynamics. Here in Chemtutor we will do something of a Sluffover and Passoff job on thermodynamics just to give you a taste of the idea.

The word "thermodynamics" means the "movement of heat." That sounds somewhat silly if you define heat as, "the way we feel the movement of molecules." Perhaps a more useful definition of thermodynamics is, "the flow or transfer of heat." The symbol, "Q" is used for this flow of heat energy.

The First Law of Thermodynamics can be stated something like this: " ***Heat is a form of energy. Types of energy can be transferred from one type to another, and it is possible to account for all of the energy to show no loss or gain of energy from the transfer.*** " This law is apparently violated by the famous Einstein equation, $E = m c^2$, in which E is energy, m is mass and c is the velocity of light. This is the equation that shows that an incredibly small mass disappears when a nuclear reaction occurs and an incredibly large amount of energy is made. Einstein's equation does not violate the first law, but just shows us the difficult idea that mass and energy are just two different forms of the same thing. Mass is just a very concentrated form of energy. It is pretty difficult to get energy from mass. (And even more difficult to get mass from energy!)

The Second Law of Thermodynamics is a bit more complex. There are several ways to express it and several parts to it. "***Usable work from a heat engine is available from a difference in temperature rather than any amount of material at the same temperature.***" and ***When two materials are combined, the temperature of both of them will become the same, a weighted average based on the specific heat and mass of the two materials coming together.***

The Third Law of Thermodynamics describes material under a very specialized condition. It shows that it is impossible to bring and keep a material to absolute zero temperature, since absolute zero is the condition wherein a material has absolutely no motion of the atoms or molecules.

If a scientist looks at you without the trace of a smile and talks about the fourth law of thermodynamics, you know to avoid playing poker with that individual. There is no such thing, but in jest many a scientist has talked about Murphy's Law as being a Fourth Law of Thermodynamics, when actually it is a special case of the Second Law. Murphy's Law says, "***If anything can go wrong, it will,***" and other humerous ways to explain perversity. The chemistry corrollary to this is that, "***All reactions tend toward maximum gunk. Buttered toast always lands butter - side - down***," is a manefestation of Murphy's Law. $|8-)

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HEAT CURVE MATH

You should know the following facts about water by rote:
The specific heat, c, of ice (solid water) is about 0.5 cal/gram degree.
The specific heat, c, of liquid water is 1 cal/gram degree
The specific heat, c, of water vapor (gaseous water) is about 0.5 cal/gram degree
The heat of fusion, H_f, of water is 80 calories per gram.
The heat of vaporization, H_v, of water is 540 calories per gram at 100 ºC.
The melting point (and freezing point) of water is 0 ºC.
The boiling point of water at one atmosphere pressure is 100 ºC.

In most of the chemistry courses numbers for any other materials should be made available to you in the form of a table or chart so you can work the problems.

The only two formulas you need to know are; $Q = m\,c\,\Delta T$ for changes of temperature with the change of heat (no phase change) and $Q = m\,H_v$ or $Q = m\,H_f$ for changes of phase.

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HEAT CURVE PROBLEMS

1. How much heat is needed to warm 25 grams of water from 10ºC to 20ºC?

2. How much heat is needed to warm 25 grams of water from -10ºC to 20ºC?

3. What is the specific heat of copper metal if 200 cal increases the temperature of 40.9 g of it from 21 ºC to 73 ºC?

4. How much heat is needed to increase the temperature of 12 grams of gold from 20 ºC to 95 ºC?

5. What is the temperature of 40 grams of water at 45 ºC added to 60 grams of water at 95 ºC?

6. What mass of live steam at 100 ºC is needed to heat 27.5 kg of water from 20 ºC to 100 ºC?

7. A 641 gram iron horse shoe at 1100 ºC is dunked into a bucket containing 12.8 kg of water at 22 ºC. Assume that no steam was lost. (All of the steam leaves its heat of vaporization and its mass to the water in the bucket.) The horse shoe is taken out at 100 ºC, just after it has quit boiling the water around it. What is the new temperature of the water?

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TABLE OF HEAT PROPERTIES OF SELECTED MATERIALS

Most of the numbers in this table are rounded to two significant digits. These numbers may be somewhat diferent a different temperatures, but that has been overlooked in this table.

MATERIAL	SPECIFIC HEAT 20ºC	HEAT OF FUSION @mp	HEAT OF VAP. @bp
water	1.0 cal/g deg	80 cal/g	540 cal/g
aluminum	0.22 cal/g deg	94 cal/g	2510 cal/g[2]
ammonia	1.1 cal/gdeg	108 cal/g	327 cal/g
copper	0.094 cal/gdeg	49 cal/g	1130 cal/g[1]
gold	0.032 cal/gdeg	16 cal/g	377 cal/g[2]
iron	0.12 cal/gdeg	1510 cal/g[2]	84.52cal/g[2]
lead	0.032 cal/gdeg	5.5 cal/g	205 cal/g[1]
mercury	0.033 cal/gdeg	2.8 cal/g	71 cal/g
silver	0.056 cal/gdeg	26 cal/g	558 cal/g [1]

1 Thanks, Paul.

2 Thanks, Dr. Lane Whitesell

ANSWERS TO PROBLEMS

1. 250 cal
2. 2625 cal
3. 0.094 cal/g deg
4. 28.8 cal
5. 75 ºC
6. 4074 grams
7. 26.0 ºC

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COMPOUNDS

IONIC AND COVALENT BONDS

A *bond* is an attachment among atoms. Atoms may be held together for any of several reasons, but all bonds have to do with the electrons, particularly the outside electrons, of atoms. There are bonds that occur due to sharing electrons. There are bonds that occur due to a full electrical charge difference attraction. There are bonds that come about from partial charges or the position or shape of electrons about an atom. But all bonds have to do with electrons. Since chemistry is the study of elements, compounds, and how they change, it might be said that chemistry is the study of electrons. If we study the changes brought about by moving protons or neutrons, we would be studying nuclear physics. In chemical reactions the elements do not change from one element to another, but are only rearranged in their attachments.

A *compound* is a group of atoms with an exact number and type of atoms in it arranged in a specific way. Every bit of that material is exactly the same. Exactly the same elements in exactly the same proportions are in every bit of the compound. Water is an example of a compound. One oxygen atom and two hydrogen atoms make up water. Each hydrogen atom is attached to an oxygen atom by a bond. Any other arrangement is not water. If any other elements are attached, it is not water. H_2O is the formula for that compound. This formula indicates that there are two hydrogen atoms and one oxygen atom in the compound. H_2S is hydrogen sulfide. Hydrogen sulfide does not have the same types of atoms as water. It is a different compound. H_2O_2 is the formula for hydrogen peroxide. It might have the right elements in it to be water, but it does not have them in the right proportion. It is still not water. The word formula is also used to mean the smallest bit of any compound. A molecule is a single formula of a compound joined by covalent bonds. *The Law of Constant Proportions* states that a given compound always contains the same proportion by weight of the same elements.

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IONIC BONDS

Some atoms, such as metals tend to lose electrons to make the outside ring or rings of electrons more stable and other atoms tend to gain electrons to complete the outside ring. An *ion* is a charged particle. Electrons are negative. The negative charge of the electrons can be offset by the positive charge of the protons, but the number of protons does not change in a chemical reaction. When an atom loses electrons it becomes a positive ion because the number of protons exceeds the number of electrons. Non-metal ions and most of the polyatomic ions have a negative charge. The non-metal ions tend to gain electrons to fill out the outer shell. When the number of electrons exceeds the number of protons, the ion is negative. The attraction between a positive ion and a negative ion is an ionic bond. Any positive ion will bond with any negative ion. They are not fussy. An ionic compound is a group of atoms attached by an ionic bond that is a major unifying portion of the compound. A positive ion, whether it is a single atom or a group of atoms all with the same charge, is called a *cation*, pronounced as if a cat were an ion. A negative ion is called an *anion*, pronounced as if Ann were an ion. The name of an ionic compound is the name of the positive ion (cation) first and the negative (anion) ion second.

The *valence* of an atom is the likely charge it will take on as an ion. The names of the ions of metal elements with only one valence, such as the Group 1 or Group 2 elements, is the same as the name of the element. The names of the ions of nonmetal elements (anions) develop an -ide on the end of the name of the element. For instance, fluorine ion is fluoride, oxygen ion is oxide, and iodine ion is iodide. There are a number of elements, usually transition elements that having more than one valence, that have a name for each ion, for instance ferric ion is an iron ion with a positive three charge. Ferrous ion is an iron ion with a charge of plus two. There are a number of common groups of atoms that have a charge for the whole group. Such a group is called a polyatomic ion or radical. Chemtutor suggests it is best to learn by rote the list of polyatomic ions with their names, formulas and charges. Chemtutor provides a Quickquiz on the common ions and a quiz on reading and writing ionic compounds.

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SOME ATOMS WITH MULTIPLE VALENCES.

NOTE THERE ARE TWO COMMON NAMES FOR THE IONS. YOU SHOULD KNOW BOTH THE STOCK SYSTEM AND THE OLD SYSTEM NAMES.

ION	STOCK SYSTEM	OLD SYSTEM	ION	STOCK SYSTEM	OLD SYSTEM
Fe^{2+}	iron II	ferrous	Fe^{3+}	iron III	ferric
Cu^{+}	copper I	cuprous	Cu^{2+}	copper II	cupric
Au^{+}	gold I	aurous	Au^{3+}	gold III	auric
Sn^{2+}	tin II	stannous	Sn^{4+}	tin IV	stannic
Pb^{2+}	lead II	plumbous	Pb^{4+}	lead IV	plumbic
Hg^{+}	mercury I	mercurous	Hg^{2+}	mercury II	mercuric
Cr^{2+}	chromium II	chromous	Cr^{3+}	chromium III	chromic
Mn^{2+}	manganese II	manganous	Mn^{3+}	manganeseIII	manganic

The ions by the Stock system are pronounced, “copper one”, “copper two”, etc. Notice that the two most likely ions of an atom that has multiple valences have suffixes in the old system to identify them. The smallest of the two charges gets the “-ous” suffix, and the largest of the two charges has the “-ic” suffix. This leads to the amusing possibility of Saint Nickelous coming down your chimney. (Boo! Hiss!)

SOME ATOMS WITH ONLY ONE COMMON VALENCE:

- ALL GROUP 1 ELEMENTS ARE +1
- ALL GROUP 2 ELEMENTS ARE +2
- ALL GROUP 7 (HALOGEN) ELEMENTS ARE -1 WHEN IONIC
- Oxygen and sulfur (GROUP 6) are -2 when ionic
- Hydrogen is usually +1
- Al^{3+}, Zn^{2+}, and Ag^{+}

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RADICALS OR POLYATOMIC IONS

The following radicals or polyatomic ions are groups of atoms of more than one kind of element attached by covalent bonds. They do not often come apart in ionic reactions. The charge on the radical is for the whole group of atoms as a unit. These are common radicals you should learn WITH THEIR CHARGE AND NAME.

- $(NH_4)^{+}$ AMMONIUM - Do not confuse with NH_3, AMMONIA GAS)
- $(NO_3)^{-}$ NITRATE (Do not confuse with NITRIDE (N^{3-}) or NITRITE)
- $(NO_2)^{-}$ NITRITE (Do not confuse with (N^{3-}) or NITRATE)
- $(C_2H_3O_2)^{-}$ ACETATE (NOTE - This is not the only way this may be written.)
- $(ClO_3)^{-}$ CHLORATE (Do not confuse with CHLORIDE (Cl^{-}) or CHLORITE)
- $(ClO_2)^{-}$ CHLORITE (Do not confuse with CHLORIDE (Cl^{-}) or CHLORATE)
- $(SO_3)^{2-}$ SULFITE (Do not confuse with (S^{2-}) or SULFATE)
- $(SO_4)^{2-}$ SULFATE (Do not confuse with SULFIDE (S^{2-}) or SULFITE)
- $(HSO_3)^{-}$ BISULFITE (or HYDROGEN SULFITE)
- $(PO_4)^{3-}$ PHOSPHATE (Do not confuse with P^{3-}, PHOSPHIDE)
- $(HCO_3)^{-}$ BICARBONATE (or HYDROGEN CARBONATE)
- $(CO_3)^{2-}$ CARBONATE
- $(HPO_4)^{2-}$ HYDROGEN PHOSPHATE
- $(H_2PO_4)^{-}$ DIHYDROGEN PHOSPHATE
- $(OH)^{-}$ HYDROXIDE
- $(CrO_4)^{2-}$ CHROMATE
- $(Cr_2O_7)^{2-}$DICHROMATE
- $(BO_3)^{3-}$ BORATE
- $(AsO_4)^{3-}$ ARSENATE
- $(C_2O_4)^{2-}$ OXALATE
- $(ClO_4)^{-}$ PERCHLORATE

- $(CN)^-$ CYANIDE
- $(MnO_4)^-$ PERMANGANATE

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ACIDS OF SOME COMMON POLYATOMIC IONS.

These are written here with the parentheses around the polyatomic ions to show their origin. Usually these compounds are written without the parentheses, such as HNO_3 or H_2SO_4. Note that the polyatomic ions with a single negative charge only have one hydrogen. Polyatomic ions with two negative charges have two hydrogens.

- H(OH) WATER (!)
- $H(NO_3)$ NITRIC ACID
- $H(NO_2)$ NITROUS ACID .
- $H(C_2H_3O_2)$ ACETIC ACID
- $H_2(CO_3)$ CARBONIC ACID
- $H_2(SO_3)$ SULFUROUS ACID
- $H_2(SO_4)$ SULFURIC ACID
- $H_3(PO_4)$ PHOSPHORIC ACID
- $H_2(CrO_4)$ CHROMIC ACID
- $H_3(BO_3)$ BORIC ACID
- $H_2(C_2O_4)$ OXALIC ACID

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WRITING IONIC COMPOUND FORMULAS

In the lists above, the radicals and compounds have a small number after and below an element if there is more than one of that type of that atom. For instance, ammonium ions have one nitrogen atom and four hydrogen atoms in them. Sulfuric acid has two hydrogens, one sulfur, and four oxygens.

Knowing the ions is the best way to identify ionic compounds and to predict how materials would join. People who do not know of the ammonium ion and the nitrate ion would have a difficult time seeing that NH_4NO_3 is ammonium nitrate. Chemtutor very highly recommends that you know all the above ions, complete with the valence or charge.

Let's consider what happens in an ionic bond using electron configuration, the octet rule, and some creative visualization. A sodium atom has eleven electrons around it. The first shell has two electrons in an *s* subshell. The second shell is also full with eight electrons in an *s* and a *p* subshell. The outer shell has one lonely electron, as do the other elements in Group 1. This outside electron can be detached from the sodium atom, leaving a sodium ion with a single positive charge and an electron. A chlorine atom has seventeen electrons. Two are in the first shell, eight are in the second shell, and seven are in the outside shell. The outside shell is lacking one electron to make a full shell, as are all the elements of Group 7. When the chlorine atom collects another electron, the atom becomes a negative ion. The positive sodium ion missing an electron is attracted to the negative chloride ion with an extra electron. The symbol for a single unattached electron is e^-.

$$\tfrac{1}{2}Cl_2 + Na \longrightarrow Cl + e^- + Na^+ \longrightarrow Cl^- + Na^+ \longrightarrow Na^+Cl^- \longrightarrow NaCl$$

Any compound should have a net zero charge. The single positive charge of the sodium ion cancels the single negative charge of the chloride ion. The same idea would be for an ionic compound made of ions of plus and minus two or plus and minus three, such as magnesium sulfate or aluminum phosphate

$$Mg^{2+} + (SO_4)^{2-} \longrightarrow Mg^{2+}(SO_4)^{2-} \longrightarrow Mg(SO_4) \text{ or } MgSO_4$$

$$Al^{3+} + (PO_4)^{3-} \longrightarrow Al^{3+}(PO_4)^{3-} \longrightarrow Al(PO_4) \text{ or } AlPO_4$$

But what happens if the amount of charge does not match? Aluminum bromide has a cation that is triple positive and an anion that is single negative. The compound must be written with one aluminum and three bromide ions. $AlBr_3$. Calcium phosphate has a double positive cation and a triple negative anion. If you like to think of it this way, the number of the charges must be switched to the other ion. $Ca_3(PO_4)_2$. Note that there must be two phosphates in each calcium phosphate, so the parentheses must be included in the formula to indicate that. Each calcium phosphate formula (Ionic compounds do not make molecules.) has three calcium atoms, two phosphate atoms, and eight oxygen atoms.

There are a small number of ionic compounds that do not fit into the system for one reason or other. A good example of this is magnetite, an ore of iron, Fe_3O_4. The calculated charge on each iron atom would be +8/3, not a likely actual charge. The deviance from the system in the case of magnetite could be accounted for by a mixture of the common ferric and ferrous ions.

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BINARY COVALENT COMPOUNDS

The word binary means that there are two types of atom in a compound. Covalent compounds are groups of atoms joined by covalent bonds. Binary covalent compounds are some of the very smallest compounds attached by covalent bonds. A covalent bond is the result of the sharing of a pair of electrons between two atoms. The chlorine molecule is a good example of the bond, even if it has only one type of atom. Chlorine gas, Cl_2, has two chlorine atoms, each of which has seven electrons in the outside ring. Each atom contributes an electron to an electron pair that make the covalent bond. Each atom shares the pair of electrons. In the case of chlorine gas, the two elements in the bond have exactly the same pull on the electron pair, so the electrons are exactly evenly shared. The covalent bond can be represented by a pair of dots between the atoms, Cl:Cl, or a line between them, Cl-Cl. Sharing the pair of electrons makes each chlorine atom feel as if it has a completed outer shell of eight electrons. The covalent bond is much harder to break than an ionic bond. The ionic bonds of soluble ionic compounds come apart in water, but covalent bonds do not usually come apart in water. Covalent bonds make real molecules, groups of atoms that are genuinely attached to each other. Binary covalent compounds have two types of atom in them, usually non-metal atoms. Covalent bonds can come in double (sharing of two pairs of electrons) and triple (three pairs of electrons) bonds.

FORMULA	COMMON NAME	SYSTEM NAME
N_2O	nitrous oxide	dinitrogen monoxide
NO	nitric oxide	nitrogen monoxide
N_2O_3	nitrous anhydride	dinitrogen trioxide
NO_2	nitrogen dioxide	nitrogen dioxide
N_2O_4	nitrogen tetroxide	dinitrogen tetroxide
N_2O_5	nitric anhydride	dinitrogen pentoxide
NO_3	nitrogen trioxide	nitrogen trioxide

With the compounds of nitrogen and oxygen to use as examples, we see that there are often more ways for any two elements to combine with each other by covalent bonds than by ionic bonds. Many of the frequently seen compounds already have names that have been in use for a long time. These names, called common names, may or may not have anything to do with the makeup of the material, but more of the common names of covalent compounds are used than of the ionic compounds.

*FGP	number	*FGP	number	*FGP	number	*FGP	number
mono-	one	di-	two	tri-	three	tetra-	four
penta-	five	hexa-	six	hepta-	seven	octa-	eight
nona-	nine	deca-	ten	undeca-	eleven	dodeca-	twelve

The system names include numbers that indicate how many of each type of atom are in a covalent molecule. The Fake Greek Prefixes (FGP's above in the chart) are used to indicate the number. It would be wise of you to know the FGP's.

In saying or writing the name of a binary covalent the FGP of the first element is said, then the name of the first element is said, then the FGP of the second element is said, and the name of the second element is said, usually with the ending "-ide" on it. The only notable exception for the rule is if the first mentioned element only has one atom in the molecule, in which case the "mono-" prefix is omitted. CO is carbon monoxide. CO_2 is carbon dioxide. In both cases there is only one carbon in the molecule, and the "mono-" prefix is not mentioned. For oxygen the last vowel of the FGP is omitted, as in the oxides of nitrogen in the above table.

COMMON NAMES OF BINARY COVALENT COMPOUNDS YOU SHOULD KNOW

- H_2O water
- NH_3 ammonia
- N_2H_4 hydrazine
- CH_4 methane
- C_2H_2 acetylene

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CHECKLIST OF KNOWLEDGE FOR WRITING COMPOUNDS

Here's a checklist of the things you need to know to be able to correctly write the formulas for materials.

- NAMES AND SYMBOLS OF THE ELEMENTS
- NAMES AND SYMBOLS OF DIATOMIC GASES
- NAMES, SYMBOLS, AND VALENCES OF THE ELEMENTS IN GROUPS 1, 2, 7, and 8
- NAMES, SYMBOLS, AND VALENCES OF METALS WITH ONE COMMON VALENCE
- NAMES AND VALENCES OF METALS WITH MORE THAN ONE COMMON VALENCE
- NAMES, FORMULAS, AND CHARGES OF COMMON POLYATOMIC IONS
- NAMES AND FORMULAS OF COMMON ACIDS
- HOW TO TELL THE DIFFERENCE BETWEEN COVALENT AND IONIC COMPOUNDS
- HOW TO WRITE THE FORMULA OF IONIC COMPOUNDS
- LIST OF FAKE GREEK PREFIXES UP TO TWELVE
- HOW TO WRITE THE FORMULA OF BINARY COVALENT COMPOUNDS

- COMMON NAMES OF SOME BINARY COVALENT COMPOUNDS

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MORE ON BONDS, SHAPES, AND OTHER FORCES

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THE CONTINUUM BETWEEN IONIC AND COVALENT BONDS

In an attempt to simplify, some books may seem to suggest that covalent and ionic bonds are two separate and completely different types of attachment. A covalent bond is a shared pair of electrons. The bond between the two atoms of any diatomic gas, such as chlorine gas, Cl_2, is certainly equally shared. The two chlorine atoms have exactly the same pull on the pair of electrons, so the bond must be exactly equally shared. In cesium fluoride the cesium atom certainly donates an electron and the fluoride atom certainly craves an electron. Both the cesium ion and the fluoride ion can exist independently of the other. The bond between a cesium and a fluoride ion is clearly ionic.

The amount of pull on an atom has on a shared pair of electrons, called electronegativity, is what determines the type of bond between atoms. Considering the Periodic Chart without the inert gases, electronegativity is greatest in the upper right of the Periodic Chart and lowest at the bottom left. The bond in francium fluoride should be the most ionic. Some texts refer to a bond that is between covalent and ionic called a polar covalent bond. There is a range of bond between purely ionic and purely covalent that depends upon the electronegativity of the atoms around that bond. If there is a large difference in electronegativity, the bond has more ionic character. If the electronegativity of the atoms is more similar, the bond has more covalent character.

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LEWIS STRUCTURES

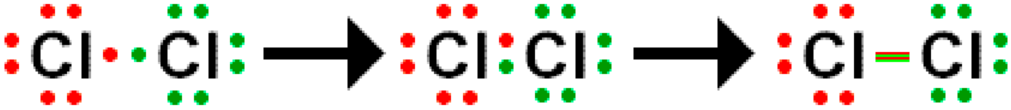
Lewis structures are an opportunity to better visualize the valence electrons of elements. In the Lewis model, an element symbol is inside the valence electrons of the s and p subshells of the outer ring. It is not very convenient to show the Lewis structures of the Transition Elements, the Lanthanides, or Actinides. The inert gases are shown having the element symbol inside four groups of two electrons symbolized as dots. Two dots above the symbol, two below, two on the right, and two on the left. The inert gases have a full shell of valence electrons, so all eight valence electrons appear. Halogens have one of the dots missing. It does not matter on which side of the symbol the dot is missing. Group 1 elements and hydrogen are shown with a single electron in the outer shell. Group 2 elements are shown with two electrons in the outer shell, but those electrons are not on the same side. Group 3 elements have three dots representing electrons, but the electrons are spread around to one per position, as in Group 2 elements. Group 4 elements, carbon, silicon, etc. are shown as having four electrons around the symbol, each in a different position.

Group 5 elements, nitrogen, phosphorus, etc. have five electrons in the outer shell. In only one position are there two electrons. So Group 5 elements such as nitrogen can either accept three electrons to become a triple negative ion or join in a covalent bond with three other items. When all three of the unpaired electrons are involved with a covalent bond, there is yet another pair of electrons in the outside shell of Group 5 elements.

Group 6 elements, oxygen, sulfur, etc., have six electrons around the symbol, again without any concern to position except that there are two electrons in two positions and one electron alone in the other two positions. Group 7 elements have all of the eight outside electrons spaces filled except for one. The Lewis structure of a Group 7 element will have two dots in all four places around the element symbol except for one.

There is a more extensive and better illustrated section on the Lewis structures of elements in the atomic structure chapter in Chemtutor. In this section there will be emphasis on the Lewis structure of small compounds and polyatomic ions.

Let's start with two atoms of the same type sharing a pair of electrons. Chlorine atoms have seven electrons each and would be a lot more stable with eight electrons in the outer shell. Single chlorine atoms just do not exist because they get together in pairs to share a pair of electrons. The shared pair of electrons make a bond between the atoms. In Lewis structures, the outside electrons are shown with dots and covalent bonds are shown by bars.



This covalent bond between chlorine is one of the most covalent bonds known. Why? A covalent bond is the sharing of a pair of electrons. The two atoms on ether side of the bond are exactly the same, so the amount of "pull" of each atom on the electrons is the same, and the electrons are shared equally.

Next let's consider a molecule in which the atoms bonded are not the same, but the bonds are balanced. Methane, CH_4, is such a molecule. If there were just a carbon and a single hydrogen, the bond between them would not be perfectly covalent. In the CH_4 molecule, the four hydrogen atoms exactly balance each other out.

The Lewis structure of methane does not have any electrons left over. The carbon began with four electrons and each hydrogen began with two electrons. Only the bars representing the shared pairs of electrons remain. The carbon now shares four pairs of electrons, so this satisfies the carbon's need for eight electrons in the outside shell. Each hydrogen has a single shared pair in the outside shell, but the outside shell of the hydrogen only has two electrons, so the hydrogen has a full outer shell also.

Carbons and hydrogens are nice and easy to write in Lewis structures, because each carbon must have four attachments to it and each hydrogen must have one and only one attachment to it. When the bonds around a carbon atom go to four different atoms, the shape of the bonds around that carbon is roughly tetrahedral, depending upon what the materials are around the carbon. Carbons are also able to have more than one bond between the same two. Consider the series ethane (C_2H_6), ethene (C_2H_4),(common name is ethylene), and ethyne (C_2H_2), (common name is acetylene).

In writing the Lewis structure of compounds, the bars representing bonds are preferred to the dots representing individual electrons.

The double bars between the carbons in ethylene, C=C, represent a double bond between the two carbons, that is four shared electrons to make a stronger attachment between the two carbons. The triple bars between the carbons of acetylene represent a triple covalent bond between those two carbons, three pairs of shared electrons between those carbons. Every carbon has four bonds to it showing a pair of electrons to make eight electrons in the outer shell. Each hydrogen has one and only one bond to it for two electrons in the outer shell. All of the outer shells are filled.

While we are doing this, notice that the Lewis structure of a molecule will show the shape of the molecule. All of the bonds in ethane are roughly the tetrahedral angle, so all of the hydrogens are equivalent. This is true. The bonds in acetylene make it a linear molecule. The bonds in ethylene are somewhat trigonal around the carbons, and the carbons can not twist around that bond as they can around a single bond, so that the molecule has a flat shape and the hydrogens are not equivalent. This is also true. (You will see this in the study of organic chemistry. This type of difference between the positions of the hydrogens is called ***cis - trans*** isomerism.)

We could set up a group of general guidelines for the drawing of Lewis structures for more complex molecules or polyatomic ions.

- Write all the atoms in the material

- Usually pick the atom type with the most number of possible bonds to it to be the central atom or group of atoms. In most organic compounds, carbon provides the main "skeleton" of the molecule.

- Arrange the other materials around the inner core according the formula of the material.
- Arrange the electrons or bonds around each atom according to how many it should have.
-
-

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SHAPES AROUND AN ATOM, VSEPR THEORY

There is no issue of shape around the Group 1 elements. There is only one attachment to them. so no angle is possible around them. Group 2 elements have two electrons in the outer shell. Many of the compounds of Group 2 elements are ionic compounds, not really making an angle in a molecule. Molecules made with Group 2 elements that have two attached items to the Group 2 element have a linear shape, because the two attached materials will try to move as far from each other as possible. A linear shape means that a straight line could be made through all three atoms with the Group 2 element in the center.

Covalent compounds with boron are good examples of trigonal shaped molecules. The trigonal shape is a flat molecule with 120 degree angles between the attached atoms. Again using the example of a boron atom in the center, the attached elements move as far away from each other as they can, forming a trigonal shape.

Group 4 elements are not in the center of a flat molecule when they have four equivalent attachments to them. As with two or three attachments, the attached items move as far as they can away from each other. In the case of a central atom with four things attached to it, the greatest angle between the attached items does not produce a flat molecule. If you were to cut off the vertical portion of a standard three-legged music stand so that it was the same length as the three legs, the angles among all four directions would be roughly equal. Try this with a gumdrop or a marshmallow. Stick four different colored toothpicks into the center at approximately the same angle. If you have done it right, the general shape of the device will be the same no matter which one of the toothpicks is up. This shape is called tetrahedral. The shape of a tetrahedron appears with the attached atoms at the points of the figure and each triangle among any three of them makes a flat plane. A tetrahedron is a type of regular pyramid with a triangular base.

Group 5 elements, for instance nitrogen or phosphorus, will become triple negative as they add three electrons in ionic reactions, but this is rare. Nitrides and phosphides do not survive in the presence of water. Covalent bonds with these elements do survive in water. From the Lewis structure of these elements in the previous section, you know that Group 5 elements have the capability of joining with three covalent bonds, but they don't make the trigonal shape because the UNSHARED PAIR OF ELECTRONS ACTS LIKE ANOTHER BONDED ATTACHMENT. The shape of the bonds around nitrogen and phosphorus is tetrahedral, just like the bonds around Group 4 elements.

Group 6 elements, oxygen and sulfur, have two pairs of unshared electrons. Just as in Group 5 elements, these two pairs of unshared electrons serve as another attached atom for the shape of the molecule. Group 6 elements make tetrahedral molecules also, but now the items making the points of the tetrahedron are now limited to two. The angle between the hydrogens in water is about 105 degrees. This peculiar shape is one of the things that makes water so special.

Group 7 elements have only one chance of attachment, so there is no shape around these atoms.

There will be more on shapes of molecules coming in Chemtutor.

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BONDING FORCES IN WATER

The alchemists of old had several other objectives aside from making gold. The though of a fluid material that could dissolve anything, the universal solvent, was another alchemical project. No alchemist would say, though, what material would hold such a fluid. Surprisingly, the closest thing we have to a universal solvent is water. Water is not only a common material, but the range of materials it dissolves is enormous. The guiding principle for predicting which materials dissolve in which solvent is that 'like dissolves like.' Fluids in which the atoms are attached with covalent bonds will dissolve covalent molecules. Fluids with a separation of charge in the bonds will dissolve ionic materials.

The bonds that hold hydrogen atoms to oxygen atoms are closer to covalent than ionic, but the bond does have a great deal of ionic character. Oxygen atoms are more electronegative than hydrogen atoms, so the electron pair is held closer to the oxygen atom. Another way to look at it is that there are only a very small number of water molecules ionized. The ionization of water, $H_2O \longrightarrow H^+ + (OH)^-$, into hydrogen ions and hydroxide ions happens in only a very small number of the water molecules, but the effect is quite important as the reason for the existence of acids and bases. Materials of a mildly covalent nature, such as small alcohols and sugars, are soluble in water due to the mostly covalent nature of the bonds in water.

The shape of the water molecule is bent at about a 105 degree angle due to the electron structure of oxygen. The two pairs of electrons that force the attached hydrogens into something close to a tetrahedral angle give the water molecule an unbalanced shape like a boomerang, with oxygen at the angle and the hydrogen atoms at the ends. We can think of the molecule has having an ‘oxygen side’ and a ‘hydrogen side’. Since the oxygen atom pulls the electrons closer to it, the oxygen side of the molecule has a slight negative charge. Cations (positive ions) are attracted to the partial positive charge on the oxygen side of water molecules. Likewise, the hydrogen side of the molecule has a slight positive charge, attracting anions. Polar materials such as salts, materials that have a separation of charge, dissolve in water due to the charge separation of water. The origin of the separation is called a *dipole moment* and the molecule itself can be called a *dipole*.

Molecules or atoms that have no center of asymmetry are non-polar. Atoms such as the inert gases have no center of asymmetry. Molecules such as methane, CH_4, are likewise totally symmetrical. Very small forces, called London forces, can be developed within such materials by the momentary asymmetries of the material and induction forces on neighboring materials. These small forces account for the ability of non-polar particles to become liquids and solids. The larger the atom or molecule, the more potent the London forces, possibly due to the greater ability to separate charge within a larger particle. The larger the inert gas, the higher its melting point and boiling point. In alkanes, a series of non-polar hydrocarbon molecules, the larger the molecule, the higher the melting and boiling point.

There may be London forces in water molecules, but the enormous force of the dipole interaction completely hides the small London forces. The dipole forces within water are particularly strong for two additional reasons. Dipole forces that involve hydrogen atoms around a strongly electronegative material such as nitrogen, oxygen, fluorine, or chlorine are particularly strong due to the small size of the hydrogen atom compared to the size of the dipole force. Such dipoles have significantly stronger forces, and have been called hydrogen bonds. In water, this effect is even greater due to the small size of the oxygen atom, thus the whole water molecule. In a water molecule hydrogen bonding is a large intermolecular force in a small volume on a small mass that makes it particularly noticeable.

Compare methane, CH_4, to water. They are similar in size and mass, but methane is non-polar and water is very highly polar due to the hydrogen bonding. The melting point for methane is -184 °C (89 K) and for water is 0 °C (273 K). The boiling point for methane is -161.5 °C (111.7 K) compared to water at 100 °C (373.2 K). The temperature range over which methane is a liquid is less than a quarter the range for water. Most of these differences are accountable from the hydrogen bonding of water. More about water later.

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COMPOUND WORKSHEET

Write chemical formula as requested. Show subscript numbers where needed. Show valences for all ions.

1. hydrochloric acid __________________ 2. sodium chloride _________________ 1. HCl 2. $NaCl$

3. sodium hexafluoride ______________ 4. strontium nitrate _________________ 3. NaF_6 4. $Sr(NO_3)_2$

5. calcium chloride __________________ 6. acetic acid ____________________ 5.$CaCl_2$ 6.$HC_2H_3O_2$

7. phosphoric acid ___________________ 8. ammonia _______________________ 7. H_3PO_4 8. NH_3

9. chlorine _______________________ 10. lithium sulfate ___________________ 9. Cl_2 10. Li_2SO_4

11. potassium chromate _____________ 12. calcium hydroxide _____________ 11.K_2CrO_4 12.$Ca(OH)_2$

13. aluminum foil __________________ 14. ammonium sulfate _______________ 13.Al 14.$(NH_4)_2SO_4$

15. sulfuric acid ___________________ 16. ammonium iodide _______________ 15. H_2SO_4 16. NH_4I

17. acetylene ______________________ 18. rubidium nitrite ________________ 17. C_2H_2 18. $RbNO_2$

19. lead II sulfite ___________________ 20. copper I sulfide _________________ 19. $PbSO_3$ 20.Cu_2S

21. aluminum oxide ________________ 22. magnesium bromide ______________ 21.Al_2O_3 22.$MgBr_2$

23. sodium chlorate _________________ 24. iron II chloride _________________ 23.$NaClO_3$ 24.$FeCl_2$

25. hydrogen gas ___________________ 26. silver chromate _________________ 25. H_2 26. Ag_2CrO_4

27. zinc bicarbonate ________________ 28. barium oxide _________________ 27.$Zn(HCO_3)_2$ 28.BaO

29. aluminum nitrate _______________ 30. diphosphorus pentoxide ___________ 29.$Al(NO_3)_3$ 30.P_2O_5

31. aluminum hydroxide ____________ 32. chromium III oxide ______________ 31.$Al(OH)_3$ 32.Cr_2O_3

33. lithium phosphate _________________ 34. ice __________________________ 33. Li_3PO_4 34. H_2O

35. nitrogen dioxide __________________ 36. iron III oxide __________________ 35. NO_2 36. Fe_2O_3

37. sodium peroxide _________________ 38. copper II oxide _________________ 37.Na_2O_3 38.CuO_2

39. liquid nitrogen ________________ 40. lead II acetate __________________ 39.N_2 40.$Pb(C_2H_3O_2)_2$

41. lead IV fluoride _________________ 42. ferrous bromide _________________ 41. PbF_4 42. $FeBr_2$

43. carbonic acid __________________ 44. silver bisulfite _________________ 43.H_2CO_3 44.$AgHSO_3$

45. cupric hydroxide ________________ 46. nitric acid ___________________ 45.$Cu(OH)_2$ 46.HNO_3

47. mercury II bromide _______________ 48. stannic sulfide ________________ 47. $HgBr_2$ 48. SnS_2

49. hydrofluoric acid _______________ 50. potassium phosphate _____________ 49. HF 50. K_3PO_4

51. iodine tribromide _______________ 52. phosphorus pentafluoride __________ 51. IBr_3 52. PF_5

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REACTIONS

WHAT IS A CHEMICAL REACTION?

A chemical reaction is material changing from a beginning mass to a resulting substance. The hallmark of a chemical reaction is that new material or materials are made, along with the disappearance of the mass that changed to make the new. This *does not mean* that new elements have been made. In order to make new elements, the nuclear contents must change. There are magnitudes of difference in the amounts of energy in ordinary chemical reactions compared to nuclear reactions, the rearrangement of the nuclei of atoms to change to new elements is enormous compared to the smaller energies of chemical changes. The alchemists, in their efforts to change less expensive metals to gold, did not have the fundamental understanding of what they were attempting to do to appreciate the difference.

A chemical equation is a way to describe what goes on in a chemical reaction, the actual change in a material. Chemical equations are written with the symbols of materials to include elements, ionic or covalent compounds, aqueous solutions, ions, or particles. There is an arrow pointing to the right that indicates the action of the reaction. The materials to the left of the arrow are the *reactants*, or materials that are going to react. The materials to the right of the arrow are the *products*, or materials that have been produced by the reaction. The *Law of Conservation of Mass* states that in a chemical reaction no mass is lost or gained. The Law of Conservation of Mass applies to individual types of atom. One could say that for any element, there is no loss or gain of that element in a chemical reaction. There are such things as reversible reactions, reactions in which the products reassemble to become the original products. Reversible reactions are symbolized in chemical equations by a double-headed arrow, but the standard remains to call the materials on the left the reactants and the materials on the right the products.

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EXAMPLES OF CHEMICAL CHANGES

Chemical reactions, also called chemical changes, are not limited to happening in a chemistry lab. Here are some examples of chemical reactions with the corresponding chemical equations:

A silver spoon tarnishes. The silver reacts with sulfur in the air to make silver sulfide, the black material we call tarnish.

$$2\ Ag + S \longrightarrow Ag_2S$$

An iron bar rusts. The iron reacts with oxygen in the air to make rust.

$$4\ Fe + 3\ O_2 \longrightarrow 2\ Fe_2O_3$$

Methane burns. Methane combines with oxygen in the air to make carbon dioxide and water vapor.

$$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$$

An antacid (calcium hydroxide) neutralizes stomach acid (hydrochloric acid).

$$Ca(OH)_2 + 2\ HCl \longrightarrow CaCl_2 + 2\ H_2O$$

Glucose (simple sugar) ferments to ethyl alcohol and carbon dioxide. The sugar in grapes or from grain ferments with yeast to make the alcohol and carbon dioxide. The carbon dioxide is the gas that bubbles out of beer or champaign.

$$C_6H_{12}O_6\ (\text{glucose}) \longrightarrow 2\ C_2H_5OH\ (\text{ethyl alcohol}) + 2\ CO_2$$

Alcohol plus oxygen becomes vinegar and a molecule of water. As in the fermentation of glucose, this is a more complex reaction than it appears here because it is a biochemical reaction.

$$C_2H_5OH + O_2 \longrightarrow HC_2H_3O_2 + H_2O$$

As a general rule, biochemical happenings make poor examples of basic chemical reactions because the actual reaction is carried on within living things and under enzyme control.

EXAMPLES OF PHYSICAL CHANGES

Here are some examples of changes that are NOT chemical reactions. In each case, the original material or materials may be reclaimed by physical processes.

Water boils out of a kettle or condenses on a cold glass.
An aluminum pot is put on a burner and gets hot.
Dry ice goes from a solid to a gaseous form of carbon dioxide (*sublimation*).
Gold melts or solidifies.
Sand is mixed in with salt.
A piece of chalk is ground to dust.
Glass breaks.
An iron rod gets magnetized.
A lump of sugar dissolves in water.

GRAY AREAS BETWEEN CHEMICAL AND PHYSICAL CHANGES

Even more telling are the gray areas. Are these changes chemical or physical? Why? (Punch the * discussion link after each one for a discussion on why that example is a gray area.)

Table salt dissolves in water. *
A hydrated crystal, such as blue vitriol, is dried with heat. *
Lightning makes ozone (O_3) from oxygen (O_2). The ozone then reverts to oxygen. *
Carbon dioxide dissolves in water. *
Ammonia gas dissolves in water. *
With pressure and heat graphite becomes diamond. *
An egg is cooked.*
A tree dies. *

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CHEMICAL EQUATIONS OF CHEMICAL REACTIONS

In order to write the chemical equations, you must first know the formulas for the materials involved. The formulas must be written on the proper side of the arrow - - reactants on the left and products on the right. The order in which the reactants and products are written does not matter, just as long as every material is on the proper side. Once the materials involved in the reaction are written correctly, DON'T TOUCH THEM. If you need to draw a box around each participant in the reaction to keep your grubby paws off the materials, do it.

Very often you will see the descriptions of the materials in the reaction in parentheses after the material. A gas is shown by ***(g)***. A solid material is shown by ***(s)***. A liquid is shown by ***(l)***. A material dissolved in water (an aqueous solution) is shown by ***(aq)***. An upwards pointing arrow (↑) indicates a gas being produced, and a downwards pointing arrow ↓ indicates a solid precipitate being produced.

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BALANCING EQUATIONS

Now comes the fun part, balancing the reaction. The Law of Conservation of Mass states that in a chemical reaction there is no loss of mass. Each type of element will have the same amount before the reaction and after the reaction, or as reactant and product. But you can't change the materials that participate in the reaction, so you must write an integer coefficient in front of (to the left of) each material in the reaction to make sure every type of atom has the same number on each side of the reaction. Let's start with the reaction of the Haber process:

Nitrogen gas plus hydrogen gas under pressure and at high temperature turn into ammonia. First write the materials correctly. Nitrogen and hydrogen are diatomic gases. Ammonia is a binary covalent memory item. The nitrogen and hydrogen are the reactants, and the ammonia is the product. Leave room for the coefficients in front of the materials.

$$\_\ N_2 + \_\ H_2 \longrightarrow \_\ NH_3$$

You can begin with either the nitrogen or the hydrogen. There are two nitrogen atoms on the left and only one on the right. In order to balance the nitrogen atoms, place a '2' in front of the ammonia.

$$\_\ N_2 + \_\ H_2 \longrightarrow 2\ NH_3$$

There are two hydrogens on the left and six on the right. We balance the hydrogens by placing a '3' in front of the hydrogen gas.

$$\_\ N_2 + 3\ H_2 \longrightarrow 2\ NH_3$$

Now go back and check to make sure everything is balanced. There are two nitrogen and six hydrogens on both sides of the reaction. It is balanced. There is no coefficient shown in front of the nitrogen. There is no need to write ones as coefficients. The reaction equation is:

$$N_2 + 3\ H_2 \longrightarrow 2\ NH_3$$

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BALANCING IONIC EQUATIONS WITH POLYATOMIC IONS

Silver nitrate and calcium chloride solutions combined produce a precipitate of silver chloride and leave a solution of calcium nitrate. This time we have ionic compounds in the reaction. Until you are sure of the compounds, you might want to write the ionic materials as the ions, as demonstrated here.

$$\_\ Ag^{+}(NO_3)^{-} + \_\ Ca^{2+}Cl^{-}_{2} \longrightarrow \_\ Ag^{+}Cl^{-} + \_\ Ca^{2+}\ (NO_3)^{-}_{2}$$

Notice that from one side to the other there is no change in the nitrate ion. In this case you can count the nitrate ion as a whole rather than splitting it up into nitrogen and oxygen. Your thoughts might go this way: How many silvers on the right? One. How many silvers on the left? One. They are the same. How many nitrates on the left? One. How many nitrates on the left? One. How many nitrates on the right? Two. We need to put a coefficient of two in front of the silver nitrate.

$$2\ AgNO_3 + \_\ CaCl_2 \longrightarrow \_\ AgCl + \_\ Ca\ (NO_3)_2$$

This changes the balance of silvers, so we have to put a two in front of the silver chloride.

$$2\ AgNO_3 + \_\ CaCl_2 \longrightarrow 2\ AgCl + \_\ Ca\ (NO_3)_2$$

Now let’s check again. Two silvers on each side. Two nitrates on each side. One calcium on each side and two chlorides on both sides. The balanced reaction is:

$$2\ AgNO_3 + CaCl_2 \longrightarrow 2\ AgCl + Ca\ (NO_3)_2$$

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BALANCING EQUATIONS WITH WATER AS A PRODUCT

Sulfuric acid and potassium hydroxide neutralize each other to make water and potassium sulfate. Here is an acid-base neutralization. These make a salt (Not necessarily common table salt.) and water. (Notice the ionic materials are written with the ion notation so they are sure to be right. Water and sulfuric acid are memory items and should not need to be written in ion form, though you could write the ions to make sure they are right.)

_ H_2SO_4 + _ $K^+(OH)^-$ ⟶ _ $K^+_2(SO_4)^{2+}$ + _ H_2O

The water is made from the hydrogen ion of the acid and the hydroxide ion of the base. Notice that it is a lot easier to understand how to balance the reaction if you write the water as if it were an ionic compound.

_ $H_2(SO_4)$+ _ $K^+(OH)^-$ ⟶ _ $K^+_2(SO_4)^{2+}$ + _ $H^+(OH)^-$

This is easier now because the hydrogen in the acid does not get confused with the hydrogen in the hydroxide of the base. Two hydrogens on each side. One sulfate on both sides. Two potassiums and two hydroxides on each side.

$$H_2(SO_4) + 2\ K(OH) \longrightarrow K_2(SO_4) + 2\ H(OH)$$

The reaction is now balanced.

Next is an example of having to go around the equation again. Phosphoric acid and calcium hydroxide react to make water and calcium phosphate.

$$\_\ H_3PO_4 + \_\ Ca^{2+}(OH)^{-}_2 \longrightarrow \_\ H^{+}(OH)^{-} + \_\ Ca^{2+}_3(PO4)^{3-}_2$$

First put a three on the water to balance the hydrogen in the phosphoric acid.

$$\_\ H_3PO_4 + \_\ Ca(OH)_2 \longrightarrow 3\ H(OH) + \_\ Ca_3(PO4)_2$$

Now put a two on the phosphoric acid to balance the phosphate from the calcium phosphate.

$$2\ H_3PO_4 + \_\ Ca(OH)_2 \longrightarrow 3\ H(OH) + Ca_3(PO4)_2$$

We have changed the amount of hydrogen ion, so we will have to change it on the right again.

$$2\ H_3PO_4 + \_\ Ca(OH)_2 \longrightarrow \underline{6}\ H(OH) + Ca_3(PO4)_2$$

And change the coefficient in front of the $Ca(OH)_2$ to match the calcium on the right side.

$$2\ H_3PO_4 + 3\ Ca(OH)_2 \longrightarrow 6\ H(OH) + Ca_3(PO4)_2$$

Only now does the rest of the equation balance with six hydrogens, six hydroxides, two phosphates, and three calciums on each side.

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BALANCING BURNING REACTIONS

Most burning reactions are the oxidation of a fuel material with oxygen gas. Complete burning produces carbon dioxide from all the carbon in the fuel, water from the hydrogen in the fuel, and sulfur dioxide from any sulfur in the fuel. Methane burns in air to make carbon dioxide and water.

$$\_\ CH_4 + \_\ O_2 \longrightarrow \_\ H_2O + \_\ CO_2$$

Easy. Put a two in front of the water to take care of all the hydrogens and a two in front of the oxygen. Anything you have to gather (any atom that comes from two or more sources in the reactants or gets distributed to two or more products) should be considered last.

$$CH_4 + \_\ O_2 \longrightarrow 2\ H_2O + CO_2$$

$$CH_4 + 2\ O_2 \longrightarrow 2\ H_2O + CO_2$$

What if the oxygen does not come out right? Let’s consider the equation for the burning of butane, C_4H_{10}.

$$\_\ C_4H_{10} + \_\ O_2 \longrightarrow \_\ CO_2 + \_\ H_2O$$

Insert the coefficients for carbon dioxide and water.

$$\_\ C_4H_{10} + \_\ O_2 \longrightarrow 4\ CO_2 + 5\ H_2O$$

We now have two oxygens on the left and thirteen oxygens on the right. The real problem is that we must write the oxygen as a diatomic gas. The chemical equation is not any different from an algebraic equation in that you can multiply both sides by the same thing and not change the equation. Multiply both sides by two to get the following.

$$2\ C_4H_{10} + \_\ O_2 \longrightarrow 8\ CO_2 + 10\ H_2O$$

Now the oxygens are easy to balance. There are twenty-six oxygens on the right, so the coefficient for the oxygen gas on the left must be thirteen.

$$2\ C_4H_{10} + 13\ O_2 \longrightarrow 8\ CO_2 + 10\ H_2O$$

Now it is correctly balanced. What if you finally balanced the same equation with:

$4\ C_4H_{10} + 26\ O_2 \longrightarrow 16\ CO_2 + 20\ H_2O$

or

$6\ C_4H_{10} + 39\ O_2 \longrightarrow 24\ CO_2 + 30\ H_2O$

Either equation is balanced, but not to the lowest integer. Algebraically you can divide these equations by two or three to get the lowest integer coefficients in front of all of the materials in the equation.

Now that we are complete pyromaniacs, let’s try burning isopropyl alcohol, C_3H_7OH.

$\_\ C_3H_7OH + \_\ O_2 \longrightarrow \_\ CO_2 + \_\ H_2O$

First take care of the carbon and hydrogen.

$\_\ C_3H_7OH + \_\ O_2 \longrightarrow 3\ CO_2 + 4\ H_2O$

But again we come up with an oxygen problem. The same process works here. Multiply the whole equation (except oxygen) by two.

$2\ C_3H_7OH + \_\ O_2 \longrightarrow 6\ CO_2 + 8\ H_2O$

Now the number nine fits in the oxygen coefficient. (Do you understand why?) The equation is balanced with six carbons, sixteen hydrogens, and twenty oxygens on each side.

$2\ C_3H_7OH + 9\ O_2 \longrightarrow 6\ CO_2 + 8\ H_2O$

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BALANCING BY OVERVIEW

Some equations are just mean, nasty, and rotten and defy your efforts to balance them. For some of these equations, a process I call overview is useful. Take as an example the smelting of magnetite, an iron ore.

$$\_\ Fe_3O_4 + \_\ CO \longrightarrow \_\ CO_2 + \_\ Fe$$

Unless you just happen to hit it right, you are unlikely to balance this equation with the trial method. (Go ahead and try it before you read further.)

The process overview shows that for each oxygen that the magnetite has, one carbon monoxide must turn to carbon dioxide. The carbon monoxide and carbon dioxide must have a coefficient that is four times the coefficient of the magnetite. Leave the magnetite coefficient and put a '4' in front of the carbon monoxide and carbon dioxide.

$$\_\ Fe_3O_4 + 4\ CO \longrightarrow 4\ CO_2 + \_\ Fe$$

The carbon and oxygen is balanced, leaving only the iron to be balanced.

$$Fe_3O_4 + 4\ CO \longrightarrow 4\ CO_2 + 3\ Fe$$

BALANCING REDOX EQUATIONS

The balancing of equations involving a reduction and oxidation will be considered in the chapter on redox (reduction and oxidation reactions).

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TYPES OF COMMON IONIC REACTION

SYNTHESIS REACTIONS

ALSO CALLED COMBINATION, CONSTRUCTION, OR COMPOSITION REACTIONS

The title of this section contains four names for the same type of reaction. Your text may use any of these. Chemtutor prefers the first of the names and will use “synthesis” where your text may use one of the other words. The hallmark of a synthesis reaction is a single product. A synthesis reaction might be symbolized by:

$$A + B \longrightarrow AB$$

Two materials, elements or compounds, come together to make a single product. Some examples of synthesis reactions are: Hydrogen gas and oxygen gas burn to produce water.

$$2\ H_2 + O_2 \longrightarrow 2\ H_2O$$ and

sulfur trioxide reacts with water to make sulfuric acid.

$$H_2O + SO_3 \longrightarrow H_2SO_4$$

What would you see in a ‘test tube’ if you were witness to a synthesis reaction? You would see two different materials combine. A single new material appears.

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DECOMPOSITION REACTIONS

ALSO CALLED DESYNTHESIS, DECOMBINATION, OR DECONSTRUCTION

Of the names for this type of reaction, Chemtutor again prefers the first. Mozart composed until age 35. After that, he decomposed. Yes, a decomposition is a coming apart. A single reactant comes apart into two or more products, symbolized by:

$$XZ \longrightarrow X + Z$$

Some examples of decomposition reactions are: potassium chlorate when heated comes apart into oxygen gas and potassium chloride

$$2\ KClO_3 \longrightarrow 2\ KCl + 3\ O_2$$

and heating sodium bicarbonate releases water and carbon dioxide and sodium carbonate.

$$6\ NaHCO_3 \longrightarrow 3\ Na_2CO_3 + 3\ H_2O + 3\ CO_2$$

In a “test tube” you would see a single material coming apart into more than one new material.

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SINGLE REPLACEMENT REACTIONS

ALSO CALLED SINGLE DISPLACEMENT, SINGLE

SUBSTITUTION, OR ACTIVITY REPLACEMENT

Here is an example of a single replacement reaction: silver nitrate solution has a piece of copper placed into it. The solution begins to turn blue and the copper seems to disappear. Instead, a silvery-white material appears.

$$2\ AgNO_3 + Cu \longrightarrow Cu(NO_3)_2 + 2\ Ag$$

A solution of an ionic compound has available an element. The element replaces one of the ions in the solution and a new element appears from the ion in solution. This type of reaction is called a replacement because a free element replaces one of the ions in a compound. There are two types of single replacement reactions, anionic and cationic. A cationic single replacement is what happened in the case of the silver being replaced by the copper in the above reaction because both the silver and the copper are only likely to make cations. An anionic single replacement is also possible. Into a potassium iodide solution chlorine gas is bubbled. The chlorine is used up and the solution turns purple-brown from the iodine. This is an example of an anionic single replacement reaction.

$$2\ KI + Cl_2 \longrightarrow 2\ KCl + I_2$$

Could you start with copper II nitrate and silver metal and get silver nitrate and copper metal, or could you start with potassium chloride and iodine and get potassium iodide and chlorine? No. The reactions don’t work that way. You can arrange cations or anions in a list of which ion will replace the next. This type of list is an activity series. The activity series of cation elements (metals) shows that gold is the least active metal. That should not be surprising, because gold does not tarnish. If we were to consider the Group 1 elements only on the activity list, lithium is the least active and francium is the most active, with each larger element being more active than the smaller one above it on the Periodic Chart. On the other side of the chart we could consider an activity series for anions. Taking just the halogens, the smallest halogen, fluorine is the most active. As the size of the halogen increases down the chart, the activity decreases. If an element is more active than the element of the same sign in an ionic solution, the more active element will replace it.

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DOUBLE REPLACEMENT REACTIONS

ALSO CALLED DOUBLE DISPLACEMENT OR METATHESIS

Some texts refer to single and double replacement reactions as solution reactions or ion reactions. That is understandable, considering these are mostly done in solutions in which the major materials we would be considering are in ion form. Chemtutor thinks that there is some good reason to call double replacement reactions de-ionizing reactions because a pair of ions are taken from the solution in these reactions. Let’s take an example.

$$AgNO_3 + KCl \longrightarrow AgCl_{(s)} + KNO_3$$

Above is the way the reaction might be published in a book, but the equation does not tell the whole story. Dissolved silver nitrate becomes a solution of silver ions and nitrate ions. Potassium chloride ionizes the same way. When the two solutions are added together, the silver ions and chloride ions find each other and become a solid precipitate. (They ‘rain’ or drop out of the solution, this time as a solid.) Since silver chloride is insoluble in water, the ions take each other out of the solution.

$$Ag^+ + (NO_3)^- + K^+ + Cl^- \longrightarrow AgCl + K^+ + (NO_3)^-$$

Here is another way to take the ions out of solution. Hydrochloric acid and sodium hydroxide (acid and base) neutralize each other to make water and a salt. Again the solution of hydrochloric acid is a solution of hydrogen (hydronium ions in the acid and base section) and chloride ions. The other solution to add to it, sodium hydroxide, has sodium ions and hydroxide ions. The hydrogen and hydroxide ions take each other out of the solution by making a covalent compound (water).

$HCl + NaOH \longrightarrow HOH + NaCl$ or

$H^{+} + Cl^{-} + Na^{+} + (OH)^{-} \longrightarrow HOH + Na^{+} + Cl^{-}$

One more way for the ions to be taken out of the water is for some of the ions to escape as a gas.

$CaCO_3 + 2\ HCl \longrightarrow CaCl_2 + H_2O + CO_2$

$Ca^{2+} + (CO_3)^{2-} + 2\ H^{+} + 2\ Cl^{-} \longrightarrow Ca^{2+} + 2\ Cl^{-} + H_2O + CO_2$

The carbonate and hydrogen ions became water and carbon dioxide. The carbon dioxide is lost as a gas to the ionic solution, so the equation can not go back.

One way to consider double replacement reactions is as follows: Two solutions of ionic compounds are really just sets of dissolved ions, each solution with a positive and a negative ion material. The two are added together, forming a mixture of four ions. If two of the ions can form (1) an insoluble material, (2) a covalent material such as water, or (2) a gas that can escape, it qualifies as a reaction. Not all of the ions are really involved in the reaction. Those ions that remain in solution after the reaction has completed are called *spectator ions*, that is, they are not involved in the reaction. There is some question as to whether they can see the action of the other ions, but that is what they are called.

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WRITE THE FORMULA FOR EACH MATERIAL CORRECTLY AND THEN BALANCE THE EQUATION. THERE ARE SOME REACTIONS THAT REQUIRE COMPLETION. FOR EACH REACTION TELL WHAT TYPE

OF REACTION IT IS.

1. sulfur trioxide and water combine to make sulfuric acid.

2. lead II nitrate and sodium iodide react to make lead iodide and sodium nitrate.

3. calcium fluoride and sulfuric acid make calcium sulfate and hydrogen fluoride (Hydrofluoric acid)

4. calcium carbonate will come apart when you heat it to leave calcium oxide and carbon dioxide.

5. ammonia gas when it is pressed into water will make ammonium hydroxide.

6. sodium hydroxide neutralizes carbonic acid

7. zinc sulfide and oxygen become zinc oxide and sulfur.

8. lithium oxide and water make lithium hydroxide

9. aluminum hydroxide and sulfuric acid neutralize to make water and aluminum sulfate.

10. sulfur burns in oxygen to make sulfur dioxide.

11. barium hydroxide and sulfuric acid make water and barium sulfate.

12. aluminum sulfate and calcium hydroxide become aluminum hydroxide and calcium sulfate.

13. copper metal and silver nitrate react to form silver metal and copper II nitrate.

14. sodium metal and chlorine react to make sodium chloride.

15. calcium phosphate and sulfuric acid make calcium sulfate and phosphoric acid.

16. phosphoric acid plus sodium hydroxide.

17. propane burns (with oxygen)

18. zinc and copper II sulfate yield zinc sulfate and copper metal

19. sulfuric acid reacts with zinc

20. acetic acid ionizes.

21. steam methane to get hydrogen and carbon dioxide

22. calcium oxide and aluminum make aluminum oxide and calcium

23. chlorine gas and sodium bromide yield sodium chloride and bromine

ANSWERS TO EQUATIONS

1. $SO_3 + H_2O \longrightarrow H_2SO_4$
SYNTHESIS

2. $Pb(NO_3)_2 + 2NaI \longrightarrow PbI_2\downarrow + 2NaNO_3$
DOUBLE REPLACEMENT (lead II iodide precipitates)

3. $CaF_2 + H_2SO_4 \longrightarrow CaSO_4\downarrow + 2\ HF$
DOUBLE REPLACEMENT (calcium sulfate precipitates)

4. $CaCO_3 \longrightarrow CaO + CO_2$
DECOMPOSITION

5. $NH_3 + H_2O \longrightarrow NH_4OH$
SYNTHESIS

6. $2\ NaOH + H_2CO_3 \longrightarrow Na_2CO_3 + 2\ H_2O$
DOUBLE REPLACEMENT OR ACID-BASE NEUTRALIZATION

7. $2\ ZnS + O_2 \longrightarrow 2\ ZnO + 2\ S$
ANIONIC SINGLE REPLACEMENT

8. $Li_2O + H_2O \longrightarrow 2\ LiOH$
SYNTHESIS

9. $2\ Al(OH)_3 + 3\ H_2SO_4 \longrightarrow 6\ H_2O + Al_2(SO_4)_3$

DOUBLE REPLACEMENT OR ACID-BASE NEUTRALIZATION

10. $S + O_2 \longrightarrow SO_2$
SYNTHESIS

11. $Ba(OH)_2 + H_2SO_4 \longrightarrow 2\ H_2O + BaSO_4$
DOUBLE REPLACEMENT OR ACID-BASE NEUTRALIZATION

12. $Al_2(SO_4)_3 + 3\ Ca(OH)_2 \longrightarrow 2\ Al(OH)_3\downarrow + 3\ CaSO_4\downarrow$
DOUBLE REPLACEMENT
(BOTH calcium sulfate and aluminum hydroxide are precipitates.)

13. $Cu + 2AgNO_3 \longrightarrow 2Ag + Cu(NO_3)_2$
CATIONIC SINGLE REPLACEMENT

14. $2Na + Cl_2 \longrightarrow 2\ NaCl$
SYNTHESIS

15. $Ca_3(PO_4)_2 + 3\ H_2SO_4 \longrightarrow 3\ CaSO_4 + 2\ H_3PO_4$
DOUBLE REPLACEMENT

16. $H_3(PO_4) + 3\ NaOH \longrightarrow Na_3PO_4 + 3\ H_2O$
DOUBLE REPLACEMENT (NEUTRALIZATION)

17. $C_3H_8 + 5\ O_2 \longrightarrow 4\ H_2O + 3\ CO_2$
BURNING OF A HYDROCARBON

18. $Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$
CATIONIC SINGLE REPLACEMENT

19. $H_2SO_4 + Zn \longrightarrow ZnSO_4 + H_2$
CATIONIC SINGLE REPLACEMENT

20. $HC_2H_3O_2 \rightleftharpoons H^+ + (C_2H_3O_2)^-$
IONIZATION (NOTICE THAT IT IS REVERSIBLE)

21. $2\ H_2O + CH_4 \longrightarrow 4\ H_2 + CO_2$

22. $3\ CaO + 2\ Al \longrightarrow Al_2O_3 + 3\ Ca$

CATIONIC SINGLE REPLACEMENT

23. $Cl_2 + 2\ NaBr \longrightarrow 2\ NaCl + Br_2$
ANIONIC SINGLE REPLACEMENT

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MOLS, PERCENTS, and STOICHIOMETRY

WHY DO WE NEED MOLS?

Every chemist has dreamed that atoms were large enough to see and manipulate one at a time. The same chemist realizes after considering it, that if individual molecules were available for manipulation, it would take far too long to get anything done. The view from the atom is very different from the view of trillions and trillions of atoms. The mass action of the atoms that we see on our ‘macro’ view of the world is the result of the action of an incredibly large number of atoms averaged in their actions. The most usual way we count the atoms is by weighing them. The mass of material as weighed on a balance and the atomic weight of the material being weighed is the way we have of knowing how many atoms or molecules we are working with. Instead of counting eggs, we can count cartons of eggs, each carton of which has a given number, a dozen. Instead of counting B-B’s, we can count liters of B-B’s and find out how many B-B’s are in a liter. Instead of counting oats, we buy train cars of oats and know the number of oats in a full train car.

There are less than one hundred naturally occurring elements. Each element has a characteristic atomic weight. Most Periodic Charts include the atomic weight of an element in the box with the element. The atomic weight is usually not an integer because it is close to being the number of protons plus the average number of neutrons of an element. Let’s use the atomic weight as a number of grams. This will give us the same number of any atom we choose. If we weigh out 1.008 grams of hydrogen and 35.45 grams of chlorine and 24.3 grams of magnesium, we will have the same number of atoms of each one of these elements. The neat trick with this system is that we can weigh the atoms on a grand scale of number of atoms and get a count of them. This number of atoms that is the atomic weight expressed in grams is Avogadro’s number, 6.022 E 23. The name for Avogadro’s number of ANYTHING is a mole or mol. A mol of aluminum is 27.0 grams of aluminum atoms. Aluminum is an element, so the particles of aluminum are atoms. There are Avogadro’s number of aluminum atoms in 27.0 grams of it. But 1.008 grams of hydrogen is NOT a mol of hydrogen! Why not? Remember that hydrogen is one of the diatomic gases. There is really no such thing as loose hydrogen atoms. The total mass of a single hydrogen diatomic molecule (H_2) is 2. 016 AMU. A mol of hydrogen gas has a mass of 2.016 grams. In that 2.016 gram mass is Avogadro’s number of H_2 molecules because that is the way hydrogen comes. A mol of water is 18.016 grams because each water molecule has two hydrogen atoms and one oxygen atom. A mol of water has in it Avogadro’s number of water molecules. Another way to view the same thing is that a formula weight is the total mass of a formula in AMU expressed with units of grams per mol.

So Avogadro’s number is just a number, like dozen or gross or million or billion, but it is a very large number. You could consider a mol of sand grains or a mol of stars. We are more likely to speak of a mol of some chemical, for which we can find the mass of a mol of the material by adding the atomic weights of all the atoms in a formula of the chemical. The unit of atomic weight or formula weight is grams/mol.

The chemical formula of a material should tell you; (a) which elements are in the material, (b) how many atoms of each element are in the formula, (c) the total formula weight, and (d) how the elements are attached to each other. The symbols of the elements tell you which elements are in the material. The numbers to the right of each symbol tells how many atoms of that element are in the formula. The type of atoms and their arrangement in the formula will tell how the elements are attached to each other. A metal and a nonmetal or negative polyatomic ion shows an ionic compound. A pair of non-metals are bonded by covalent bonds. Some crystals have water of hydration loosely attached in the crystal. This is indicated by the dot such as in blue vitriol, $Cu(SO_4)\cdot 5H_2O$, showing five molecules of water of hydration to one formula of cupric sulfate.

The unit of the formula weight or molecular weight or atomic weight is "grams per mol," so it provides a relationship between mass in grams and mols of material.

$$nF_w = m$$

'n' is the number of mols, 'Fw is the formula weight, and 'm' is the mass.

Back to the beginning of Mols, Percents, and Stoichiometry.

PERCENTS BY WEIGHT

All men weigh 200 pounds. All women weigh 125 pounds. What is the percent by weight of woman in married couples? A married couple is one man and one woman. The total weight is 325 pounds. The formula for percent is:

$$\frac{\text{TARGET}}{\text{TOTAL}} \text{ X } 100\% = \text{PERCENT}$$

In this case the woman is the target.

$$\frac{125\cancel{\#}}{325\cancel{\#}} \text{ x } 100\% = 38.461\% \qquad = 36.5\%$$

Notice that the units of pound cancel to make the percent a pure number of comparison.

The weights of atoms are the atomic weights. What is the percentage of chloride in potassium chloride? The atomic weight of potassium is 39.10 g/mol. The atomic weight of chlorine is 35.45 g/mol. So the formula weight of potassium chloride is 74.55 g/mol. The chloride is the target and the potassium chloride is the total. 35.45 g/mol / x 100% = 47.55198 % or 47.6 % to three significant figures.

$$\frac{35.45\cancel{\text{g/mol}}}{74.55\cancel{\text{g/mol}}} \text{ x } 100\% \quad = 47.5520\% \quad = 47.6\%$$

You can do that with any part of a compound. What is the percentage of sulfate in beryllium sulfate tetrahydrate?

Notice that the examples here are done to two decimal points of the atomic weights. The problems in the practice bunch at the end of this chapter are done to one decimal point of the atomic weight.

Back to the beginning of Mols, Percents, and Stoichiometry.

BASIC STOICHIOMETRY

Pronounce stoichiometry as “stoy-kee-ah-met-tree,” if you want to sound like you know what you are talking about, or “stoyk:,” if you want to sound like a real geek. Stoichiometry is just a five dollar idea dressed up in a fifty dollar name. You can compare the amounts of any materials in the same chemical equation using the formula weights and the coefficients of the materials in the equation. Let’s consider the equation for the Haber reaction, the combination of nitrogen gas and hydrogen gas to make ammonia.

$$N_2 + 3\ H_2 \longrightarrow 2\ NH_3$$

The formula for nitrogen is N_2 and the formula for hydrogen is H_2. They are both diatomic gases. The formula for ammonia is NH_3. The balanced equation requires one nitrogen molecule and three hydrogen molecules to make two ammonia molecules, meaning that one nitrogen molecule reacts with three hydrogen molecules to make two ammonia molecules or one MOL of nitrogen and three MOLS of hydrogen make two MOLS of ammonia. Now we are getting somewhere. The real way we measure amounts is by weight (actually, mass), so 28 grams (14 g/mol times two atoms of nitrogen per molecule) of nitrogen and 6 grams of hydrogen (1 g/mol times two atoms of hydrogen per molecule times three mols) make 34 grams of ammonia. Notice that no mass is lost or gained, since the formula weight for ammonia is 17 (one nitrogen at 14 and three hydrogens at one g/mol) and there are two mols of ammonia made. Once you have the mass proportions, any mass-mass stoichiometry can be done by good old proportionation. What is the likelihood you will get just a simple mass-mass stoich problem on your test? You should live so long. Well, you should get ONE.

Rather than thinking in terms of proportions, think in mols and mol ratios, a much more general and therefore more useful type of thinking. A mol ratio is just the ratio of one material in a chemical equation to another material in the same equation. The mol ratio uses the coefficients of the materials as they appear in the balanced chemical equation. What is the mol ratio of hydrogen to ammonia in the Haber equation? 2 mols of hydrogen to 3 mols of ammonia. Easy. In the standard stoichiometry calculations you should know, ALL ROADS LEAD TO MOLS. You can change any amount of any measurement of any material in the same equation with any other material in any measurement in the same equation. That is powerful. The setup is similar to Dimensional Analysis.

1. Start with what you know (GIVEN), expressing it as a fraction.

2. Use definitions or other information to change what you know to mols of that material.

3. Use the mol ratio to exchange mols of the material given to the mols of material you want to find.

4. Change the mols of material you are finding to whatever other measurement you need.

How many grams of ammonia can you make with 25 grams of hydrogen? (Practice your mol math rather than doing this by proportion. Check it by proportion in problems that permit it.)

You are given the mass of 25 grams of hydrogen. Start there.

$$\underbrace{\left(\frac{25\ \cancel{\mathrm{g}}\ \cancel{H_2}}{1}\right)}_{\text{GIVEN}}\underbrace{\left(\frac{\cancel{\mathrm{mol}}}{2.0\ \cancel{\mathrm{g}}}\right)}_{\text{Fw}}\underbrace{\left(\frac{2\ \cancel{\mathrm{mols}}\ NH_3}{3\ \cancel{\mathrm{mols}}\ \cancel{H_2}}\right)}_{\text{MOL RATIO}}\underbrace{\left(\frac{17\mathrm{g}}{\cancel{\mathrm{mol}}}\right)}_{\text{Fw}} =$$

25 g H_2/1 Change to mols of hydrogen by the formula weight of hydrogen 1 mol of H_2 = 2.0 g. (The 2.0 g goes in the denominator to cancel with the gram units in the material given.) Change mols of hydrogen to mols of ammonia by the mol ratio. 3 mols of hydrogen = 2 mols of ammonia. (The mols of hydrogen go in the denominator to cancel with the mols of hydrogen. You are now in units of mols of ammonia.) Convert the mols of ammonia to grams of ammonia by the formula weight of ammonia, 1 mol of ammonia = 17 g. (Now the mols go in the denominator to cancel with the mols of ammonia.) Cancel the units as you go.

The math on the calculator should be the last thing you do. 2 5 ÷ 2 . 0 x 2 ÷ 3 x 1 7 = and the number you get (141.66667) will be a number of grams of ammonia as the units in your calculations show. Round it to the number of significant digits your instructor requires (often three sig. figs.) and put into scientific notation if required. Most professors suggest that scientific notation be used if the answer is over one thousand or less than a thousandth. The answer is 142 grams of ammonia.

The calculator technique in the preceding paragraph illustrates a straightforward way to do the math. If you include all the numbers in order as they appear, you will have less chance of making an error. Many times students have been observed gathering all the numbers in the numerator, gathering all the numbers in the denominator, presenting a new fraction of the collected numbers, and then doing the division to find an answer. While this method is not wrong, the extra handling of the numbers has seen to produce many more errors.

See the Stoichiometry Roadmap for a way to consider this idea graphically. This example starts at "mass given" and goes throught the mol ratio to "mass find."

$$\mathrm{mass}_1 \rightarrow F_{w1} \rightarrow \mathrm{mol}_1 \rightarrow \mathrm{mol\ ratio}\ {}^{2}\!/_{1} \rightarrow \mathrm{mol}_2 \rightarrow F_{w2} \rightarrow \mathrm{mass}_2$$

Notice by the chart above we may get the number of mols of material given if we change the mass by the formula weight, but in our continuous running math problem, we don’t have to stop and calculate a number of mols. Students who insist on doing so tend to get more calculator errors.

The more traditional formula for converting mols to mass would be, where Fw is the formula weight, m is the mass, and n is the number of mols: n x Fw = m. You should be able to "see" these formula relationships on the roadmap.

Back to the beginning of Mols, Percents, and Stoichiometry.

DENSITY TIMES MASS OF A PURE MATERIAL

Density multiplied by the volume of a pure material is equal to the mass of that material. If we know the density of a material and the volume of the pure material, with D = density and V = volume, DV = m so:

$$D_1V_1 \rightarrow \text{mass}_1 \rightarrow F_{w1} \rightarrow \text{mol}_1 \rightarrow \text{mol ratio } {}^2\!/_1 \rightarrow \text{mol}_2 \rightarrow F_{w2} \rightarrow \text{mass}_2 \rightarrow 1/D_2 = V_2$$

If you were given the density and volume of pure material you could calculate the volume of another material in that equation if you know it’s density. Notice that the density must be inverted to cancel the units properly if you want the volume to find. If you need to find the density, the volume must be inverted.

See the Stoichiometry Roadmap for a graphic view of this idea. Start with "Given density times volume of a pure material.

Back to the beginning of Mols, Percents, and Stoichiometry.

ATOMS OR MOLECULES TO MOLS

One of the hardest ideas for some students is that the individual particles of a material are a single one of a formula of that material. Copper element comes only in the form of atoms. Water only comes in the form of a molecule with one oxygen and two hydrogen atoms. A mol, then is Avogadro's number of individual particles of whatever type of pure material the substance is made. There is no such thing as a mol of mud because mud is a mixture. There is no one mud molecule.

The word "pure" also can be misunderstood. We do not mean that a material is one hundred percent the same material for us to use it, but that we are only considering the amount of that material.

The formula behind this relationship is: where n is the number of mols, A is Avogadro's number, and # is the number of individual particles of material,

$$A \times n = \#.$$

Refer to the Stoichiometry Roadmap for a graphic view of this idea.

Back to the beginning of Mols, Percents, and Stoichiometry.

CONCENTRATION TIMES VOLUME OF A SOLUTION

A *solution* is a mixture of a fluid (often water, but not always) and another material mixed in with it. The material mixed in with it is called the *solute*. There is more on solutions in the chapter devoted to that. The volume of a solution, V, is measured the same way the volume of a pure liquid is measured. The concentration can be expressed in a number of ways, the most common in chemistry is the M, molar. One molar is one mol of solute in a liter of fluid. It is important to notice that the fluid is usually nothing more than a diluting agent. For most of the reactions, the fluid does not participate in any reaction.

Concentration times volume is number of mols of the solute material.

$$C \times V = n$$

The "given" side of concentration times volume is easy. As with density times volume of a pure material, but the "find" side may need more work. You need one or the other of the concentration and volume before you can calculate the other. At the end of the Dimensional Analysis if you want concentration, you will be using the volume inverted. If you want the volume, you will be using the concentration inverted. This is not so difficult because the units will guide you.

Refer to the Stoichiometry Roadmap for a graphic view of this idea.

Back to the beginning of Mols, Percents, and Stoichiometry.

GASES

Standard temperature is zero degrees Celsius. Standard pressure is one atmosphere. A mol of ANY gas at standard temperature and pressure (STP) occupies 22.4 liters. That number is good to three significant digits. The equation would be 1 mol gas = 22.4 L @STP. The conversion factor, the Molar Volume of Gas, is 1 mol gas/22.4 L @STP or 22.4 L @STP/1 mol gas

Where n is the number of mols, V is the volume of a gas, and MVG is the molar volume of gas,

$$V = n \times MVG$$

Gases not at STP will require the Ideal Gas Law Formula,

$$P V = n R T$$

where P is the pressure of the gas in atmospheres, V is the volume of the gas in liters, n is the number of mols of gas, T is the Kelvin temperature of the gas, and R is the "universal gas constant" with the measurement of 0.0821 liter-atmospheres per mol-degree. We will have to do some algebra on the $PV = nRT$ gas equation to do the gas portion of the stoichiometry problems.

In GIVEN we only need to solve for n. $n = PV/RT$. If we need to find the volume, pressure, or temperature of a gas, we need to solve for the unknown and include the "mols find" as the n. More about gases later. See the Chemtutor section on Gases for math problems using the gas laws.

The earmarks of a stoichiometry problem are: There is a reaction. (A new material is made.) You know the amount of one material and you are asked to calculate the amount of another matierial in the same equation.

Back to the beginning of Mols, Percents, and Stoichiometry.

HOW TO USE THE "ROADMAP" FOR SOLVING CHEMISTRY PROBLEMS

* 1. Write all the compounds and elements in the problem correctly.

* 2. Write the balanced chemical equation for the problem.

* 3. Write the MATERIAL you have enough information about to use as GIVEN. (This has been one of the major stumbling blocks in using the roadmap.) If you know the number of moles, the mass, or the number of molecules of a material, you have all you need to start the problem. You need CONCENTRATION AND VOLUME of a solution to have the amount of solute that reacts. You need VOLUME AND DENSITY of a solid or liquid to have an amount of that. You need VOLUME, PRESSURE AND TEMPERATURE of a gas to have a complete set of information. (Notice it is useful to understand the properties of the states of matter as you do this.)

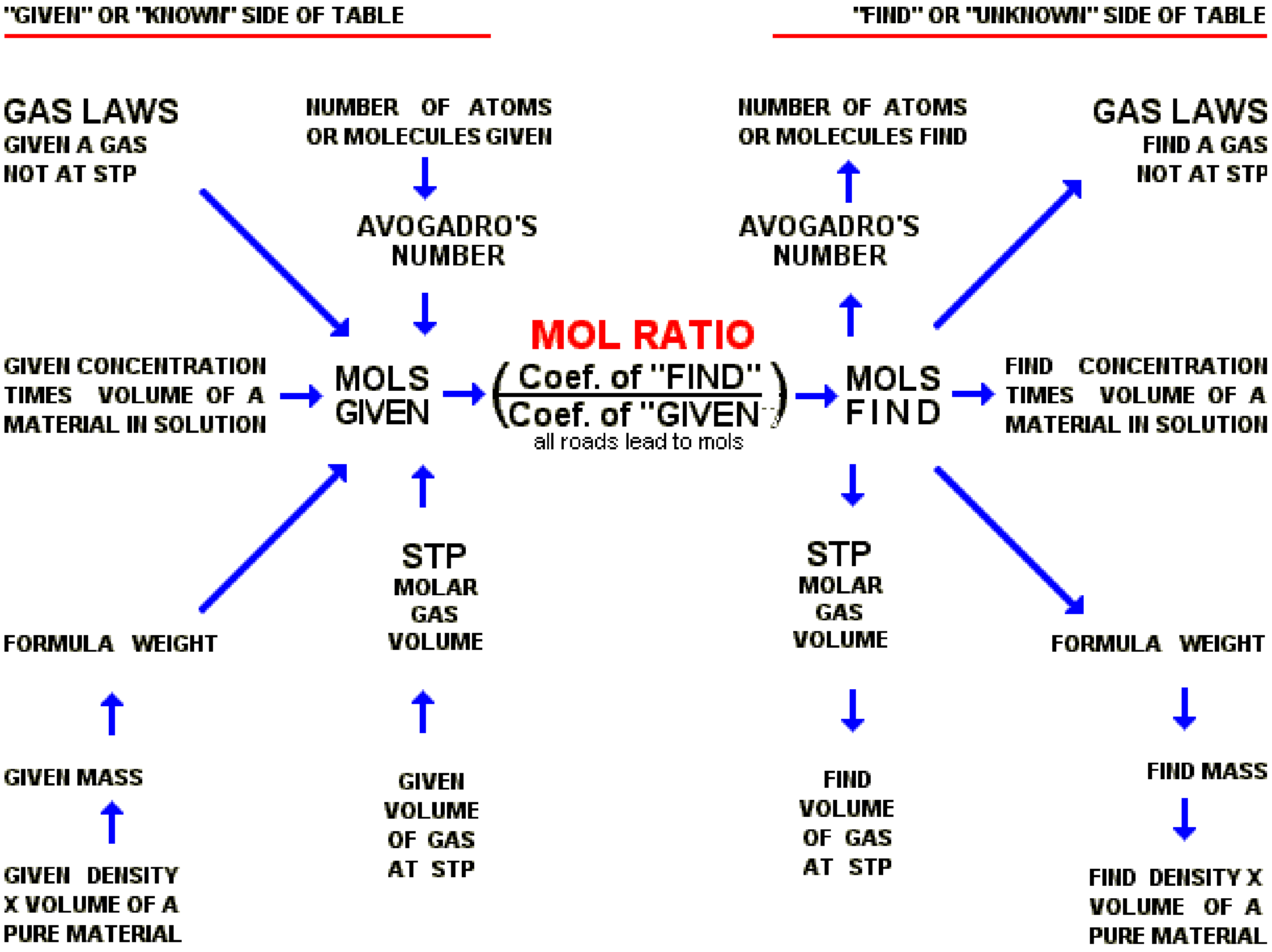
* 4. Write what you need to FIND and all the other pertinent information about that material. For instance, if you need to find the volume of a gas, you must also list the pressure and temperature of that gas in FIND. In this manner: FIND V, volume of gas at 79 °C and 1.8 atm.

* 5. Sketch out an outline of the math according to the roadmap. You know there are some points in the roadmap

that you miss on the outline because they are calculated in the process, for instance if you are given a mass of one material and asked to find the density of another material with its volume, you would start at the MASS GIVEN and use the FORMULA WEIGHT to get to the MOLES GIVEN, but MOLES GIVEN does not appear in the outline because it is already calculated. You next need the MOLE RATIO to get the MOLES FIND. Again, MOLES FIND does not appear in the outline.

* 6. Fill in the outline with the numbers, units and materials (for instance, 15 kg Mg) and do the calculations. Be careful of numbers that need to be inverted. You can tell the coefficients that need to be inverted by the units.

STOICHIOMETRY ROADMAP



One of the really nice things about the Stoichiometry Roadmap is that once you understand it thoroughly, it can be carried around with you between your ears. Just remember that ALL ROADS LEAD TO MOLS.

Back to the beginning of Mols, Percents, and Stoichiometry.

MOLE AND PERCENT WORKSHEET

1. How many pennies are in a mole of pennies? How many thousand-dollar bills (k-notes!) is that mole of pennies equal to?

2. NO_2 is the molecular formula for nitrous dioxide (also known as nitrogen dioxide). List the information available to you from this formula?.

3. C_2H_2 is the molecular formula for ethylyne (A.K.A. acetylene). (a) How many atoms are in one molecule? (b) Which atoms make up acetylene? (c) How many moles of atoms are in one molecule of acetylene? (d) How many molecules are in 5.3 moles of acetylene? (e) How many atoms are in a mole of acetylene?

4. Calculate the molar mass of a mole of the following materials: (a) Al (b) Ra (c) Co (d) CO (e) CO_2 (f) HCl (g) Na_2CO_3 (h) $Ca(NO_3)_2$ (i) $(NH_4)_3(PO_4)$ (j) H_2O (k) Epsom salts - $Mg(SO_4)\cdot 7H_2O$ (m) blue vitriol - $Cu(SO_4)\cdot 5H_2O$?

5. Calculate the number of moles in: (a) 2.3 # of carbon (b) 0.014 g of Tin (c) a 5 Oz silver bracelet (d) a pound of table salt (e) a 350 kg cast iron engine block (f) a gal. of water (8.3 #) (g) a ton of sand (SiO_2) (h) 6.2 grams of blue vitriol (i) a pound of Epsom salts ?

6. Calculate the number of atoms in: (a) 100 g of Argon (b) 1.21 kg aluminum foil (c) a 28 # lead brick (d) the E7 kg of water in an olympic swimming pool (e) 7 kg of hydrogen gas (f) a tonne of calcium nitrate ?

7. What is the percentage composition of oxygen in each of the following materials: (a) CO (b) CO_2 (c) $(NO_3)^-$ (d) isopropyl alcohol C_3H_8O (e) calcium nitrate (f) blue vitriol - $Cu(SO_4)\cdot 5H_2O$?

8. What is the percentage composition of phosphate in each of the following materials: (a) phosphoric acid (b) sodium carbonate (c) ammonium phosphate (d) calcium phosphate ?

9. What is the percentage composition of sulfate in each of the following materials: (a) sulfuric acid (b) sodium sulfate (c) Epsom salts (d) aluminum sulfate ?

ANSWERS TO MOL AND PERCENT PROBLEMS

1a. 6.023 E23 pennies
1b. 6.023 E18 k-Notes
2a. Covalent
2b. Elements in it (N and O)
2c. Number of atoms of each element
3a. 4
3b. C & H
3c. 6.64 E-24
3d. 3.1922 E24
3e. 2.4092 E24
4a. 27.0
4b. 226.0
4c. 58.9
4d. 28.0
4e. 44.0
4f. 36.5
4g. 106.0
4h. 164.1
4i. 149.0
4j. 18.0
4k. 246.4
4m. 249.6
5a. 86.9
5b. 1.18 E-4
5c. 1.31
5d. 7.75
5e. 6.27 E3
5f. 210
5g. 1.51 E4
5h. 0.0248
5i. 1.84
6a. 1.51 E24
6b. 2.69 E25
6c. 3.69 E25
6d. 1.00 E33
6e. 4.22E27
6f. 3.30 E28
7a. 57.1%
7b. 72.7%
7c. 77.4%
7d. 26.7%
7e. 58.5%
7f. 57.7%
8a. 96.9%
8b. 0%
8c. 63.8%
8d. 61.2%
9a. 98.0%
9b. 67.6%
9c. 39.0%
9d. 84.2%

Back to the beginning of Mols, Percents, and Stoichiometry.

STP GAS AND MASS STOICHIOMETRY PROBLEMS (PRELIMINARY TO GAS LAW)

All of the problems below are stoichiometry problems with at least one equation participant as a gas at STP. (a) Write and balance the chemical equation. (2) Do the math in DA style using 1 mole gas at STP = 22.4 liters as a factor. In the following problems ALL GASES ARE AT STP. Click here for a general idea of how to do the problems in this set.

1. How many moles of nitrogen gas is needed to react with 44.8 liters of hydrogen gas to produce ammonia gas?

2. How many liters of ammonia are produced when 89.6 liters of hydrogen are used in the above reaction?

3. Ten grams of calcium carbonate was produced when carbon dioxide was added to lime water (calcium hydroxide in solution). What volume of carbon dioxide at STP was needed?

4. When 11.2 liters of hydrogen gas is made by adding zinc to sulfuric acid, what mass of zinc is needed?

5. What volume of ammonia at STP is needed to add to water to produce 11 moles of ammonia water?

6. How many grams of carbonic acid is produced when 55 liters of carbon dioxide is pressed into water?

7. magnesium hydroxide + ammonium sulfate ⟶ magnesium sulfate + water + ammonia

How much (grams) magnesium hydroxide do you need to use in the above reaction to produce 500 liters of ammonia?

8. How much strontium bromide is needed to add to chlorine gas to produce 75 liters of bromine?

9. What mass of ammonium chlorate is needed to decompose to give off 200 liters of oxygen?

10. Your car burns mostly octane, C_8H_{18}, as a fuel. How many liters of oxygen is needed to burn a kilogram of octane?

11. copper + sulfuric acid ⟶ copper II sulfate + water + sulfur dioxide

How many moles of copper are needed to produce 1000 L of SO_2?

12. What volume of oxygen is needed to burn a pound of magnesium?

13. How many grams of sodium do you have to put into water to make 30 liters of hydrogen at STP?

14. ammonia gas and hydrogen chloride gas combine to make ammonium chloride. What volume of ammonia at STP is needed to react with 47.7 liters of hydrogen chloride at STP?

15. How many liters of oxygen are needed to burn 10 liters of acetylene?

ANSWERS TO STP GAS AND MASS STOICHIOMETRY PROBLEMS

1. 0.667 mol	2. 59.7 L	3. 2.24 L	4. 32.7 g
5. 246 L	6. 152 g	7. 651 g	8. 828 g
9. 604 g	10. 2.46 kL	11. 44.6 mol	12. 210 L
13. 61.6 g	14. 47.7 L	15. 25 L	

Back to the beginning of Mols, Percents, and Stoichiometry.

PROBLEMS ON CONCENTRATION AND DENSITY

WRITE AND BALANCE THE CHEMICAL EQUATION FOR THOSE PROBLEMS THAT NEED IT. SHOW ALL YOUR WORK. USE W5P OR DA METHOD ACCORDING TO THE ROADMAP.

1. The lead brick on my desk measures 3 by 5 by 11 cm. Lead has a density of 11.34 g/cc. How many lead atoms are in that block?

2. The lab technician at the Planter's Peanut packing factory takes a bag of peanuts, puts water into it to dissolve the salt, and dilutes the solution to one liter. She then takes ten ml of that solution and titrates it against 0.132 M silver nitrate. One bag sample takes 31.5 ml of silver nitrate to endpoint. What mass of salt was in the bag?

3. What is the concentration of sugar ($C_{12}H_{22}O_{11}$) if twenty grams are dissolved in enough water to make 2 liters?

4. Methyl alcohol (CH_3OH) has a density of 0.793 kg/l. What volume of it is needed to add to water to make five liters of 0.25 M solution?

5. Magnesium has a density of 1.741 g/cc. What volume of Mg will burn in 20 liters of oxygen at 2.1 atm and 0°C?

6. Uranium metal can be purified from uranium hexafluoride by adding calcium metal. Calcium metal has a density of 1.54 g/cc. Uranium has a density of 18.7 g/cc. What mass of uranium do you get for a Kg of Ca? What volume of uranium do you get for a cubic meter of calcium?

7. What volume of 0.27 M sodium hydroxide is needed to react with 29.5 ml of 0.55 M phosphoric acid?

8. What volume of carbon dioxide is produced at 1 atm and 87 °C when 1.6 liters of methyl alcohol burns? What volume of liquid water is produced in this reaction?

9. Seven kilograms of mercury II oxide decomposes into mercury and oxygen. Mercury has a density of 13.6 g/cc/ What volume of mercury is produced?

10. Water and calcium oxide produce calcium hydroxide. How many grams of calcium hydroxide are made if you add 275 liters of water to enough calcium oxide?

11. Gasoline (C_7H_{16}) has a density of 0.685 kg/liter. How many liters of oxygen at 37 °C and 950 mmHg are needed to burn 15 liters of gasoline?

12. Sodium hydroxide and hydrochloric acid combine to make table salt and water. 14 mL of 0.1 M sodium hydroxide is added to an excess of acid. How many moles of table salt are made? How many grams of salt is that?

13. 50 mL of 0.25 M copper II sulfate evaporates to leave $CuSO_4 \cdot 5H_2O$. (That is the pentahydrate crystal of copper II sulfate.) What is the mass of this beautiful blue crystal from the solution?

14. Chlorine gas is bubbled into 100 mL of 0.25 M potassium bromide solution. This produces potassium chloride and bromine gas. The bromine (which dissolves in water) is taken from the solution and measured at 27 °C and 825 mmHg. What is the volume of bromine?

15. 95.0 mL of 0.55 M sulfuric acid is put on an excess of zinc. This produces zinc sulfate and hydrogen. How many grams of zinc sulfate are made?

16. 27.6 mL of a 0.190 M solution of silver nitrate and 15.4 mL of an unknown (but excess) amount of sodium chloride combine to make a white precipitate silver chloride and some dissolved sodium nitrate. (a) How many moles of silver chloride are made? (b) How many grams of silver chloride is that? (c) How many moles of sodium nitrate are made? (d) What is the concentration of sodium nitrate in the final solution?

17. How many grams of potassium permanganate, $KMnO_4$, is needed to make 1.72 liters of 0.29 M solution?

18. By my calculations, a drop of ethyl alcohol, C_2H_5OH , in an olympic-sized swimming pool produces a 1.20 E-10 M solution of alcohol in water. A drop is a twentieth of a mL. How many molecules of ethyl alcohol are in a drop of the water in the pool?

19. 93.0 mL of 0.150 M magnesium hydroxide is added to 57.0 mL of 0.4 M nitric acid. (Magnesium nitrate and water are formed. What is the concentration of the magnesium nitrate after the reaction?

ANSWERS TO PROBLEMS ON CONCENTRATION AND DENSITY

1. 5.44 E24 atoms
2. 24.3 g
3. 0.0292 M
4. 0.0504 L
5. 52.3 ml(cc) Mg
6a. 1.98 kg of U
6b. 1.63 E6 mL
7. 180 mL
8a. 1.17 kL CO_2
8b. 1.43 L
9. 0.477 L
10. 1.13 E 6 g
11. 23.0 kL
12a. 1.4 E-3 mols
12b. 0.0819 g
13. 3.12 g
14. 284 mL
15. 8.44 g
16a. 5.24E-3 mol
16b. 0.752 g
16c. 5.24E-3 mols
16d. 122 mmolar
17. 78.8 mg
18. 3.61E9 molecules
19. 0.152 M

Back to the beginning of Mols, Percents, and Stoichiometry.

PROBLEMS USING COMPLETE ROADMAP

1. How many liters of ammonia at 0 °C and 25 atm. are produced when 10 g of hydrogen is combined with nitrogen?

2. How many milliliters of hydrogen at 0 deg C and 1400 mmHg are made if magnesium reacts with 15 mL of 6 M sulfuric acid?

3. How many atoms are in 25 liters of fluorine gas at 2.85 atm and 450 °C?

4. Liquid butane (C4H10 has a density of 0.60 g/cc. It burns to make carbon dioxide at 120 °C. What volume of carbon dioxide is produced at one atm when 350 liters of liquid butane burns?

5. Isopropyl alcohol, C3H7OH , makes a good fuel for cars. What volume of oxygen at 785 mmHg and 23 °C is needed to burn 8.54 E25 molecules of isopropyl alcohol?

6. How many moles of NaCl are in a liter of a 0.15 M NaCl solution? (0.15 M NaCl is physiological saline when sterilized.)

7. How many grams of NaCl must you put into a 50 liter container to make a physiological saline solution?

8. Chlorine gas is bubbled into 100 mL of 0.25 M potassium bromide solution. This produces potassium chloride and bromine gas. The bromine dissolves completely in the water. What is the concentration of bromine?

9. 95 mL of 0.55 M sulfuric acid is put on an excess of zinc. This produces zinc sulfate and hydrogen. How many grams of zinc sulfate are made?

10. Methyl alcohol (CH3OH) has a density of 0.793 Kg/L. What volume of it is needed to add to water to make twenty-five liters of 0.15 M solution?

11. Magnesium has a density of 1.741 g/cc. What volume of Mg will burn to produce a kilogram of magnesium oxide?

12. What volume of water vapor is produced at 716 mmHg and 87°C when 2.6 liters of methyl alcohol burns?

ANSWERS TO PROBLEMS USING COMPLETE ROADMAP

1. 2.99 L
2. 1.10 E3 mL
3. 1.45 E24 atoms
4. 4.67 E5 L
5. 1.50 E4 L
6. 0.15 moles
7. 439 g
8. 0.125 M
9. 8.44 g
10. 151 mL
11. 0.346 L
12. 1.29 E5 L

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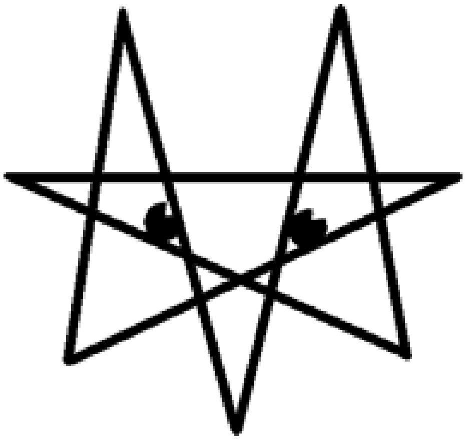

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REDUCTION AND OXIDATION REACTIONS

HOW ARE REDOX REACTIONS DIFFERENT?

Redox is the term used to label reactions in which the acceptance of an electron (reduction) by a material is matched with the donation of an electron (oxidation). A large number of the reactions already mentioned in the

Reactions chapter are redox reactions.

Synthesis reactions are also redox reactions if there is an exchange of electrons to make an ionic bond. If chlorine gas is added to sodium metal to make sodium chloride, the sodium has donated an electron and the chlorine has accepted an electron to become a chloride ion or an attached chlorine.

If a compound divides into elements in a decomposition, a decomposition reaction could be a redox reaction. The electrolysis of water is a redox reaction. With a direct electric current through it, water can be separated into oxygen and hydrogen. $H_2O \longrightarrow H_2 + O_2$ The oxygen and hydrogen in the water are attached by a covalent bond that breaks to make the element oxygen and the element hydrogen. Learning more about the conditions for redox reactions will show that the electrolysis of water is a redox reaction.

A single replacement reaction is always a redox reaction because it involves an element that becomes incorporated into a compound and an element in the compound being released as a free element.

A double replacement reaction usually is not a redox reaction.

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OXIDATION STATES

Before we go any further into redox, we must understand oxidation states. The idea of oxidation state began with whether or not a metal was attached to an oxygen. Unattached (free) atoms have an oxidation state of zero. Since oxygen almost always takes in two electrons when it is not a free element, the combined form of oxygen (oxide) has an oxidation state of minus two. The exception to a combined oxygen taking two electrons is the peroxide configuration. Peroxide can be represented by -O-O- where the each dash is a covalent bond and each ‘O’ is an oxygen atom. Peroxide can be written as a symbol, $(O_2)^{2-}$. The over-simplified way of showing this is that each oxygen atom has a negative one oxidation state, but that is not really so because the peroxides do not come in individual oxygen atoms. Peroxides are not as stable as oxides, and there are very many fewer peroxides in nature than oxides. H_2O_2 is hydrogen peroxide.

Hydrogen in compound always an oxidation state of plus one except as a hydride. A hydride is a compound of a metal and hydrogen. Hydrides react with water, so there are no hydrides found in nature. The formula XH or XH_2 or XH_3 or even XH_4 where X is a metal is the general chemical formula for hydride.

The rules for oxidation state are in some ways arbitrary and unnatural, but here they are:

1. Any free (unattached) element with no charge has the oxidation state of zero. Diatomic gases such as O_2 and H_2 are also in this category.

2. All compounds have a net oxidation state of zero. The oxidation state of all of the atoms add up to zero.

3. Any ion has the oxidation state that is the charge of that ion. Polyatomic ions (radicals) have an oxidation state for the whole ion that is the charge on that ion. The ions of elements in Group I, II, and VII (halogens) and some other elements only have one likely oxidation state.

4. Oxygen in compound has an oxidation state of minus two, except for oxygen as peroxide, which is minus one.

5. Hydrogen in compound has an oxidation state of plus one, except for hydrogen as hydride, which is minus one.

6. In radicals or small covalent molecules, the element with the greatest electronegativity has its natural ion charge as its oxidation state.

KNOW THIS

Now would be a good time to try the oxidation state problems beginning the practice page at the end of this chapter. Problems 1-30 are good examples for practice of assigning oxidation states.

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IS IT A REDOX REACTION?

A redox reaction will have at least one type of atom releasing electrons and another type of atom accepting electrons. How can you most easily tell if a reaction is redox? Label every atom on both the reactant and product side of the equation with its oxidation number. If there is a change in oxidation number from one side of the equation to the other of the same species of atom, it is a redox reaction. Each complete equation must have at least one atom species losing electrons and at least one atom species gaining electrons. The loss and gain of electrons will be reflected in the changes of oxidation number.

Let’s take the following equation: $K_2(Cr_2O_7) + KOH \longrightarrow 2\ K_2(CrO_4) + H_2O$ Is it a redox equation or not? Potassium dichromate and potassium hydroxide make potassium chromate and water. Some of the atoms are easy. All of the oxygens in compound have an oxidation state of minus two. All of the hydrogens have an oxidation state of plus one. Potassium is a group one element, so it should have an oxidation state of plus one in the compounds. That seems to make sense because dichromate and chromate ions have a charge of minus two and there are two potassium atoms in each compound. Hydroxide ion has a charge of minus one and it has one potassium. But what about the chromium atoms? We can do a little primitive math on the material either from the starting point of the compound or the ion to find the oxidation state of chromium in that compound. The entire compound must have a net oxidation state of zero, so the oxidation numbers of two potassiums one chromium and four oxygens must equal to zero. 2 K + Cr + 4 O = 0 We know the oxidation state of everything else but the chromium. 2(+1) + Cr + 4 (-2) = 0 and Cr = +6. Or we could do it from the point of view of the chromate ion. Cr + 4 O = -2 The oxygens are minus two each. Cr + 4 (-2) = -2 Either way Cr = +6. Now the dichromate; 2 K + 2 Cr + 7 O = 0 and 2 (+1) + 2 Cr + 7 (-2) = 0. Then 2 Cr = +12 and Cr = +6. You can do the math for the dichromate ion to see for yourself that the chromium does not change from one side of this equation to the other. As suspicious-appearing as the equation might have seemed to you, it is not a redox reaction.

Consider copper metal in silver nitrate solution becomes silver metal and copper II nitrate. The oxygens do not change. Oxygen in compound is negative two on both sides. The nitrogen can not change. It does not move out of the nitrate ion where it has an oxidation state of plus five. (Is that right?) The other two have to change because they both are elements with a zero oxidation state on one side and in compound on the other. Silver goes from plus one to zero and Copper goes from zero to plus two.
$AgNO_3 + Cu \longrightarrow Cu(NO_3)_2 + Ag$ (not a balanced reaction)

Think of this on a number line. The copper is oxidized because its oxidation number goes up from zero to plus two. The silver is reduced because its oxidation number reduces from plus one to zero.

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HALF REACTIONS

Consider the reaction: $AgNO_3 + Cu \longrightarrow Cu(NO_3)_2 + Ag$ (not a balanced reaction)

Half reactions are either an oxidation or a reduction. Only the species of atom that is involved in a change is in a half reaction. In the above reaction, silver goes from plus one to zero oxidation state, but to account for everything, the electrons must be placed into the half reaction. $e- + Ag^{+} \longrightarrow Ag^{0}$ (Reduction) Notice that the half reaction must be balanced in charge also and that the only way to balance it is to add electrons to the more positive side. The other half reaction is that of copper. $Cu^{0} \longrightarrow Cu^{+2} + 2\ e-$ (Oxidation)

This time the material is oxidized and the electrons must appear on the product side. We must double the silver half reaction to cancel out the electrons from right to left. The two half reactions can be added together to make one reaction, thus.

$2(\ e- + Ag^{+} \longrightarrow Ag^{0})$
$Cu^{0} \longrightarrow Cu^{+2} + 2\ e-$ and the total reaction is:
$Cu^{0} + 2Ag^{+} \longrightarrow Cu^{+2} + 2Ag^{0}$

In the complete reaction the number of electrons lost must equal the number of electrons gained. The number of electrons used in the reduction half reaction must equal the number of electrons produced in the oxidation half reaction. The entire half reactions must be multiplied by numbers that will equalize the numbers of electrons, and the final complete balanced chemical reaction must show these number relationships.

One of the important bits of information from adding the half reactions in this case is that the entire chemical equation will have to have two silver atoms for every copper atom in the reaction for the reaction to balance electrically. This type of information from the half reactions is sometimes the easiest or only way to balance a chemical equation. The redox balancing problems beginning with number 31 at the end of the chapter are good help for your further understanding.

From doing this math on a number of materials, you will find that it is possible to get some strange-looking oxidation states, to include some fractional ones. The oxidation state math works on fractional oxidation states also, even though fractional charges are not possible.

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REDUCTION OR OXIDATION?

A reduction of a material is the gain of electrons. An oxidation of a material is the loss of electrons. This system comes from the observation that materials combine with oxygen in varying amounts. For instance, an iron bar oxidizes (combines with oxygen) to become rust. We say that the iron has oxidized. The iron has gone from an oxidation state of zero to (usually) either iron II or iron III. This may be difficult to remember. The easier way to tell if a half reaction is a reduction or oxidation is to plot the changing ion into the number line. If the oxidation state of the ion goes up the number line, it is an oxidation. If it goes down the number line, it is a reduction. Based on the KIS principle (Keep It Simple), remember only one rule for this.

Someone, in a fit of perversity, decided that we needed more description for the process. A material that becomes oxidized is a reducing agent, and a material that becomes reduced is an oxidizing agent.

COMING ATTRACTIONS

ELECTROLYSIS
Water, aluminum, copper

ELECTROPLATING
chromium, gold,

ELECTRIC CELLS
carbon zinc , etc electrical potential and voltages

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REDOX PROBLEMS

For each element in the following materials list the number of the rule you use to assign oxidation state of that element and list the oxidation state you have found it to be.

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Summary of Oxidation State Rules

1. Free element O.S. = 0
2. Compound total O.S. = 0
3. Ion O.S. = charge
4. Oxygen O.S. = -2
5. Hydrogen O.S. = +1
6. Electronegativity rules

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MATERIAL	RULES	OXIDATION STATES
1. NaCl	Na 3; Cl 3	Na = +1 , Cl = -1
2. $KMnO_4$	K 3; O 4; Mn 3,4 or 2,3,4	K = +1, O = -2, Mn = +7
3. diamond	C 1	C = 0
4. CO_2	O 4; C 4,2	C = +4, O = -2
5. CO	O 4; C 4,2	C = +2, O = -2
6. KCN	K 3; N 6; C 3,6, 2	K = +1, C = +2, N=-3
7. $Na_4Fe(CN)_6$	Na 3; N 6; C 6,3; Fe 3,6,2	Na= +1, N= -3, C= +2, Fe= +2
8. Fe_2O_3	O 4; Fe 4,2	O = -2, Fe = +3
9. Fe_3O_4	O 4; Fe 4,2	O = -2, Fe = +8/3

10. $(ClO_4)-$	O 4; Cl 4,3	O = -2, Cl = +7
11. $(ClO_3)-$	O 4; Cl 4,3	O = -2, Cl = +5
12. $(ClO_2)-$	O 4; Cl 4,3	O = -2, Cl = +3
13. $(ClO)-$	O 4; Cl 4,3	O = -2, Cl = +1
14. $Cl-$	Cl 3	Cl = -1
15. Cl_2	Cl 1	Cl = 0
16. P_2O_5	O 4; P 4,2	O = -2, P = +5
17. P_4O_6	O 4; P 4,2	O = -2, P = +3
18. H_3PO_4	H 5; O 4; P 5,4,2 or 4,3	H = +1, O = -2, P = +5
19. Mg_3N_2	Mg 3; N 3,2	Mg = +2, N = -3
20. MgH_2	Mg 3; H 3,2	Mg = +2, H = -1 (hydride!)
21. NH_3	H 5; N 5,2	H = +1, N = -3
22. N_2H_4	H 5; N 5,2	H = +1, N = -2
23. $(NH_4)+$	H 5; N 5,2	H = +1, N = -3
24. N_2	N 1	N = 0
25. $(NO_3)-$	O 4; N 4,3	O = -2, N = +5
26. $(NO_2)-$	O 4; N 4,3	O = -2, N = +3
27. NO_2	O 4; N 4,2	O = -2, N = +4
28. NO	O 4; N 4,2	O = -2, N = +2
29. N_2O	O 4; N 4,2	O = -2, N = +1
30. Na_2O_2	Na 3; O 2	Na = +1, O = -1 (peroxide!)

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B. For the each word reaction, write the chemical equation without balancing it, write the oxidation state of each element above that element, and write the two half reactions, labeling which is oxidation and which is reduction. You can check your work by balancing the complete reaction using the numbers from the half reaction addition. If you have a problem with an example, check first with the completed balanced equation in the answer section.

31. Hydrogen gas burns in oxygen to make water.

32. Mercuric oxide, a red powder, is put into a test tube and warmed. Liquid mercury forms on the sides and in the bottom of the tube and oxygen gas escapes from the test tube.

33. Potassium chlorate is heated in a test tube. Oxygen gas is made and potassium chloride is left in the bottom of the tube.

34. Hydrochloric acid is poured onto zinc metal to make zinc chloride and hydrogen gas.

35. A copper wire is put into silver nitrate. Silver metal appears and the solution turns blue from copper II nitrate.

36. Magnetite, an ore of iron, is smelted in large hot furnaces by blowing carbon monoxide gas through the ore. The result is liquid (molten) iron and carbon dioxide bubbles.

37. Lead metal and lead IV oxide in sulfuric acid produce lead II sulfate and water. This is the reaction in a common lead-acid car battery.

38. Methane gas burns in oxygen to make water vapor and carbon dioxide.

39. Octane burns with oxygen to make carbon dioxide and water.

40. Concentrated nitric acid is put on copper wire. Water and copper II nitrate in the water solution is produced, along with a brownish gas, nitrogen monoxide or nitric oxide, NO.

41. Potassium dichromate and hydrochloric acid in solution will make chlorine gas, water, chromium III chloride and potassium chloride. (The soluble salts, of course, remain in the water solution.)

42. Potassium permanganate solution when added to potassium cyanide in water solution will make managanese IV oxide and potassium hydroxide and water and potassium cyanate (KOCN).

43. In a sulfuric acid solution potassium permanganate will titrate with oxalic acid to produce manganese II sulfate, carbon dioxide, water, and potassium sulfate in solution.

ANSWERS TO REDOX EQUATIONS

31. $\overset{0}{H_2} + \overset{0}{O_2} \longrightarrow \overset{+1}{H_2}\overset{-2}{O}$

$2(\ H^0 \longrightarrow H^{+1} + e\text{-})$ Oxidation
$2e\text{-} + O^0 \longrightarrow O^{-2}$ Reduction

Balanced equation $2\ H_2 + O_2 \longrightarrow 2\ H_2O$

32. $\overset{+2}{Hg}\overset{-2}{O} \longrightarrow \overset{0}{O_2} + \overset{0}{Hg}$

$2e\text{-} + Hg^{+2} \longrightarrow Hg^0$ Reduction
$O^{-2} \longrightarrow O^0 + 2e\text{-}$ Oxidation

Balanced equation $2\ HgO \longrightarrow O_2 + 2\ Hg$

33. $\overset{+1}{K}\overset{+5}{Cl}\overset{-2}{O_3} \longrightarrow \overset{+1}{K}\overset{-1}{Cl} + \overset{0}{O_2}$

$6e\text{-} + Cl^{+5} \longrightarrow Cl^{-1}$ Reduction
$3(\ O^{-2} \longrightarrow O^0 + 2e\text{-})$ Oxidation

Balanced equation $2\ KClO_3 \longrightarrow 2\ KCl + 3\ O_2$

34. $\overset{+1}{H}\overset{-1}{Cl} + \overset{0}{Zn} \longrightarrow \overset{+2}{Zn}\overset{-1}{Cl_2} + \overset{0}{H_2}$

$2(\ e\text{-} + H^{+1} \longrightarrow H^0)$ Reduction
$Zn^0 \longrightarrow Zn^{+2} + e\text{-}$ Oxidation

Balanced equation $2\ HCl + Zn \longrightarrow ZnCl_2 + H_2$

35. $\overset{+1}{Ag}\overset{+5}{N}\overset{-2}{O_3} + \overset{0}{Cu} \longrightarrow \overset{+2}{Cu}(\overset{+5}{N}\overset{-2}{O_3})_2 + \overset{0}{Ag}$

$2(\ e\text{-} + Ag^{+1} \longrightarrow Ag^0)$ Reduction
$Cu^0 \longrightarrow Cu^{+2} + 2\ e\text{-}$ Oxidation

Balanced chemical equation $2\ AgNO_3 + Cu \longrightarrow Cu(NO_3)_2 + 2\ Ag$

36. $\overset{+8/3}{Fe_3}\overset{-2}{O_4} + \overset{+2}{C}\overset{-2}{O} \longrightarrow \overset{0}{Fe} + \overset{+4}{C}\overset{-2}{O_2}$

$4\ (\ C^{+2} \longrightarrow C^{+4} + 2\ e\text{-})$ Oxidation
$3\ (\ 8/3\ e\text{-} + Fe^{+8/3} \longrightarrow Fe^0)$ Reduction

Balanced chemical reaction $3\ Fe_3O_4 + 4\ CO \longrightarrow 3\ Fe + 4\ CO_2$

37. $\overset{0}{\mathrm{Pb}} + \overset{+4}{\mathrm{Pb}}\overset{-2}{\mathrm{O}}_2 + \overset{+1}{\mathrm{H}}_2\overset{+6}{\mathrm{S}}\overset{-2}{\mathrm{O}}_4 \longrightarrow \overset{+2}{\mathrm{Pb}}\overset{+6}{\mathrm{S}}\overset{-2}{\mathrm{O}}_4 + \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}$

$\mathrm{Pb}^0 \longrightarrow \mathrm{Pb}^{+2} + 2e-$ Oxidation
$2e- + \mathrm{Pb}^{+4} \longrightarrow \mathrm{Pb}^{+2}$ Reduction

Balanced equation $\mathrm{Pb} + \mathrm{PbO_2} + 2\ \mathrm{H_2SO_4} \longrightarrow 2\ \mathrm{PbSO_4} + 2\ \mathrm{H_2O}$ - lead oxidizes and reduces.

38. $\overset{-4}{\mathrm{C}}\overset{+1}{\mathrm{H}}_4 + \overset{0}{\mathrm{O}}_2 \longrightarrow \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}} + \overset{+4}{\mathrm{C}}\overset{-2}{\mathrm{O}}_2$

$\mathrm{C}^{-4} \longrightarrow \mathrm{C}^{+4} + 8e-$ Oxidation
$4(2e- + \mathrm{O}^0 \longrightarrow \mathrm{O}^{-2})$ Reduction

Balanced equation $\mathrm{CH_4} + 2\ \mathrm{O_2} \longrightarrow 2\ \mathrm{H_2O} + \mathrm{CO_2}$

39. $\overset{-9/4}{\mathrm{C}}_8\overset{+1}{\mathrm{H}}_{18} + \overset{0}{\mathrm{O}}_2 \longrightarrow \overset{+4}{\mathrm{C}}\overset{-2}{\mathrm{O}}_2 + \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}$

$25 (2e- + \mathrm{O}^0 \longrightarrow \mathrm{O}^{-2})$ Reduction
$2 (\mathrm{C}^{-9/4} \longrightarrow \mathrm{C}^{+4} + 25/4\ e-)$ Oxidation

Balanced equation $2\ \mathrm{C_8H_{18}} + 25\ \mathrm{O_2} \longrightarrow 16\ \mathrm{CO_2} + 18\ \mathrm{H_2O}$

40. $\overset{0}{\mathrm{Cu}} + \overset{+1}{\mathrm{H}}(\overset{+5}{\mathrm{N}}\overset{-2}{\mathrm{O}}3) \longrightarrow \overset{+2}{\mathrm{N}}\overset{-2}{\mathrm{O}} + \overset{+2}{\mathrm{Cu}}(\overset{+5}{\mathrm{N}}\overset{-2}{\mathrm{O}}_3)_2 + \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}$

$2(3e- + \mathrm{N}^{+5} \longrightarrow \mathrm{N}^{+2})$ Reduction
$3(\mathrm{Cu}^0 \longrightarrow \mathrm{Cu}^{+2} + 2e-)$ Oxidation

Balanced equation $3\ \mathrm{Cu} + 8\ \mathrm{HNO3} \longrightarrow 4\ \mathrm{H_2O} + 2\ \mathrm{NO} + 3\ \mathrm{Cu(NO_3)_2}$

41. $\overset{+1}{\mathrm{K}}_2(\overset{+6}{\mathrm{Cr}}_2\overset{-2}{\mathrm{O}}_7) + \overset{+1}{\mathrm{H}}\overset{-1}{\mathrm{Cl}} \longrightarrow \overset{0}{\mathrm{Cl}}_2 + \overset{+3}{\mathrm{Cr}}\overset{-1}{\mathrm{Cl}}_3 + \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}} + \overset{+1}{\mathrm{K}}\overset{-1}{\mathrm{Cl}}$

$3(\mathrm{Cl}^{-1} \longrightarrow \mathrm{Cl}^0 + 1e-)$ Oxidation
$3\ e- + \mathrm{Cr}^{+6} \longrightarrow \mathrm{Cr}^{+3}$ Reduction

Balanced equation $\mathrm{K_2(Cr_2O_7)} + 14\ \mathrm{HCl} \longrightarrow 3\ \mathrm{Cl_2} + 7\ \mathrm{H_2O} + 2\ \mathrm{CrCl_3} + 2\ \mathrm{KCl}$

42. $\overset{+1}{\mathrm{K}}\overset{+7}{\mathrm{Mn}}\overset{-2}{\mathrm{O}}_4 + \overset{+1}{\mathrm{K}}(\overset{+2}{\mathrm{C}}\overset{-3}{\mathrm{N}}) + \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}} \longrightarrow \overset{+4}{\mathrm{Mn}}\overset{-2}{\mathrm{O}}_2 + \overset{+1}{\mathrm{K}}(\overset{-2}{\mathrm{O}}\overset{+1}{\mathrm{H}}) + \overset{+1}{\mathrm{K}}(\overset{-2}{\mathrm{O}}\overset{+4}{\mathrm{C}}\overset{-3}{\mathrm{N}})$

$3(\mathrm{C}^{+2} \longrightarrow \mathrm{C}^{+4} + 2e-)$ Oxidation
$2(3e- + \mathrm{Mn}^{+7} \longrightarrow \mathrm{Mn}^{+4})$ Reduction

Balanced equation $2\ \mathrm{KMnO_4} + 3\ \mathrm{KCN} + \mathrm{H_2O} \longrightarrow 2\ \mathrm{MnO_2} + 2\ \mathrm{KOH} + 3\ \mathrm{K(OCN)}$

43. $\overset{+1}{K}\overset{+7}{Mn}\overset{-2}{O_4} + \overset{+1}{H_2}\overset{+3}{C_2}\overset{-2}{O_2} + \overset{+1}{H_2}\overset{+6}{S}\overset{-2}{O_4} \longrightarrow \overset{+2}{Mn}\overset{+6}{S}\overset{-2}{O_4} + \overset{+4}{C}\overset{-2}{O_2} + \overset{+1}{H_2}\overset{-2}{O} + \overset{+1}{K_2}\overset{+6}{S}\overset{-2}{O_4}$

$5e^- + Mn^{+7} \longrightarrow Mn^{+2}$ Reduction

$5(C^{+3} \longrightarrow C^{+4} + e^-)$ Oxidation

Balanced $2\ KMnO_4 + 5\ H_2C_2O_4 + 3\ H_2SO_4 \longrightarrow 2\ MnSO_4 + 10\ CO_2 + 8\ H_2O + K_2SO_4$

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GASES

WHAT IS A GAS?

Gases appear to us as material of very low density that must be enclosed to keep together. Unlike solids, gases have no definite shape. Unlike liquids, gases have no definite volume, but they completely fill a container. The volume of the container is the volume of the gas in it. A gas exerts a pressure on all sides of the container that holds it. Gas can be compressed by pressures greater than the pressure the gas on its container. The words vapor, fume, air, or miasma also describe a gas. Air describes the common mixture of gases in the atmosphere. A miasma is usually a bad-smelling or poisonous gas. The words vapor and fume suggest that the gas came from a particular liquid.

In the gaseous state matter is made of particles (atoms or molecules) that are not attached to each other. The intermolecular or interatomic forces that hold solids and liquids have been overcome by the motion of the molecules. The particles of a gas have too much thermal energy to stay attached to each other. The motion and vibration of the atoms pull the individual molecules apart from each other.

Liquid air (with all of the molecules touching each other) has a density of 0.875 grams per milliliter. By Avogadro's law, a mol of any gas occupies 22.4 liters at standard temperature and pressure (STP).

1 mol of any gas at STP = 22.4 liters

Air in the gas phase at standard temperature and pressure (1 atmosphere of pressure and 0°C.) has a mol of it (28.96 g) in 22.4 liters, coming to 1.29 grams per liter. Liquid air is over 675 times denser than the air at one atmosphere. As an estimate, each molecule of gas in the air has 675 times its own volume to rattle around in. Gases are mostly unoccupied space. Each molecule of a gas can travel for a long distance before it encounters another molecule. We can think of a gas as having a 'point source of mass', that is, the volume of the molecule is negligible compared to the space it occupies.

When a gas molecule hits another one, they bounce off each other, ideally in a completely elastic encounter. There is pressure within the gas that is caused by the gas molecules in motion striking each other and anything else in the gas. The pressure that a gas exerts on its container comes from the molecules of gas hitting the inside of the container and bouncing off.

There are some materials that do not appear in the form of a gas because the amount of molecular motion necessary to pull a molecule away from its neighbors is enough to pull the molecule apart. For this reason you are not likely to see large biological molecules such as proteins, fats, or DNA in the form of a gas.

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THE IDEAL GAS LAW FORMULA

A gas may be completely described by its makeup, pressure, temperature, and volume. Where P is the pressure, V is the volume, n is the number of mols of gas, T is the absolute temperature, and R is the Universal Gas Constant,

$$\mathbf{P\ V = n\ R\ T}$$

KNOW THIS

This formula is the "Ideal Gas Law Formula." The formula is pretty accurate for all gases as we assume that the gas molecules are point masses and the collisions of the molecules are totally elastic. (A completely elastic collision means that the energy of the molecules before a collision equals the energy of the molecules after a collision, or, to put it another way, there is no attraction among the molecules.) The formula becomes less accurate as the gas becomes very compressed and as the temperature decreases. There are some correction factors for both of these factors for each gas to convert it to a Real Gas Law Formula, but the Ideal Gas Law is a good estimation of the way gases act. We will consider only the Ideal Gas Law Formula here. The Universal Gas Constant, R, can be expressed in several ways, depending upon the units of P, V, and T. One common R is 0.0821 liter - atmospheres per mol - degree. It is highly recommended that you know this value for R and the Ideal Gas Law Formula.

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VARIATIONS ON THE IDEAL GAS LAW FORMULA

The Ideal Gas Law Formula is a wonderful place to begin learning almost all of the formulas for gases. You are not likely to get out of a chemistry class without a question like: What is the mass of neon in a neon light at 0.00545 Atmospheres at 24 degrees Celsius if the inside volume is 0.279 liters?

GIVEN: P = 0.00545 Atmospheres   T = 24°C + 273° = 297K   V = 0.279 liters

FIND: mass (m) of neon

m/Fw can now substitute for **n** and **P V = (m/Fw) R T** or **Fw P V = m R T**. When you solve for **m**, you almost have the problem completely done.

$$\boxed{\mathbf{P\ V = (m/F_w)\ R\ T}}$$

KNOW THIS

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THE COMBINED GAS LAW FORMULA

The Combined Gas Law Formula is the relationship of changing pressure, temperature, and volume of an ideal gas. The same amount of the same gas is given at two different sets of conditions. Let's call the first set of measurements, 'condition #1,' and the second set of measurements, 'condition #2.' We could label the pressure, temperature and volume symbols each with the subscripted number of the condition it represents. $\mathbf{P_1}$ is the pressure at condition #1. $\mathbf{P_2}$ is the pressure at condition #2. $\mathbf{V_1}$ is the volume at condition #1, etc. The gas laws apply to both conditions, so $\mathbf{P_1\ V_1 = n\ R\ T_1}$ and $\mathbf{P_2\ V_2 = n\ R\ T_2}$. **R** is always the same Universal Gas Constant. If we are considering the same gas only at two different conditions, then $\mathbf{n_1 = n_2}$. Since they are both equations, we could divide one equation by the other to get:

$$\frac{P_1 V_1 = n_1 R T_1}{P_2 V_2 = n_2 R T_2} \quad \text{or} \quad \frac{P_1 V_1 = T_1}{P_2 V_2 = T_2} \quad \text{or} \quad \frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}$$

The last form can be a very useful one. This is the form of the Combined Gas Law Formula that Chemtutor finds easiest to remember. The formulas that most books call the Gas Laws are all contained in the Combined Gas Law. The Combined Law Formula is the one to use if you have any doubt about which of the Gas Laws to use.

$$\boxed{\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}}$$

KNOW THIS

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BOYLE'S LAW

Boyle's Law is useful when we compare two conditions of the same gas with no change in temperature. (Remember, "Always Boyle's at the same temperature!") No change in temperature means $\mathbf{T_1 = T_2}$, so we can cancel the two temperatures in the Complete Gas Law Formula and get:

$$\frac{P_1 V_1}{P_2 V_2} = 1 \quad \text{or} \quad P_1 V_1 = P_2 V_2$$

the usual Boyle's Law

$$\mathbf{P_1 V_1 = P_2 V_2}$$

KNOW THIS

The usual expression of Boyle's Law was lurking right there in the Combined Gas Law Formula. As you can see, Boyle's Law is in the classic form of, "**P** is inversely proportional to **V**." We could predict that from the **P** and **V** being together in the numerator of the same side of the equation.

To get a feel for Boyle's Law, visualize a small balloon between your hands. The balloon is so small that you can push all sides of it together between your hands without any of the balloon pouching out at any point. When you push your hands together the volume of the gas in the balloon decreases as the pressure increases. When you let up on the pressure, the volume increases as the pressure decreases.

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CHARLES'S LAW

Again we start with the Combined Law to get Charles's Law, but now there is no change in the pressure volume, so $\mathbf{P_1 = P_2}$.

$$\mathbf{\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}}$$

If you cancel out the two pressures, you get a form of Charles's Law that I consider easiest to remember. You can still see the **P V = n R T** in it if you look hard enough.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

KNOW THIS

You may have seen this written differently, as in the following form:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

These two expressions are mathematically exactly the same, but the first one shows its origin in the Combined Law. Remember it by, "Charles is under constant pressure."

To get a better feeling for Charles's Law, consider a child's toy balloon. At points between the beginning of filling of a balloon and the maximum stretching of a balloon, the change in internal pressure of a balloon is negligible as the balloon increases in size. A balloon is partially filled at room temperature and placed in the sun inside a car on a hot day in summer. The balloon expands in proportion to the Kelvin temperature. When the same balloon is take out of the car and put into a home freezer, the volume of the balloon decreases.

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THE THIRD LAW

The third gas law from the Combined Gas Law has been named for Gay-Lussac in some books, Amonton in others, and not named in a large number of books. It is sometimes amusing to read a book that does not name the third law and needs to refer to it. The third law is the relationship of pressure and temperature with constant volume (**$V_1 = V_2$**.) the pressure and absolute temperature of a gas are directly proportional.

$$\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}$$

And so we get the third law, the relationship between the pressure and temperature of a gas.

$$\boxed{\frac{P_1}{P_2} = \frac{T_1}{T_2}}$$

KNOW THIS

Similarly to Charles's Law, it can be arranged so that it appears in the same form you see in most books.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

To get a feel for the third Law, consider an automobile tire. With a tire gauge measure the pressure of the tire before and immediately after a long trip. When cool, the tire has a lower pressure. As the tire turns on the pavement, it alters its shape and becomes hot. There is some expansion of the air in the tire, as seen by the tire riding slightly higher, but we can ignore that small effect. If you were to plot the temperature versus pressure of a car tire, would zero pressure extrapolate out to absolute zero? Remember what you are measuring. The pressure of a car tire is actually the air pressure <u>above atmospheric pressure</u>. If you add atmospheric pressure to your tire gauge, you would certainly come closer to extrapolating to absolute zero.

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GAS STOICHIOMETRY MATH

As you know from the Mols, percents, and stoichiometry section, stoichiometry is the calculation of an unknown material in a chemical reaction from the information given about another of the materials in the same chemical reaction. What if either the given material or the material you are asked to find is a gas? In stoichiometry you need to know the amount of one material. For gases not at STP, you must know the pressure, temperature, and volume to know the amount of material given. If you are given a gas not at STP, you will be able to substitute **P V = n R T** for the given side and plug it directly into the mols place by solving the equation for '**n**'. Here is a sample problem using a gas not at STP as the given.

What mass of ammonia would you get from enough nitrogen with 689 liters of hydrogen gas at 350°C and 4587 mmHg?
Given: 689 l H_2 = V T = 350°C + 273° = 623K P = 4587 mmHg (change to Atm)
Notice we have all three of the bits of data to know the amount of hydrogen.
Find: Mass (m) of NH_3
$\mathbf{3\ H_2 + N_2 \longrightarrow 2\ NH_3}$

The outline plan of direction from the stoichiometry roadmap is:

(gas laws) ⟶ (mols given) ⟶ (mol ratio) ⟶ (formula weight find) ⟶ (mass find)

The ideal gas law (**P v = n R T**) must be solved for '**n**' so it can be used as the 'given' of the outline.

$$\underset{\text{given}}{\left(\frac{P\ V}{R\ T}\right)}\underset{\text{mol ratio}}{\left(\frac{\text{mols } NH_3}{\text{mols } H_2}\right)}\underset{\text{Fw find}}{\left(\frac{\text{Fw } NH_3}{\text{mols } NH_3}\right)} = \underset{\text{mass find}}{\text{ammonia mass}}$$

Things are a bit different when you need to find the volume, pressure, or temperature of a gas not at STP. You will need to solve **P V = n R T** for the dimension you need to find and attach it to the end of the sequence using the roadmap to find '**n**' for the gas. Let's take another problem based on the same chemical equation to explore how to set up finding a gas not at STP.

What volume of ammonia at 7.8 atmospheres and 265°C would you get from 533 grams of nitrogen?
Given: m H_2 = 533 g (Now hydrogen is the known material.)
Find: Volume of ammonia at P = 7.8 Atm and T = 265°C + 273° = 538K

The outline plan is now: (mass given) ⟶ (Fw given) ⟶ (mols given) ⟶ (mol ratio) ⟶ (gas laws)

$$\underset{\text{given}}{\left(\frac{\text{mass of } H_2}{1}\right)}\underset{\text{Fw given}}{\left(\frac{\text{mols } H_2}{\text{Fw of } H_2}\right)}\underset{\text{mol ratio}}{\left(\frac{\text{mols } NH_3}{\text{mols } H_2}\right)} = \underset{\text{mols find}}{\text{mols of ammonia}}$$

Now the result of the stoichiometry is the number of mols of ammonia, '**n**' in the ideal gas formula. We solve for the volume we want to find.

V = n R T/P and insert the numbers with '**n**' coming from the stoichiometry, or we can tack (**RT/P**) onto the end of the stoichiometry.

$$\underset{\text{given}}{\left(\frac{\text{mass of } H_2}{1}\right)}\underset{\text{Fw given}}{\left(\frac{\text{mols } H_2}{\text{Fw of } H_2}\right)}\underset{\text{mol ratio}}{\left(\frac{\text{mols } NH_3}{\text{mols } H_2}\right)}\underset{\text{gas law}}{\left(\frac{R\,T}{P}\right)} = \underset{\text{volume}}{V \text{ of } NH_3}$$

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POINTERS ON GAS LAW MATH PROBLEMS

1. Know the units and dimensions of pressure, volume and temperature and how to convert them to what you want.

2. The gas laws require an absolute temperature, usually Kelvin, in the formulas. Know how to convert any temperature measurement you are given to Kelvin.

3. Know the number and units of 'R' to use in the gas equations. Remember to convert all the units to the units of the 'R' you use to cancel the units.

4. Carefully label the dimension and condition of each variable. The dimensions of the same condition must be labeled with the same subscript.

> A 20.6 liter tire at 23°C and 3.21 Atmospheres inside pressure is run on the Interstate for four hours. The tire is now 20.8 liters at 235°C. What is the pressure in the hot tire? You must group the V = 20.6 liters, P = 3.21 Atmospheres, and T = 296 K as one condition. Each of these measurements must have the same subscript, whatever you choose. For instance, V_1 = 20.6 liters, P_1 = 3.21 Atmospheres, and T1 = 296 K The second condition has a missing component. You are given the volume and temperature, but not the pressure. V_2 = 20.8 Liters, T_2 = 508 K, and you need to find P_2.

5. You can use the Combined Gas Law Formula for any of these problems, but you must carefully cancel any dimensions that are the same in both conditions.

6. Solve for the unknown, insert the given quantities, and cancel the units to make sure your answer will come out right.

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AVOGADRO'S LAW

There is even more we can do with good old **P V = n R T**. The first part of this section introduced you to Avogadro's Law. One mole of any gas takes up a volume of 22.4 liters at standard temperature and pressure (STP). If we go back to the comparison of two formulas of the Ideal Gas Law, we have:

$$\frac{P_1 V_1 = n_1 R T_1}{P_2 V_2 = n_2 R T_2}$$

The **R**'s are the same, so they can be cancelled. At standard temperature, $T_1 = T_2 = 273K$, and the **T**'s can be cancelled. At standard pressure, $P_1 = P_2 = 1$ **atmosphere**, and the **P**'s can be cancelled. When all the canceling has been done,

$$\frac{V_1}{V_2} = \frac{n_1}{n_2}$$

If the volume is proportional to the number of mols of a gas, there is a constant, k, that we can use in the formula, **V = k n**, to express the proportionality of **V** and **n**. What is that proportionality constant? At standard temperature and pressure, the pressure is one atmosphere and the temperature is 273K. The Universal Gas Constant is still 0.0821 Liter - atmospheres per mol - degree. Let's set **n** at one to find out what **k** is.

P V = n R T and V = n R T/P

V = (1 mol) (0.0821 L - A/ mol - K) (237 K) / (1 A)

Cancel the mols, the A's (for Atmosphere) and the K's. Do the math.

$V = 22.4$ Liters

We have seen this number before in Avogadro's Law, and this is where it comes from. When **n** is one mol and **V** is 22.4 Liters, **k** is 22.4 Liters/mol.

1 mol of any gas at STP = 22.4 liters

KNOW THIS

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DALTON'S LAW OF PARTIAL PRESSURES

Similarly to the way we derived **V = k n** for Avogadro's Law above when the pressure is constant, we can derive **P = k n** for conditions when the volume does not change. This time there is no notable significance to the **k**, so we will just say that **P** is proportional to **n** when the temperature and pressure are constant. In conditions when more than one gas is mixed, we could number and add the pressures and mols. If we were to have P_1 of gas #1 due to n_1 mols of it and P_2 of another gas (#2) due to n_2 mols of it, those two gases in the same volume (They must be at the same temperature.) can be added together. P_T is the total pressure and n_T is the total number of mols.

$n_1 + n_2 = n_T$ and $P_1 + P_2 = P_T$

This has nothing to do with whether gas #1 is the same as gas #2. Dalton's Law of Partial Pressures says that, " The sum of all the partial pressures of the gases in a volume are equal to the total pressure." Where $\mathbf{P_T}$ is the total pressure, $\mathbf{P_1}$ is the partial pressure of 'gas #1', $\mathbf{P_2}$ is the partial pressure of 'gas #2', $\mathbf{P_n}$ is the pressure of the last gas, whatever number (n) it is.

$$P_T = P_1 + P_2 + ... + P_n$$

KNOW THIS

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GRAHAM'S LAW OF DIFFUSION (OR EFFUSION)

Gases under no change of pressure that either diffuse in all directions from an original concentration or effuse through a small hole move into mixture at a rate that is inversely proportional to the square root of the formula weight of the gas particle.

The mental picture of diffusion could be the drop of ink (with the same specific gravity as water) being carefully placed in the center of a glass of water. The ink will diffuse from the original point where it was deposited with no mixing of the glass of water. The mixing of diffusion is due to the movement of the molecules. Gases diffuse more quickly than liquids because the energy of motion is higher and the available path for unobstructed straight movement is much greater in gases.

Temperature is a type of energy. Temperature is the way we feel the motion of the molecules. $\mathbf{E = 1/2\ m\ v^2}$ is the formula for energy of motion. This very motion of the molecules is the operating motion of the mixing action of diffusion. The mass of the molecule is the formula weight or molecular weight of the gas particle.

From the formula for energy of motion we can see that the mass of the particle (the formula weight) is inversely proportional to the square of the velocity of the particle. This is the easiest way to remember Graham's Law.

$$\frac{(v_1)^2}{(v_2)^2} = \frac{Fw_2}{Fw_1}$$

KNOW THIS

Notice in the above formula that 'v_1' is over 'v_2' and that 'Fw_2' is over 'Fw_1'. This is so that the inverse relationship can be expressed in the formula.

If you are solving for the effusion velocity of a particle, you might take the square root of both sides to get the other useful Graham's Law formula.

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GAS LAW MATH PROBLEMS

1. Helium takes up 5.71 liters at O°C and 3.95 atmospheres. What is the volume of the same helium at 32°F and 800 mmHg?

2. 257 mL of oxygen in a gas tube goes from 17°C to 42°C from being out in the sun. The pressure in the tube is 39 #/in2, but it does not change as the temperature increases. What is the volume of the tube after it has heated?

3. An enormous (57,400 cubic meter) expandable helium balloon at 22°C is heated up by a fire under it and the action of the sun on the dark plastic covering on top. There will be a small increase in pressure from 785 mmHg to 790 mmHg, but the major effect wanted is an increase in volume so the balloon can lift its cargo. To what temperature must the balloon get in order to fill out to 60,500 cubic meters?

4. What volume of air at standard pressure gets packed into an 11 ft^3 SCUBA tank at the same temperature at 15.8 atmospheres?

5. Air is 20% oxygen and 80% nitrogen. What is the mass of air in an automobile tire of 19.7 L and internal pressure of 46.7 PSI at 24°C? (That pressure is the same as the 32 PSI difference you usually measure as the tire pressure 32 PSI + 14.7 PSI. You will have to use a weighted average for the molar mass of air.)

6. A constant pressure tank of gas at 1.01 Atm has propane in it at 15°C when it is at 255 cubic meters. What is its volume at 48°C?

7. A SCUBA tank is filled with air at 16.7 Atm at 24°C, but someone leaves it out in the sun to warm to 65°C. What is the tank pressure?

8. The usual partial pressure of oxygen that people get at sea level is 0.20 Atm., that is, a fifth of the usual sea level air pressure. People used to 1 Atm. air pressure begin to become "light-headed" at about 0.10 Atm oxygen. As a rule of thumb, the air pressure decreases one inch of mercury each thousand feet of altitude above sea level. At what altitude should airplane cabins be pressurized? Up to about what altitude should you be able to use unpressurized pure oxygen? (Express your answer in feet above Mean Sea Level, or MSL.)

9. Which diffuses faster, the bad smell from a cat-pan due to ammonia or an expensive French perfume with an average molecular weight of 170 g/mol? "How much faster does the faster one diffuse?

10. What is the mass of neon in a 625 mL neon tube at 357 mmHg & 25°C?

11. What is the mass of 15 liters of chlorine gas at STP?

12. How many liters of ammonia at STP are produced when 10 g of hydrogen is combined with nitrogen?

13. How many milliliters of hydrogen at 0°C and 1400 mmHg are produced if 15g of magnesium reacts with sulfuric acid?

14. What is the mass of 25 liters of fluorine gas at 2.85 atm, 450°C?

15. A nine liter tank has 150 atmospheres of bromine in it at 27°C. What is the added mass of the tank due to the gas?

16. A 250 Kg tank of liquid butane (C_4H_1O) burns to produce carbon dioxide at 120°C. What volume of carbon dioxide is produced at 1 Atm?

17. How many liters of product at 950 mmHg and O°C is produced by the burning of three liters of acetylene (C_2H_2) at 5 atm and 20°C?

18. Five grams of octane (C_8H_{18}) and enough oxygen to burn it are in an automobile cylinder compressed to 20 atm at 28°C. The mixture explodes and heats the cylinder to 150°C. What is the pressure in the (same sized) cylinder after the explosion?

19. If 0.515g of magnesium is added to HCl, it makes hydrogen gas and magnesium chloride. The hydrogen is collected at 23°C and 735mmHg. What is the volume of hydrogen?

20. What is the mass of 150 liters of propane gas (C_3H_8) at 37°C and 245 inHg?

21. Isopropyl alcohol, C_3H_7OH , makes a good fuel for cars. What volume of oxygen at 735 mmHg and 23°C is needed to burn one kilogram of isopropyl alcohol?

22. What volume does 4 Kg of nitrogen gas take up at 27°C and 3 atm?

23. The dirigible Hindenberg had 3.7E6 m^3 of hydrogen in its gas bags at 1.1 atm and 7°C. What was the weight of the hydrogen in pounds?

ANSWERS TO GAS LAW MATH PROBLEMS

1. 21.4 L
2. 279 ml
3. 39.9°C
4. 174 ft^3
5. 73.9 g
6. 284 cubic meters
7. 19.0 Atm
8a. 15,000 ft. MSL
8b. 27,000 ft. MSL
9. Ammonia diffuses 3.16 times faster (Wouldn't you KNOW it?)
10. 0.242 g
11. 47.5 g
12. 74.7 L
13. 7.51 L
14. 45.6 g
15. 8.76 Kg
16. 5.56 E5 L
17. 33.5 L
18. 35.4 Atm.
19. 532 ml
20. 2.12 Kg
21. 209 KL
22. 1.17 KL
23. 7.80 E5 L

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SOLUTIONS

PROPERTIES OF SOLUTIONS

A *solution* is a mixture of materials, one of which is usually a *fluid*. A fluid is a material that flows, such as a liquid or a gas. The fluid of a solution is usually the *solvent*. The material other than the solvent is the *solute*. We say that we *dissolve* the solute into the solvent.

Some solutions are so common to us that we give them a unique name. A solution of water and sugar is called *syrup*. A solution of sodium chloride (common table salt) in water is called *brine*. A sterilized specific concentration (0.15 molar) of sodium chloride in water is called *saline*. A solution of carbon dioxide in water is called *seltzer*, and a solution of ammonia gas in water is called *ammonia water*.

A solution is said to be *dilute* if there is less of the solute. The process of adding more solvent to a solution or removing some of the solute is called *diluting*. A solution is said to be *concentrated* if it has more solute. The process of adding more solute or removing some of the solvent is called *concentrating*. The *concentration* of a solution is some measurement of how much solute there is in the solution.

It might initially offend your sensibilities to consider a solution in which the solvent is a gas or a solid. The molecules of a gas do not have much interaction among them, and so do not participate to a large extent in the dissolving process. Solids are difficult to consider as solvents because there is a lack of motion of the particles of a solid relative to each other. There are, however, some good reasons to view some mixtures of these types as solutions. The molecules of a gas do knock against each other, and the motion of a gas can assist in vaporizing material from a liquid or solid state. The fan in a 'frost free' home freezer moves air around inside the freezer to sublimate any exposed ice directly into water vapor, a process clearly akin to dissolving. Solid metals can absorb hydrogen gas in a mixing process in which the metal clearly provides the structure.

True solutions with liquid solvents have the following properties:

PROPERTIES OF SOLUTIONS

1. **The particles of solute are the size of individual small molecules or individual small ions. One nanometer is about the maximum diameter for a solute particle.**
2. **The mixture does not separate on standing. In a gravity environment the solution will not come apart due to any difference in density of the materials in the solution.**
3. **The mixture does not separate by common fiber filter. The entire solution will pass through the filter.**
4. **Once it is completely mixed, the mixture is *homogeneous*. If you take a sample of the solution from any point in the solution, the proportions of the materials will be the same.**
5. **The mixture appears clear rather than cloudy. It may have some color to it, but it seems to be transparent otherwise. The mixture shows no *Tyndall effect*. Light is not scattered by the solution. If you shine a light into the solution, the pathway of the light through the solution is not revealed to an observer out of the pathway.**
6. **The solute is completely dissolved into the solvent up to a point characteristic of the solvent, solute, and temperature. At a *saturation point* the solvent no longer can dissolve any more of the solute. If there is a saturation point, the point is distinct and characteristic of the type of materials and temperature of the solution.**
7. **The solution of an ionic material into water will result in an *electrolyte* solution. The ions of solute will separate in water to permit the solution to carry an electric current.**
8. **The solution shows an increase in osmotic pressure between it and a reference solution as the amount of solute is increased.**
9. **The solution shows an increase in boiling point as the amount of solute is increased.**
10. **The solution shows a decrease in melting point as the amount of solute is increased.**
11. **A solution of a solid non-volatile solute in a liquid solvent shows a decrease in vapor pressure above the solution as the amount of solute is increased.**

KNOW THIS

These last four of the properties of solutions collectively are called *colligative* properties. These characteristics are all dependent only on the number of particles of solute rather than the type of particle or the mass of material in solution.

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OTHER TYPES OF MIXTURE

Take a spoonful of dirt and vigorously mix it with a glass of water. As soon as you stop mixing, a portion of the dirt drops to the bottom. Any material that is suspended by the fluid motion alone is only in *temporary suspension*. A portion of the dirt makes a true solution in the water with all of the properties of the above table, but there are some particles, having a diameter roughly between 1 nm and 500 nm, that are suspended in a more lasting fashion. A suspended mixture of particles of this type is called a *colloid*, or *colloidal suspension*, or *colloidal dispersion*.

For colloids or temporary suspensions the phrase *dispersed material* or the word *dispersants* describes the material in suspension, analogous to the solute of a solution. The phrase *dispersing medium* is used for the material of similar function to a solvent in solutions.

As with true solutions, it is a bit of a stretch to consider solids as a dispersing medium or gases as forming a large enough particle to be a colloid, but most texts list some such. A *sol* is a liquid or solid with a solid dispersed through it, such as milk or gelatin. *Foams* are liquids or solids with a gas dispersed into them. *Emulsions* are liquids or solids with liquids dispersed through them, such as butter or gold-tinted glass. *Aerosols* are colloids with a gas as the dispersing medium and either a solid or liquid dispersant. Fine dust or smoke in the air are good examples of colloidal solid in a gas. Fog and mist are exampes of colloidal liquid in a gas.

Liquid dispersion media with solid or liquid dispersants are the most often considered. Homogenized whole milk is a good example of a liquid dispersed into a liquid. The cream does not break down into molecular sized materials to spread through the milk, but collects in small *micelles* of oily material and proteins with the more ionic or *hydrophilic* portions on the outside of the globule and the more fatty, or oily, or non-polar, or *hydrophobic* portions inside the ball-shaped little particle. Blood carries liquid lipids (fats) in small bundles called *lipoproteins* with specific proteins making a small package with the fat.

Proteins are in a size range to be considered in colloidal suspension in water. Broth or the independent proteins of blood or the casein (an unattached protein) in milk are colloidal. There are many proteins in the cellular fluids of living things that are in colloidal suspension.

Colloidal dispersants in water stay in suspension by having a layer of charge on the outside of the particle that is attractive to one end of water molecules. The common charge of the particles and the water *solvation layer* keep the particles dispersed. A *Cottrel precipitator* collects the smoke particles from air by a high voltage charge and collection device. Boiling an egg will denature and coagulate the protein in it. Proteins can be fractionally 'salted out' of blood by adding specific amounts of sodium chloride to make the proteins coagulate. The salt adds ions to the liquid that interfere with the dispersion of the colloidal particles.

Colloids with liquid as a dispersing agent have the following properties:

PROPERTIES OF COLLOIDS

1. **The particles of dispersant are the between about 500 nm to 1 nm in diameter.**
2. **The mixture does not separate on standing in a standard gravity condition. (One 'g.')**
3. **The mixture does not separate by common fiber filter, but might be filterable by materials with a smaller mesh.**
4. **The mixture is not necessarily completely homogeneous, but usually close to being so.**
5. **The mixture may appear cloudy or almost totally transparent, but if you shine a light beam through it, the pathway of the light is visible from any angle. This scattering of light is called the *Tyndall effect***
6. **There usually is not a definite, sharp saturation point at which no more dispersant can be taken by the dispersing agent.**
7. **The dispersant can be *coagulated,* or separated by clumping the dispersant particles with heat or an increase in the concentration of ionic particles in solution into the mixture.**
8. **There is usually only small effect of any of the colligative properties due to the dispersant.**

KNOW THIS

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CONCENTRATION

The concentration of a solution is an indication of how much solute there is dissolved into the solvent. There are a number of ways to express concentration of a solution. By far the most used and the most useful of the units of concentration is *molarity*. You might see '6 M HCl' on a reagent bottle. The 'M' is the symbol for *molar*. One molar is one mol of solute per liter of solution. The reagent bottle has six mols of HCl per liter of acid solution. Since the unit 'molar' rarely appears in the math of chemistry other than as a concentration, to do the unit analysis correctly, you will have to insert concentrations into the math as 'mols per liter' and change answers of 'mols per liter' into molar.

Molality is concentration in mols of solute per kilogram of solvent. Mol fraction is the number of mols of solute per number of mols of solution. Weight-weight percent (really mass percent) is the number of grams of solute per grams of solution expressed in the form of a percent. Mass-volume concentration is the number of grams of solute per milliliter of solution. There are other older units of concentration, such as Baumé, that are still in use, mainly in industrial chemicals.

Normality is the number of mols of effective material per liter. In acid-base titrations, the hydroxide ion of bases and the hydrogen (hydronium) ion of acids is the effective material. Sulfuric acid (H_2SO_4) has two ionizable hydrogens per formla of acid, or one mol of acid has two mols of ionizable hydrogen. 0.6 M H_2SO_4 is the same concentration as 1.2 N H_2SO_4.

We say that sulfuric acid is *diprotic* because it has two protons (hydrogen ions) per formula available. Hydrochloric acid (HCl) is *monoprotic*, phosphoric acid (H_3PO_4) is *triprotic*, and acids with two or more ionizable hydrogens are called polyprotic. Sodium hydroxide (NaOH) is *monobasic*, calcium hydroxide ($Ca(OH)_2$) is *dibasic*, and aluminum hydroxide is *tribasic*.

Where 'X' is the number of available hydrogen ions or hydroxide ions in an acid or base, N, the normality, is equal to the molarity, M, times X.

The normality system can be used for redox reactions, but the effective material is now available electrons or absorption sites for electrons. Consider the following reaction, #43 in the redox section.

In a sulfuric acid solution potassium permanganate will titrate with oxalic acid to produce manganese II sulfate, carbon dioxide, water, and potassium sulfate in solution.

$$\overset{+1}{K}\overset{+7}{Mn}\overset{-2}{O_4} + \overset{+1}{H_2}\overset{+3}{C_2}\overset{-2}{O_2} + \overset{+1}{H_2}\overset{+6}{S}\overset{-2}{O_4} \longrightarrow \overset{+2}{Mn}\overset{+6}{S}\overset{-2}{O_4} + \overset{+4}{C}\overset{-2}{O_2} + \overset{+1}{H_2}\overset{-2}{O} + \overset{+1}{K_2}\overset{+6}{S}\overset{-2}{O_4}$$

$5e^- + Mn^{+7} \longrightarrow Mn^{+2}$ Reduction

$5(C^{+3} \longrightarrow C^{+4} + e^-)$ Oxidation

Balanced $2\ KMnO_4 + 5\ H_2C_2O_4 + 3\ H_2SO_4 \longrightarrow 2\ MnSO_4 + 10\ CO_2 + 10\ H_2O + 2\ KCl$

Since the manganese has a place for five electrons and the potassium permanganate contains the manganese, we could say that the normality of the permanganate solution is five times the molarity. The oxalic acid solution contains the carbon that becomes oxidized with only one electron added. The normality of the oxalic acid solution is the same as the molarity.

Where 'X' is the number of electrons either donated or accepted by a material in a redox reaction, the normality, N, is the molarity, M, times X.

In acid-base or redox titrations, the math is made easier by the use of normality. There is no need for a chemical equation because only the net reaction is considered. Where 'C' is the concentration in normality, and 'V' is the volume of solution, the formula is:

$$\boxed{C_1 V_1 = C_2 V_2}$$

KNOW THIS

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DISSOLVING SOLIDS INTO LIQUIDS

The best way to measure the amount of a solid material is usually to weigh it. The best way to find the amount of a liquid is to find the volume. The formula for solutions is: $C\ V = n$, where C is concentration in molar, V is the volume in liters, and n is the number of mols of solute. Further, $n = m/Fw$, where m is the mass and Fw is the formula weight of the solute. Solving for the mass, $m = C\ V\ Fw$.

$$\boxed{\begin{array}{c} \mathbf{C\ V = n} \\ \textbf{or} \\ \mathbf{m = C\ V\ F_w} \end{array}}$$

KNOW THIS

How do you make the solution of a solid in a liquid. First weigh the solid to get the mass. The concentration you want times the volume of solution times the formula weight of the solute will get you the mass of solute you need to weigh. Place the mass of solute in a volume measuring device such as a volumetric flask or a graduated cylinder. Use a small amount of water to dissolve the solute in the volumetric device. Add water to the volume desired and mix.

The act of dissolving a solid into a liquid is a process that happens on the surface of the particles of the solute. The smaller the particles (the larger the surface area) the faster the solute dissolves. Triple-X sugar, called 'confectioner's sugar,' has smaller particles than regular 'table sugar.' Rock candy is just regular table sugar that has been crystallized in large lumps. When you put each crystal size the chemically identical materials in your mouth, which one dissolves faster? The triple-X sugar tastes sweetest because more of it has dissolved in the same short time. (You can only taste dissolved sugar.)

Expose the surface area of the solid to more solid and the solute will dissolve faster. Mixing helps dissolve the solid. You can try this with sugar. Take two glasses of water at the same temperature and add a spoonful of sugar to each. Mix one, but not the other. In which glass does the sugar dissolve more easily?

Most solid materials will dissolve faster with increased temperature. Since the increased temperature increases the motion of the molecules, you can think of this effect as being similar to mixing. You have seen this effect. Sugar dissolves more quickly in warm tea than iced tea. Table salt dissolves more quickly in hot water than in cold.

HOW TO DISSOLVE A SOLID INTO A LIQUID

1. Increase surface area of solid by decreasing the size of particle.
2. Increase temperature of the mixture.
3. Mix.

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DISSOLVING GASES INTO LIQUIDS

Gases are more easily measured by knowing the pressure, volume, and temperature of the gas. Seltzer water and ammonia water are two good examples of solutions of a gas in a liquid. Seltzer, or carbonated water, is the result of pressing carbon dioxide gas into water. Seltzer is used as the base liquid in any carbonated beverage. The bubbles in beer or sparkling wines are also due to carbon dioxide, but the CO_2 is a natural product of the fermentation process, so it does not have to be added artificially. Ammonia water, also called ammonium hydroxide solution, is made from ammonia (NH_3) being pressed into water. It is used as a weak base and as a cleaning material, particularly for glass.

Because the process is better done under pressure, it is often difficult to directly observe the actual dissolving done in most cases. The notable exception is the addition of dry ice, solid carbon dioxide, to water as described in the section on carbon dioxide.

As with a solid dissolving in a liquid, a gas dissolves in a liquid more easily with agitation or mixing, but that is where the similarity ends. Remove a carbonated beverage from its container and it becomes obvious that pressure is necessary to keep the gas in the liquid. The drink fizzes and bubbles, releasing the gas. As the beverage sits for a few hours, the taste becomes what we describe as 'flat.' Almost all of the carbon dioxide has escaped from the liquid. The only CO_2 remaining in the water will produce a partial pressure equal to the partial pressure of the gas in the atmosphere. Water carries dissolved oxygen from the partial pressure of the oxygen in the atmosphere.

As the combination of liquid and gas is NOT the favored (lowest energy) condition, an increase in temperature causes the separation. Lower temperature favors dissolving the gas into the liquid. You can verify this experimentally on your own. Leave one can of carbonated beverage at room temperature. Refrigerate a can of the same carbonated beverage. Gently heat a third can of the same beverage. Open them all and record the results. You are likely to find that the gas stays in solution better in the cooler liquid.

HOW TO DISSOLVE A GAS INTO A LIQUID

1. Increase the gas pressure on the liquid.
2. Decrease the temperature.
3. Mix.

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LIQUIDS IN LIQUIDS

A solution of two liquids is relatively uncomplicated. For the most part, liquids either mix together or they don't. When liquids will mix together, they do so in all proportions and are said to be *miscible*. If they do not mix, as oil and water, they are said to be *immiscible*. Using ethyl alcohol and water as examples of miscible liquids, we can have a solution of the two liquids with one drop of alcohol in a bucketful of water or one drop of water in a bucketful of alcohol.

Immiscible liquids can make a mixture of the nature of a colloidal suspension by very finely dividing one of the liquids and dispersing it through the other liquid. Milk fresh from the cow separates into a milk and a cream layer, the cream rising to the top. The cream of milk is a fatty material of a lower density, so it floats. The milk may be *homogenized*, a process that violently shakes the milk so that the cream forms very small ball-shaped particles. This homogenized milk will remain well mixed with normal treatment.

The stability of homogenized milk as a mixture is helped by the presence of the proteins of milk. Proteins often have areas of large amounts of available electrical charge and areas of very little charge. The areas of higher charge are more soluble in water and the areas of lower charge are more soluble in the fat of the cream. In this way the protein acts as a *surface active agent*, or *surfactant*. A surfactant is a large molecule with one area in one liquid and another area in another. Proteins of milk on the surface of the small globules of fat in homogenized milk will keep the globules from attaching back to each other, so the milk stays homogenized. Soaps and detergents are surfactants that help get oily dirt into suspension in water.

Agitation (mixing) is usually the most important factor in making a liquid-liquid mixture. The agitation of milk to homogenize it is a good example for colloids, but many other liquids do not mix without considerable agitation. If you make a highly concentrated syrup and pour it into water, the syrup will drop to the bottom of the water and stay there until it is agitated or (in a much longer time) diffusion mixes the layers.

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SOLUBILITY

For the best view of solubility, we will use the examples of a solid solute dissolved into a liquid solvent. This does not mean that other materials do not work in the same fashion.

The solubility of a solution is a measure of how much of the solute can be dissolved into the solvent. The solution reaches a point called the *saturation point* when no more solute will be accepted by the solvent. Any further addition of solute will result in solid solute mixed in with the saturated solution. Each solvent and solute pair has a characteristic solubility at a given temperature. Usually as you increase the temperature, an increased amount of solute will be able to dissolve.

Take a Pyrex measuring cup and put in exactly a cup of table sugar. Heat water to boiling and pour in a small amount. Notice what happens. The volume of material in the cup appears to shrink! Continue adding boiling water until the level is back up to the 'one cup' mark. Notice the temperature of the solution. It takes heat to dissolve sugar. Stir. You should be able to almost dissolve all the sugar. The solution should be very close to the saturation point at that temperature. The solution should end up at about room temperature. Now add a few heaping tablespoons of sugar. Stir and attempt to dissolve all the sugar. If you succeed, add another few tablespoonsful of sugar. Put the saturated solution with a lot of undissolved sugar into the microwave, and heat until all the sugar is dissolved. If you have a meat thermometer, find the temperature of the boiling mixture. (Be careful. The solution is VERY hot. Handle with something to insulate you from the heat.)

Observe the solution after you take it out of the microwave and put it on the counter. Notice the temperature at which the sugar crystals begin to form again.

If you have done the experiment just right, you may see the crystals appearing at a temperature far below what you might think. If you boil the solution enough in the microwave, you will dissolve all traces of a seed crystal for the saturated solution to deposit sugar onto. At one time your solution will be *supersaturated*, or beyond the normal amount of solute in the solution. Supersaturation is an unstable condition. If any crystal is presented to a supersaturated solution, the crystallization of the solute onto it will occur fairly rapidly.

At home if you have done this demonstration with only sugar and water in a clean cup, don't waste the sugar solution. A little bit of maple flavoring will make it a fine syrup for pancakes, or you can use it in the frosting of the chocolate cake I have published here on the site. Do not eat any material made at school. Lab materials may contain traces of contaminants. If you eat anything in the school laboratory, the school lawyers will turn green and purple, have a conniption fit, and likely take their discomfort out upon you.

Solubility of salts depends upon the type of ions in the salt. There is a very great range of solubility of salts in water. Even the most insoluble, such as silver chloride, have a very small but detectable solubility. Some salts, called *deliquescent salts*, are so soluble that they grab water molecules out of the air and can dissolve themselves in this way.

Using the simplification of classifying materials as either soluble or not in water at room temperature, there are some nice easy general rules for predicting whether or not a salt will dissolve in water. These rules are useful not just for predicting how to make solutions, but ion reactions, such as a double displacement reaction, depend upon the insolubility of a salt as a possible product for the reaction to happen. Depending upon what your instructor suggests, it may be a good idea for you to know the following rules:
(a) Almost all simple ionic compounds with Group I elements or ammonium ion, $(NH_4)^+$, are soluble.
(b) All nitrates $(NO_4)^-$, most sulfates, $(SO_4)^{2-}$, and most chlorides, Cl^-, are soluble. ** Notable exceptions to this rule are: barium sulfate, $BaSO_4)^{2-}$, lead II sulfate, $PbSO_4)^{2-}$, and silver chloride, AgCl. (c) Most hydroxides, $(OH)^-$, carbonates, $(CO_3)^{2-}$ sulfides, S^{2-}, and phosphates, $(PO_4)^{3-}$, are insoluble except for the compounds of rule (a). Barium hydroxide, $Ba(OH)_2$ is a soluble exception to this rule.

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COLLIGATIVE PROPERTIES

The colligative properties of solutions have already been mentioned in the section on properties of solutions. A colligative property is one that depends only on the number of particles in solution rather than the type of particle. Molecular solutes have only one particle per formula, but ionic materials come apart into their ions and have almost as many particles in the solution as there are ions available. The word 'almost' was included on purpose because there is a small tendency for ions to re-associate with each other, making ion pairs that decrease the number of particles. The ion pair effect depends upon the properties of the species dissolved and the concentration of solute. The more concentrated the solute, the greater percentage of ion pairing takes place.

The colligative properties of solutions are;

1. The solution shows an increase in osmotic pressure between it and a reference solution as the amount of solute is increased.

   Osmotic pressure occurs when a semipermeable membrane divides two solutions, one of which has more solute than the other. A semipermeable membrane is one that lets through water but not any material in solution or in suspension in the water. Semipermeable membranes are an important part of any living thing. Cell membranes are semipermeable. The membranes on the outside of eggs are semipermeable.

Trees pull up water from their roots by osmosis.

Here is an easy way to demonstrate osmotic pressure. Take two similar hen's eggs and keep them in a dilute vinegar solution for a few days. The acid in the vinegar will react with the calcium compounds that are the hardening materials for the shell. There are two semipermeable membranes under the hard shell of the egg. Replace the vinegar solution if the process stops for a few days before all of the shell is removed. When all of the hard shell has gone, compare the size of the eggs. They should be fairly close. Put one egg into pure water (or tap water). Put the other egg into a brine solution (table salt dissolved in water). Observe the eggs over a few days.

Water goes through the semipermeable membrane in a direction to make the particle concentration on either side equal. The egg in just water will absorb water and become very large. The egg in brine will shrivel from water going out of it. The tight skin on the large egg is a demonstration of the pressure provided by osmosis.

Don't eat the eggs. Open them up and see what's inside. Inspect them carefully, particularly the yolk and its size. The membranes of the egg are a pretty good barrier to bacteria, but the stretched membrane particularly may not be able to keep bacteria out. Smell the eggs after you have opened them. Is there an odor that would indicate bacterial contamination? Cook them to see if the proteins react the same way as other eggs, but do not eat them due to the possibility of hidden bacterial contamination.

Red blood corpuscles (in humans) are not much more than semipermeable bags containing oxygen-absorbing protein (hemoglobin) floating in the blood. If you were to pump pure water into a person, the osmotic pressure due to the difference in *osmolarity* would swell and burst the red corpuscles. If the blood plasma has too many dissolved particles, the red corpuscles would shrivel up or *crenate*. Saline is a solution that is designed to be the same osmolarity as the cellular and corpuscular contents.

2. A solution of a solid non-volatile solute in a liquid solvent shows a decrease in vapor pressure above the solution as the amount of solute is increased.

   Honey has some moisture in it that is close to saturation in sugar. Take two small shallow dishes and put in an equal (small) amount of honey in one and water in the other. Leave them exposed to the air in the same place, and observe them over a few days. The sugar in the honey will reduce the vapor pressure of the solution.

3. The solution shows an increase in boiling point as the amount of solute is increased.

   The boiling point of a liquid is just the point at which the vapor pressure of the liquid equals the surrounding pressure. If the vapor pressure decreases, it will take a greater temperature to boil the liquid.

   Put a small amount of honey in the bottom of a glass and about the same level of water in the same kind of glass. Place them both in a microwave oven. Which one boils first? Try the same experiment with various amounts of salt in solution.

4. The solution shows a decrease in melting point as the amount of solute is increased.

   It may be that the dissolved materials block the water molecules from attaching on to the rest of the water crystal. Or possibly that the dissolved material holds on to the water molecules more tightly than the water in the crystals.

Whatever the cause, you have seen this in action in the making of homemade barrel ice cream. The barrel on the outside of the ice cream container has ice and salt (sodium chloride) in it. The ice melts (grabs up the heat) at a temperature lower than the usual melting point of water. Just ice in the barrel would not work, because it does not get cold enough to freeze the ice cream inside that has dissolved materials in it itself.

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CONCENTRATION MATH IN STOICHIOMETRY

If you are given the concentration and volume of a solution, you know the amount of solute in that solution. (C V = n) The concentration times volume can serve as the 'given' and will go directly to the mol ratio on the stoichiometry roadmap.

Since C V = n, and the first thing found from stoichiometry is the number of mols of a material (n), if you need to find the volume of a known concentration of a solution, you must attach (1/C) to the end of the roadmap to get the volume. If you need to find the concentration of a known volume of a solution, you must attach (1/V) to the end of the roadmap DA.

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MATH PROBLEMS ON CONCENTRATION

MATH PROBLEMS ON CONCENTRATION AND SOLUTION-MAKING

1. Explain how to make up five liters of a 0.175 M NaCl solution.

2. What volume of 0.86 M table sugar ($C_{12}H_{23}O_{12}$) has 50 grams of sugar in it?

3. How many grams of $KMnO_4$ would you get if you evaporated the water from 85.75 mL of 1.27 M solution?

4. To what volume must you dilute 15 grams of silver nitrate to make it 0.05 M?

5. What is the concentration of KCl if five grams of it are in 25.3 L?

6. How many moles of chlorine gas are in 17 L of 1.02 M solution?

7. How many grams of sulfuric acid are in 5 mL of 3.2 M acid?

8. I make up 500 ml of 0.1 M sodium hydroxide solution. Explain how I did it.

9. To what volume must you take 27 g of table salt if you want a physiological saline solution? (Physiological saline is 0.15 M NaCl.)

10. What is the concentration of silver nitrate if 15 grams of it are dissolved into 14.28 liters?

11. How many moles of NaCl are in 68 mL of a 0.15 M NaCl solution?
(That is physiological saline when sterilized.)

12.How many grams of NaCl do you have to put into a 5 liter container to make a physiological saline solution?

13. What volume of physiological saline solution would give you a gram of salt when evaporated?

14. What is the concentration of KCl if ten grams are dissolved in enough water to make 12 liters?

WRITE AND BALANCE THE CHEMICAL EQUATION FOR THOSE PROBLEMS THAT NEED IT.SHOW ALL YOUR WORK. USE W5P OR DA METHOD ACCORDING TO THE ROADMAP.

15. Sodium hydroxide and hydrochloric acid combine to make table salt and water. 14 mL of 0.1 M sodium hydroxide is added to an excess of acid. How many moles of table salt are made? How many grams of salt is that?

16. 50 mL of 0.25 M copper II sulfate evaporates to leave $CuSO_4 \cdot 5H_2O$. (That is the pentahydrate crystal of copper II sulfate.) What is the mass of this beautiful blue crystal from the solution?

17. Chlorine gas is bubbled into 100 mL of 0.25 M potassium bromide solution. This produces potassium chloride and bromine gas. The bromine (which dissolves in water) is taken from the solution and measured at 27°C and 825 mmHg. What is the volume of bromine?

18. 95 mL of 0.55 M sulfuric acid is put on an excess of zinc. This produces zinc sulfate and hydrogen. How many grams of zinc sulfate are made?

19. 27.6 mL of a 0.19 M solution of silver nitrate and 15.4 mL of an unknown (but excess) amount of sodium chloride combine to make a white precipitate silver chloride and some dissolved sodium nitrate. (a) How many moles of silver chloride are made? (b) How many grams of silver chloride is that? (c) How many moles of sodium nitrate are made? (d) What is the concentration of sodium nitrate in the final solution?

20. How many grams of potassium permanganate, $KMnO_4$, is needed to make 1.72 liters of 0.29 M solution?

21. By my calculations, a drop of ethyl alcohol, C_2H_5OH , in an olympic-sized swimming pool produces a 1.2 E-10 M solution of alcohol in water. A drop is a twentieth of a mL. How many molecules of ethyl alcohol are in a drop of the water in the pool?

22. 93 mL of 0.15 M magnesium hydroxide is added to 57 mL of 0.4 M nitric acid. (Magnesium nitrate and water are formed.) What is the concentration of the magnesium nitrate after the reaction?

23. Does concentration ruin your concentration?

ANSWERS TO MATH PROBLEMS

1. (a) Weigh out 51.2 grams of NaCl. (b) Dissolve the solid in a small amount of water in a suitable volumetric device. (c) Bring the solution to volume by adding water (q.s.) and mix to completely disburse.

2. 0.162 L
3. 17.2 g
4. 1.77 L

5. 2.65 m mols
6. 17.34 mols
7. 1.57 g

8. (a) Weigh out 2.00 grams of NaOH. (b) Dissolve the solid in a small amount of water in a suitable volumetric device. (c) Bring the solution to volume by adding water (q.s.) and mix to completely disburse.

9. 3.08 L
10. 6.18 m molar
11. 10.2 millimols

12. 43.9 g
13. 0.114 L
14. 0.0112 M

15a. 1.4 E-3 mols
15b. 0.0819 g
16. 3.12 g
17. 284 ml
18. 8.44 g
19a. 5.24 E-3 mols
19b. 0.752 g
19c. 5.24 E-3 mols
19d. 122 mmolar
20. 78.8 g
21. 3.61 E9 molecules
22. 0.152 M

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ACIDS AND BASES

WHAT IS AN ACID OR A BASE?

By the 1884 definition of Svante Arrhenius (Sweden), an acid is a material that can release a proton or hydrogen ion (H^+). Hydrogen chloride in water solution ionizes and becomes hydrogen ions and chloride ions. If that is the case, a base, or alkali, is a material that can donate a hydroxide ion (OH^-). Sodium hydroxide in water solution becomes sodium ions and hydroxide ions. By the definition of both Thomas Lowry (England) or J.N. Brønsted (Denmark) working independently in 1923, an acid is a material that donates a proton and a base is a material that can accept a proton. Was Arrhenius erroneous? $| 8-) No. The Arrhenius definition serves well for a limited use. We are going to use the Arrhenius definitions most of the time. The Lowry- Brønsted definition is broader, including some ideas that might not initially seem to be acid and base types of interaction. Every ion dissociation that involves a hydrogen or hydroxide ion could be considered an acid- base reaction. Just as with the Arrhenius definition, all the familiar materials we call acids are also acids in the Lowry- Brønsted model. The G.N. Lewis (1923) idea of acids and bases is broader than the Lowry- Brønsted model. The Lewis definitions are: Acids are elecron pair acceptors and bases are electron pair donors.

We can consider the same idea in the Lowry- Brønsted fashion. Each ionizable pair has a proton donor and a proton acceptor. Acids are paired with bases. One can accept a proton and the other can donate a proton. Each acid has a proton available (an ionizable hydrogen) and another part, called the ***conjugate base***. When the acid ionizes, the hydrogen ion is the acid and the rest of the original acid is the conjugate base. Nitric acid, HNO_3, ***dissociates*** (splits) into a hydrogen ion and a nitrate ion. The hydrogen almost immediately joins to a water molecule to make a hydronium ion. The nitrate ion is the conjugate base of the hydrogen ion. In the second part of the reaction, water is a base (because it can accept a proton) and the hydronium ion is its conjugate base.

$$\underset{\text{ACID}}{HNO_3} + \underset{\text{BASE}}{H_2O} \rightarrow \underset{\text{CONJUGATE BASE}}{NO_3^-} + \underset{\text{CONJUGATE ACID}}{H_3O^+}$$

In a way, there is no such thing as a hydrogen ion or proton without anything else. They just don't exist naked like that in water solution. Remember that water is a very polar material. There is a strong partial negative charge on the side of the oxygen atom and a strong partial negative charge on the hydrogen side. Any loose hydrogen ion, having a positive charge, would quickly find itself near one of the oxygens of a water molecule. At close range from the charge attraction, the hydrogen ion would find a pair (its choice of two pairs) of unshared electrons around the oxygen that would be capable of filling the its outer shell. Each hydrogen ion unites with a water molecule to produce a ***hydronium ion***, H_3O^+, the real species that acts as acid. The hydroxide ion in solution does not combine with a water molecule in any similar fashion. As we write reactions of acids and bases, it is usually most convenient to ignore the hydronium ion in favor of writing just a hydrogen ion.

Back to the beginning of Acids and Bases.

PROPERTIES OF ACIDS

For the properties of acids and bases we will use the Arrhenius definitions.

Acids release a hydrogen ion into water (aqueous) solution.

Acids neutralize bases in a neutralization reaction. An acid and a base combine to make a ***salt*** and water. A salt is any ionic compound that could be made with the anion of an acid and the cation of a base. The hydrogen ion of the acid and the hydroxide ion of the base unite to form water.

Acids corrode active metals. Even gold, the least active metal, is attacked by an acid, a mixture of acids called 'aqua regia,' or 'royal liquid.' When an acid reacts with a metal, it produces a compound with the cation of the metal and the anion of the acid and hydrogen gas.

Acids turn blue litmus to red. Litmus is one of a large number of organic compounds that change colors when a solution changes acidity at a particular point. Litmus is the oldest known pH indicator. It is red in acid and blue in base. The phrase, 'litmus test,' indicates that litmus has been around a long time in the English language. Litmus does not change color exactly at the neutral point between acid and base, but very close to it. Litmus is often impregnated onto paper to make 'litmus paper.'

Acids taste sour. TASTING LAB ACIDS IS NOT PERMITTED BY ANY SCHOOL. The word 'sauer' in German means acid and is pronounced almost exactly the same way as 'sour' in English. (Sauerkraut is sour cabbage, cabbage preserved in its own fermented lactic acid. http://www.bact.wisc.edu/lindquistjohn/324kraut.html) Stomach acid is hydrochloric acid. Although tasting stomach acid is not pleasant, it has the sour taste of acid. Acetic acid is the acid ingredient in vinegar. Citrus fruits such as lemons, grapefruit, oranges, and limes have citric acid in the juice. Sour milk, sour cream, yogurt, and cottage cheese have lactic acid from the fermentation of the sugar lactose.

Back to the beginning of Acids and Bases.

PROPERTIES OF BASES

Bases release a hydroxide ion into water solution. (Or, in the Lowry- Brønsted model, cause a hydroxide ion to be released into water solution by accepting a hydrogen ion in water.)

Bases neutralize acids in a neutralization reaction. The word reaction is:
Acid plus base makes water plus a salt. Symbolically, where 'Y' is the anion of acid 'HY,' and 'X' is the cation of base 'XOH,' and 'XY' is the salt in the product, the reaction is: $HY + XOH \longrightarrow HOH + XY$

Bases denature protein. This accounts for the "slippery" feeling on hands when exposed to base. Strong bases that dissolve in water well, such as sodium or potassium lye are very dangerous because a great amount of the structural material of human beings is made of protein. Serious damage to flesh can be avoided by careful used of strong bases.

Bases turn red litmus to blue. This is not to say that litmus is the only acid- base indicator, but that it is likely the oldest one.

Bases taste bitter. There are very few food materials that are alkaline, but those that are taste bitter. It is even more important that care be taken in tasting bases. Again, NO SCHOOL PERMITS TASTING OF LAB CHEMICALS. Tasting of bases is more dangerous than tasting acids due to the property of stronger bases to denature protein.

Back to the beginning of Acids and Bases.

STRONG ACIDS AND STRONG BASES

The common acids that are almost one hundred percent ionized are:
HNO_3 - nitric acid
HCl - hydrochloric acid
H_2SO_4 - sulfuric acid
$HClO_4$ - perchloric acid
HBr - hydrobromic acid
HI - hydroiodic acid

The acids on this short list are called ***strong acids***, because the amount of acid quality of a solution depends upon the concentration of ionized hydrogens. You are not likely to see much HBr or HI in the lab because they are expensive. You are not likely to see perchloric acid because it can explode if not treated carefully. Other acids are incompletely ionized, existing mostly as the unionized form. Incompletely ionized acids are called ***weak acids***, because there is a smaller concentration of ionized hydrogens available in the solution. Do not confuse this terminology with the concentration of acids. The differences in concentration of the entire acid will be termed ***dilute*** or ***concentrated***. Muriatic acid is the name given to an industrial grade of hydrochloric acid that is often used in the finishing of concrete.

In the list of strong acids, sulfuric acid is the only one that is ***diprotic***, because it has two ionizable hydrogens per formula (or two mols of ionizable hydrogen per mol of acid). (Sulfuric acid ionizes in two steps. The first time a hydrogen ion splits off of the sulfuric acid, it acts like a strong acid. The second time a hydrogen splits away from the sulfate ion, it acts like a weak acid.) The other acids in the list are ***monoprotic***, having only one ionizable proton per formula. Phosphoric acid, H_3PO_4, is a weak acid. Phosphoric acid has three hydrogen ions available to ionize and lose as a proton, and so phosphoric acid is ***triprotic***. We call any acid with two or more ionizable hydrogens ***polyprotic***.

Likewise, there is a short list of strong bases, ones that completely ionize into hydroxide ions and a conjugate acid. All of the bases of Group I and Group II metals except for beryllium are strong bases. Lithium, rubidium and cesium hydroxides are not often used in the lab because they are expensive. The bases of Group II metals, magnesium, calcium, barium, and strontium are strong, but all of these bases have somewhat limited solubility. Magnesium hydroxide has a particularly small solubility. Potassium and sodium hydroxides both have the common name of ***lye***. Soda lye (NaOH) and potash lye (KOH) are common names to distinguish the two compounds.

LiOH - lithium hydroxide
NaOH - sodium hydroxide
KOH - potassium hydroxide
RbOH - rubidium hydroxide
CsOH - cesium hydroxide
$Mg(OH)_2$ - magnesium hydroxide
$Ca(OH)_2$ - calcium hydroxide
$Sr(OH)_2$ - strontium hydroxide
$Ba(OH)_2$ - barium hydroxide

The bases of Group I metals are all ***monobasic***. The bases of Group II metals are all ***dibasic***. Aluminum hydroxide is ***tribasic***. Any material with two or more ionizable hydroxyl groups would be called ***polybasic***. Most of the alkaline organic compounds (and some inorganic materials) have an amino group ($-NH_2$) rather than an ionizable hydroxyl group. The amino group attracts a proton (hydrogen ion) to become $(-NH_3)^+$. By the Lowry- Brønsted definition, an amino group definitely acts as a base, and the effect of removing hydrogen ions from water molecules is the same as adding hydroxide ions to the solution.

Memorize the strong acids and strong bases. Other acids or bases are weak.

Back to the beginning of Acids and Bases.

SOLUBILITY AND DISSOCIATION

Now, after considering the bases of Group II metals, is a fine time to think about acidity of a solution and the solubility of the compound. Calcium and magnesium hydroxides are used in ***antacids***, materials used to combat gastrointestinal acidity. How can that be if they are strong bases? In order to act as a base, the material must be dissolved. Almost all of these bases that are dissolved are dissociated, or ionized, but the low solubility of these bases makes them safe to swallow. An acid or base must first dissolve before it can dissociate (come apart) or ionize (become a pair of ions).

It is important to notice that just because a compound has a hydrogen or an OH group as a part of the structure does not mean that it can be an acid or a base. The hydrogens of methane, CH_4, are all very covalently attached to the carbon atom. Glycerin (or glycerol) has three OH groups in its structure.

CH_2OH
|
CHOH
|
CH_2OH

These are alcoholic OH groups attached to a carbon atom. THE AVAILABILITY OF THE HYDROXIDE OR HYDROGEN AS AN ION DEPENDS UPON WHAT IT IS ATTACHED TO.

The chemical equation for the dissociation of nitric acid is:

$$HNO_3 \longrightarrow (NO_3)^- + H^+$$

For strong acids and strong bases the equation goes completely to the right. There is none of the original acid or base, but only the ions of the material unattached to each other in the water.

Back to the beginning of Acids and Bases.

OVERVIEW OF pH

pH is just a handy way to express how acidic or alkaline a water solution is. The pH of a solution is the negative log of the hydrogen ion concentration. The hydrogen ion concentration is inversely proportional to the hydroxide ion concentration, and the two of them multiplied together give the number 1 E-14. The table below shows the relationship among these measurements at the integers.

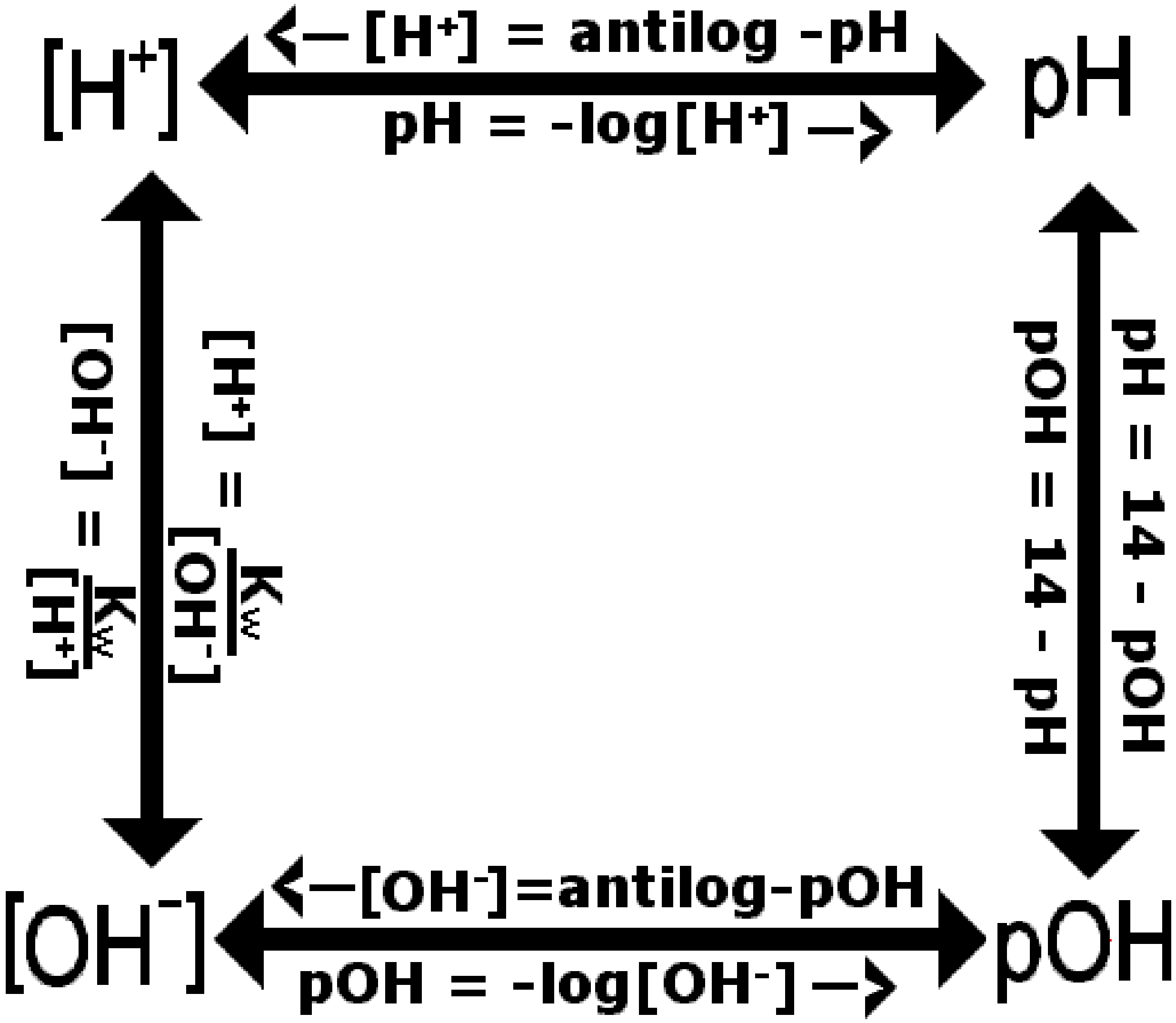
comments	**$[H^+]$**	**pH**	**pOH**	**$[OH^-]$**
very base	E-14	14	0	E-0
	E-13	13	1	E-1
base	E-12	12	2	E-2
	E-11	11	3	E-3
slightly base	E-10	10	4	E-4
	E-9	9	5	E-5
	E-8	8	6	E-6
NEUTRAL	E-7	7	7	E-7
	E-6	6	8	E-8
	E-5	5	9	E-9
slightly acid	E-4	4	10	E-10
	E-3	3	11	E-11
acid	E-2	2	12	E-12
	E-1	1	13	E-13
very acid	E-0	0	14	E-14

Back to the beginning of Acids and Bases.

THE pH BOX

The pH box is a similar sort of self-torture device to the temperature box. All four of the measurements are different ways to express exactly the same condition. The Kw of water, the dissociation constant, is a natural number amazingly close to 1 E-14. That is, when you multiply the hydrogen ion concentration $[H^+]$ by the hydroxide ion concentration $[(OH)^-]$ in pure water at near room temperature, the number is 1 E-14. If you know the $[(OH)^-]$, you know the $[H^+]$ and visa-versa. These two measurements are not the same scale, but they are two different measurements of the same thing. The pH is just the negative log of the $[H^+]$ and the pOH is just the negative log of the $[(OH)^-]$. The final leg of the box is the relationship between the pH and pOH, and that is the easiest one. pH + pOH = 14 because this is the exponential form of the Kw equation.

The hardest part of working the pH box is doing the "number crunching." The math is easier on a scientific calculator. Only a masochist would think about trying to do the computations by hand with a log table. Due to the large number of differences among hand calculators, there is a limit to the amount of help Chemtutor can give you in calculator work, but there are a few tips we can lend you.



[Back to the beginning of Acids and Bases.]

SCIENTIFIC CALCULATOR USE WITH pH BOX

[Click for instructions on how to use a graphing calculator.]

The calculator can be somewhat unfriendly in the math of the pH box. Let's take an example of using the box. The pH table before the pH box makes integer pH calculations easy, but the calculator is best used on non-integer pH's.

$[H^+]$ = 2.75 E-6

Start with $[H^+]$ = 2.75 E-6. Input 2 . 7 5 E +/- 6. To get the pH, punch 'log' (not *ln*, the natural log). The display shows -5.5607. The pH is the negative log, so it is 5.5607, rounded to 5.6, but you leave the -5.5607 on the display to keep going around the box.

pH = 5.5607

Punch + 1 4 = to add 14 to the negative pH. This will give you the pOH of 8.4393.

pOH = 8.4393

Punch the ‘change sign’ button, +/-. This changes 8.4393 to -8.4393. We need to get the antilog of -8.4393, and this function is not the same on many calculators. You may find a 2nd or an INV or shift or some other button to push before the log. My TI-30 SLR has INV on the button. Punch INV and then 'log' to get the $[OH^-]$. You may see a number like: 0.000,000,004 on your display. What did you do wrong? The correct answer is 3.6364 E-9.

$[OH^-]$ = 3.6364 E-9

Why is the display lying to you? It isn't. The numbers are the same, but your calculator showed you the long form (because it COULD) that is a large number of place-holding zeros and a single significant digit. The calculator actually has that number in its memory to eight or ten or sixteen digits, but it chose to only show you one significant digit. You can see the other digits on the display by multiplying by E6 (1 E6) or E9 (1 E9), but if you want to keep going around the box, you need to divide by the same number (with as many significant digits as you can) to get the $[OH^-]$ back. Or, you could store the $[OH^-]$ number before you take a look at it. Your calculator should have a button marked STO or M+ or M1 that will store your number into memory. Do that before you peek at the number. To get back that stored number, you punch RCL or M-. To get back to the original $[H^+]$, punch in: 1 E +/- 1 4 ÷ RCL = . You should see your good old $[H^+]$ of 2.75 E-6 on the display.

$[H^+]$ = 2.75 E-6

Now for practice, go around the pH box the other way.

The rules are:

- To get pH from $[H^+]$ or to get pOH from $[OH^-]$, use the negative of the log.

- To go from $[OH^-]$ to pOH or from $[H^+]$ to pH, use antilog of the negative number.

- To go from $[H^+]$ to $[OH^-]$ or back, first put in the Kw, 1E-14 and divide by the one you are leaving.

- To go from pH to pOH or back, subtract the number you have from 14.

Proficiency in pH box calculations requires practice. There is no Chemtutor Quickquiz on the pH box because you can make your own exercises and check your answers by coming back to the same number. You will use the pH box calculations in many problems in this acid- base section.

Back to the beginning of Acids and Bases.

WEAK ACIDS AND WEAK BASES

We can write the chemical equation for the dissociation of a weak acid, using 'A^-' to represent the conjugate base, as;

$$HA \rightarrow A^- + H^+$$

And, similarly, we can write the chemical equation for the dissociation of a weak base, using 'X^+' to represent the conjugate acid, as;

$$XOH \rightarrow OH^- + X^+$$

The equilibrium expression for the dissociation of a weak acid is;

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

In language, the equilibrium expression reads; "The dissociation constant of an acid is equal to the concentration of hydrogen ions times the concentration of the conjugate base of the acid divided by the concentration of un-ionized acid."

$$k_B = \frac{[X^+][OH^-]}{[XOH]}$$

Similarly, the equilibrium expression for a weak base reads: "The dissociation constant of a base equals concentration of hydroxide ions times concentration of conjugate acid divided by the concentration of un-ionized base."

The k_A of an acid or the k_B of a base are properties of that acid or base at the given temperature. The temperature at which these dissociation constants are listed is usually near room temperature.

The equilibrium expressions are for monoprotic acids or monobasic alkalis or the first dissociation of a polyprotic acid or a polybasic alkali. Phosphoric acid (H_3PO_4) is a good example of a polyprotic acid. When completely ionized, a mol of phosphoric acid will give three hydrogen ions and a phosphate ion, but the hydrogen ions come off one at a time at different pH's and with different k_A's.

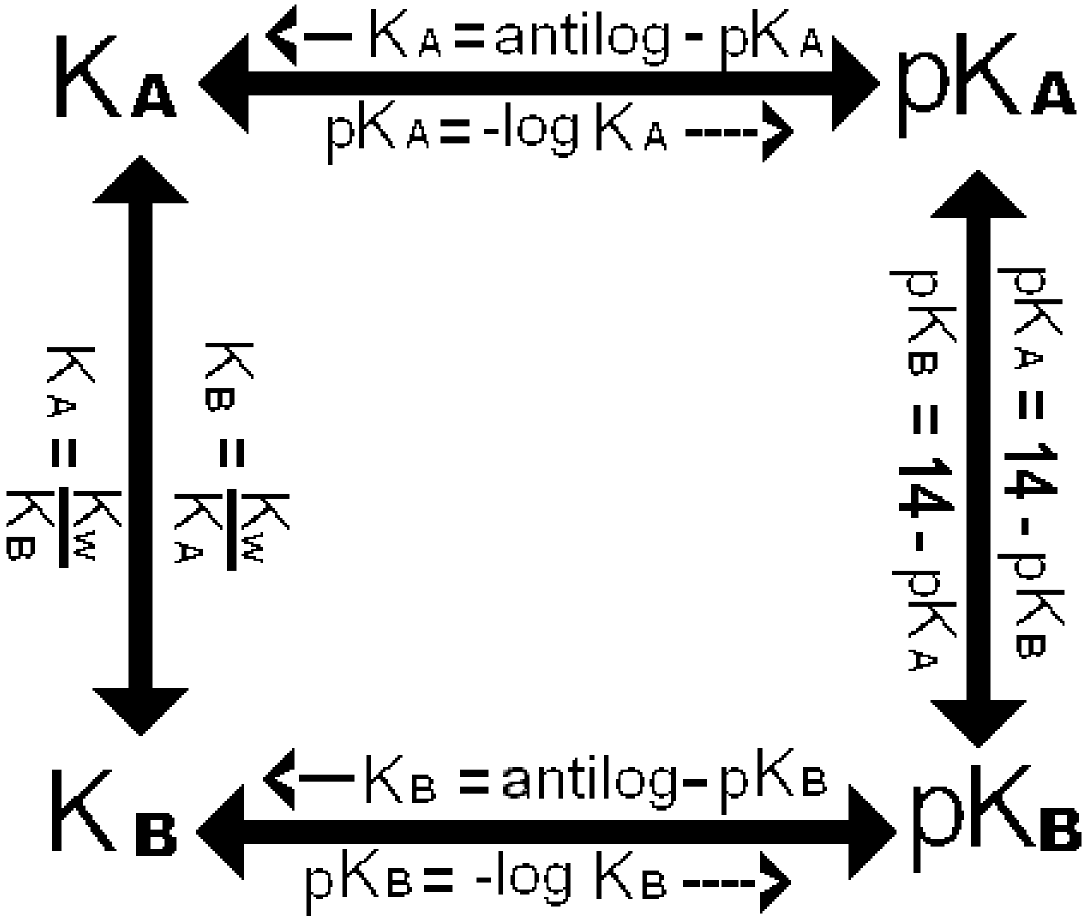
$H_3PO_4 \longrightarrow (H_2PO_4)^- + H^+$	first ionization	k_A = 6.92 E-3
$(H_2PO_4)^- \longrightarrow (HPO_4)^{2-} + H^+$	second ionizaton	k_A = 6.17 E-8
$(HPO_4)^{2-} \longrightarrow (PO_4)^{3-} + H^+$	third ionization	k_A = 2.09 E-12

Any acid with more than one ionizable hydrogen or any base with more than one ionizable hydroxide will usually separate stepwise as phosphoric acid.

Back to the beginning of Acids and Bases.

THE pK_A BOX

The pK_A of an acid is a very useful number, as you will see in the math below. The pK_A is the negative log of the k_A, the pK_B is the negative log of the k_B, and the pK_A plus the pK_B equal fourteen. The k_A box is the same as the pH box, but substitute k_A for $[H^+]$, pK_A for pH, k_B for $[OH^-]$, and pK_B for pOH.



Back to the beginning of Acids and Bases.

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pH OF STRONG ACIDS AND BASES

Strong acids and bases have all of the dissolved material completely ionized. The concentration of a monoprotic acid is equal to the concentration of hydrogen ion. The concentration of a monobasic alkali is equal to the concentration of hydroxide ion. The actual concentration of hydrogen ion (or hydroxide ion) from pure water is on the order of concentration of E-7 Molar, so any concentration of a strong acid or base over E-5 Molar completely swamps the comparatively tiny amount of ion from the ionization of water.

What is the pH of 0.0850 M HNO_3? Nitric acid is a monoprotic strong acid. $[HNO_3] = [H^+]$ and pH = - log $[H^+]$, so, pH = - log (0.085) = 1.07 Only one step on the pH box.

What is the pH of 0.00765 KOH? Potassium hydroxide is a monobasic strong base. $[KOH] = [OH^-]$ and pOH = - log $[OH^-]$ and pH = 14 - pOH Or you could go around the pH box the other way. The pOH = 2.12 and pH = 11.88.

Back to the beginning of Acids and Bases.

WEAK ACIDS

The following tables are published here for your convenience in working problems and seeing examples of weak acids and bases. There is no need for you to memorize the names, formulas, or numbers associated with these materials.

ACID	**FORMULA**	**k_A**	**pk_A**
acetic acid	$H(C_2H_3O_2)$	1.74 E-5	4.76
ascorbic acid (1)	$H_2(C_6H_6O_6)$	7.94 E-5	4.10
ascorbic acid (2)	$(HC_6H_6O_6)^-$	1.62 E-12	11.79
boric acid (1)	H_3BO_3	5.37 E-10	9.27
boric acid (2)	$(H_2BO_3)^-$	1.8 E-13	12.7
boric acid (3)	$(HBO_3)^=$	1.6 E-14	13.8
butanoic acid	$H(C_4H_7O_2)$	1.48 E-5	4.83
carbonic acid (1)	H_2CO_3	4.47 E-7	6.35
carbonic acid (2)	$(HCO_3)^-$	4.68 E-11	10.33
chromic acid (1)	H_2CrO_4	1.82 E-1	0.74
chromic acid (2)	$(HCrO_4)^-$	3.24 E-7	6.49
citric acid (1)	$H_3(C_6H_5O_7)$	7.24 E-4	3.14
citric acid (2)	$(H_2C_6H_5O_7)^-$	1.70 E-5	4.77
citric acid (3)	$(HC_6H_5O_7)^=$	4.07 E-7	6.39
formic acid	$H(CHO_2)$	1.78 E-4	3.75
heptanoic acid	$H(C_7H_{13}O_2)$	1.29 E-5	4.89
hexanoic acid	$H(C_6H_{11}O_2)$	1.41 E-5	4.84
hydrocyanic acid	HCN	6.17 E-10	9.21
hydrofluoric acid	HF	6.31 E-4	3.20
lactic acid	$H(C_3H_5O_3)$	8.32 E-4	3.08
nitrous acid	HNO_2	5.62 E-4	3.25
octanoic acid	$H(C_8H_{15}O_2)$	1.29 E-4	4.89
oxalic acid (1)	$H_2(C_2O_4)$	5.89 E-2	1.23
oxalic acid (2)	$(HC_2O_4)^-$	6.46 E-5	4.19

pentanoic acid	$H(C_5H_9O_2)$	3.31 E-5	4.84
phosphoric acid (1)	H_3PO_4	6.92 E-3	2.16
phosphoric acid (2)	$(H_2PO_4)^-$	6.17 E-8	7.21
phosphoric acid (3)	$(HPO_4)^{=}$	2.09 E-12	12.32
propanoic acid	$H(C_3H_5O_2)$	1.38 E-5	4.86
sulfuric acid (2)	$(HSO_4)-$	1.05 E-2	1.98
sulfurous acid (1)	H_2SO_3	1.41 E-2	1.85
sulfurous acid (2)	$(HSO_3)^-$	6.31 E-8	7.20
uric acid	$H(C_5H_3N_4O_3)$	1.29 E-4	3.89

The organic acids in the table above have been written as acid with conjugate base as different from the standard notation. Notice that sulfuric acid's first ionization is a strong acid, so it is not on this table. Ascorbic acid is vitamin C. Some of the acids in the table are not very soluble, such as uric acid.

An organic acid usually has a **-** COOH group in it. The shape of that group is more like;

O = C – OH
|

There is a double bond between the carbon and the single oxygen. There is a single bond with an alcohol group (-OH). There is one more bond to the central carbon that is usually attached to another carbon. The hydrogen of the alcohol group is the one that has a tendency to ionize away from the group, leaving a $(-COO)^-$ ion at the end of the acid.

Notice the set of organic acids that begin with formic acid. Formic acid has a hydrogen attached to the carbon in the organic acid group. Acetic acid has a $(-CH_3)$ group attached to the carbon in the organic acid group. The line of carbons becomes longer for the acids that follow. There are no branched chains of carbon atoms or any double or triple bonds between the carbons of the organic acids on this list.

The physiological organic acids (the organic acids that are found in living things) all have even numbers of carbons. Hexanoic, octanoic, and decanoic (C-6, C-8, and C-10 acids) are named for goats, which will give you an idea of the smell of those compounds.

The name most used for the organic acid is in bold print in this table.

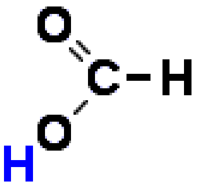
SYSTEM NAME	NUMBER OF CARBONS	COMMON NAME
methanoic acid	1 carbon	**formic acid**
ethanoic acid	2 carbons	**acetic acid**
propanoic acid	3 carbons	**propionic acid**

butanoic acid	4 carbons	**butyric acid**
pentanoic acid	5 carbons	valeric acid
hexanoic acid	6 carbons	caproic acid
heptanoic acid	7 carbons	enanthic acid
octanoic acid	8 carbons	caprylic acid
nonanoic acid	9 carbons	pelargonic acid
decanoic acid	10 carbons	capric acid

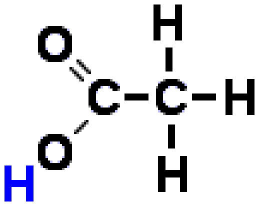
THE FOLLOWING ARE 'FATTY ACIDS'

dodecanoic acid	12 carbons	**lauric acid**
tetradecanoic acid	14 carbons	**myristic acid**
hexadecanoic acid	16 carbons	**palmitic acid**
octadecanoic acid	18 carbons	**stearic acid**
eicosanoic acid	20 carbons	**arachidic**
tetracosanoic acid	24 carbons	**lignoceric**

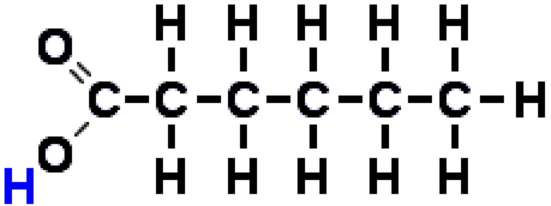
Below are some of the molecular formulas of some of the organic acids in the stick and symbol form. The ionizable hydrogen is in blue.



formic acid



acetic acid



hexanoic acid

Organic acids with straight carbon even- number chains of twelve to twenty- four are called ***fatty acids***. See soap for more on fatty acids. You can see that the pKA's are very close for all of the similar organic acids. Formic and acetic acids are water soluble. As the carbon chain increases in length, the molecule becomes less and less water soluble. Beginning with propanoic acid, even as the number of carbons increase, the pKA's do not change much.

Back to the beginning of Acids and Bases.

WEAK BASES

Many materials are weak bases due to the presence of an amino group ($-NH_2$) attached to an organic compound. Nitrogen has five electrons in the outside shell. The three solo electrons can participate in (covalent) bonds to the nitrogen. The unshared pair of electrons can be donated by the nitrogen atom to constitute a complete covalent bond with a material that lacks a pair of electrons. The Lewis definition most clearly shows that the donor of the pair of electrons (the N atom) is a base and anything that attaches to the nitrogen by accepting a position of covalent attachment to the nitrogen is an acid.

BASE	**FORMULA**	**k_B**	**pk_B**
alanine	$C_3H_5O_2NH_2$	7.41 E-5	4.13
ammonia (water)	NH_3 (NH_4OH)	1.78 E-5	4.75
dimethylamine	$(CH_3)_2NH$	4.79 E-4	3.32
ethylamine	$C_2H_5NH_2$	5.01 E-4	3.30
glycine	$C_2H_3O_2NH_2$	6.03 E-5	4.22
hydrazine	N_2H_4	1.26 E-6	5.90
methylamine	CH_3NH_2	4.27 E-4	3.37
trimethylamine	$(CH_3)_3N$	6.31 E-5	4.20

Alanine and glycine are amino acids, two of the twenty- or- so types of building blocks of protein. Each amino acid has both an amino (base) end and an acid end. Only the amino end (the base side) numbers are listed.

Back to the beginning of Acids and Bases.

THE 5% RULE

The measurement and calculation of pH is not as accurate as some other of the chemical measures due to differences in temperature, other ions present, purity of solutes, concentration changes due to evaporation, etc. Measurement of pH in medicine, for instance must be at 37 degrees Celsius. There may be machines that claim to measure pH to hundredths or thousandths of a pH unit, but the standard that calibrates the machine may be off a little. A change of five percent in the hydrogen ion concentration will not change the pH more than a few hundredths of a pH unit. You try it on the calculator. Enter a number, say 0.001 and punch log. Now punch a number 95% or 105% of the first number (in this case, 0.00105 or 0.00095) and punch log. How different is the pH? Our answers in pH are going to be to the nearest tenth of a pH unit, so the hydrogen ion concentration needs to be only within 5% of an accurate number. This idea is the 'five percent rule.'

You may remember we mentioned that the concentration of a strong acid is equal to the hydrogen ion concentration. That is not exactly so. In any water solution of an acid there is another source of hydrogen ions, the ***water***. Water alone has a hydrogen ion concentration of E-7 Molar. Let's say you have a a E-5 M HCl solution, the contribution of the water is only a hundredth of the amount of hydrogen ion from the acid at the first approximation. You could approximate the real hydrogen ion concentration better by finding the hydroxide ion concentration of a solution with E-5 hydrogen ion concentration and then finding the added hydrogen ion concentration due to the dissociation of water from that. The total hydrogen ion concentration will be even further from having any significant contribution of hydrogen ion from the ionization of water. Does the ionization of water have an significance in this case? Of course not. There is much less than five percent difference difference between the two numbers. Here is an obvious situation where you can use the simpler approximation of the hydrogen ion concentration to find the pH. There are some times when the simpler approximation is not accurate enough. There are some times when you may be in doubt and would need to work it BOTH ways to show whether you can use a simplified method.

Another way to state the five percent rule is: If you have a simplified way of solving for the hydrogen ion concentration that would give you an answer you can show would be within 5% of the more accurate way of calculating it, you can use the simpler method.

Back to the beginning of Acids and Bases.

---

pH OF WEAK ACIDS AND BASES

Weak acids and bases do not ionize very much, so the $[H^+]$ or $[(OH)^-]$ must be calculated by the equilibrium expression.

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

This would be easy to know exactly, except that the [HA] is not always equal to the concentration of solute that actually went into the solution. The more accurate way to express the equilibrium expression would be to include in the denominator the idea that the [HA] is really the concentration of solute originally put into solution minus the amount of that solute that ionized. We could represent the amount that ionized by either the $[A^-]$ or the $[H^+]$, so the denominator should be either $[HA] - [A^-]$ or $[HA] - [H^+]$. Let's use the second option for alternative denominator because we want to solve for the hydrogen ion concentration. By the 5% rule, $[HA] = [HA] - [H^+]$ only if the hydrogen ion concentration is less than five percent of the total solute concentration. This is the case for most weak acids. The only exceptions are when the strongest of the weak acids are in the most dilute solutions.

If you have a stronger weak acid (one with a high k_A), you should check to see if the $[H^+]$ is near 5% of the total solute concentration. If it is, you will have to use the alternative denominator in the equation and solve it for $[H^+]$ by quadratic equation.

start with the ionization equilibrium expression
with the alternative denominator

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

simplify by combining $[A^-]$ and $[H^+]$ and
then multiply by the denominator to get:

$$k_A[HA] - k_A[H^+] = [H^+]^2$$

and, eventually, you get an expression that
looks like a real quadratic equation in $[H^+]$ that
can be solved by the quadratic formula.

$$[H^+]^2 + k_A[H^+] - k_A[HA] = 0$$

Heaven forfend the need for using a quadratic equation. (I would rather kiss a BIG alligator.) It's a lot easier if the $[H^+]$ is less than five percent of the [HA].

If there is only water and a weak acid in the solution, each mol of the acid dissociates into only one mol of hydrogen ions and only one mol of conjugate base ions. $[H^+] = [A^-]$! So;

$$k_A = \frac{[H^+]^2}{[HA]}$$

and solving for $[H^+]^2$,

$$[H^+]^2 = k_A\,[HA]$$

then taking the square root of both sides, you have $[H^+]$.

$$[H^+] = \sqrt{k_A\,[HA]}$$

Once you have the hydrogen ion concentration, you can go anywhere on the pH box.

The same idea goes for a weak base as the only material in water solution. Start with the equilibrium expression and the conjugate acid ion being equal to the hydroxide concentration. You will start with the base equilibrium expression:

$$k_B = \frac{[X^+]\,[OH^-]}{[XOH]}$$

and solve for $[OH^-]$ to get;

$$[OH^-] = \sqrt{k_B\,[XOH]}$$

And it's back to the pH box for anything else you need.

Back to the beginning of Acids and Bases.

BUFFERS AND pH OF BUFFERS

A buffer is a solution that resists changes in pH. A buffer is made with a weak acid and a soluble salt containing the conjugate base of the weak acid <u>or</u> a weak base and a soluble salt containing the conjugate acid of the weak base. Some examples of buffer material pairs are:

acetic acid and sodium acetate,

phosphoric acid and potassium phosphate,

oxalic acid and lithium oxalate

carbonic acid and sodium carbonate,

or ammonium hydroxide and ammonium nitrate.

A buffer is most effective in solutions of pH at or close to the pKA of the weak acid. (Or solutions of pOH at or close to the pKB of the weak base.) The most buffering capacity is available when the concentration of weak acid or base is close to the concentration of the conjugate ion and when the concentration of both is greatest.

Thinking backwards, if you need a buffer at a particular pH lower than seven, chose the weak acid that has a pKA close to that pH and a conjugate base to go with it.

We can start again from the equilibrium expression of the ionization of a weak acid or a weak base;

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

In buffer solutions the concentration of hydrogen ion is **not** equal to the concentration of conjugate ion. The concentration of conjugate ion from the dissociation of the acid is negligible, so we can calculate as if all the conjugate ion comes from the salt. If the soluble salt has only one mol of conjugate ion per mol of salt, the concentration of conjugate ion is the same as the concentration of salt.

The entrance to the pH box again is the hydrogen ion concentration. Solve for the hydrogen ion concentration if you need it, the pH of the solution, the pOH, or the hydroxide ion concentration.

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

which is the same as:

$$[H^+] = (k_A)\left(\frac{1}{[A^-]}\right)([HA])$$

The Henderson-Hasselbalch (H-H) equation can be somewhat confusing, but it is nothing more than the negative log of the the equation above, the equilibrium expression solved for the hydrogen ion concentration. If you know the equilibrium equation, know how to solve the equilibrium equation for the hydrogen ion concentration, and know how to convert the hydrogen ion concentration to the pH, you have it licked. If you really need the H-H equation for a test, it is best to make sure you are getting it right by deriving it from the equilibrium expression.

$$-\log[H^+] = pH$$

$$-\log k_A = pK_A$$

$$-\log(1/[A^-]) = +\log[A^-]$$

$$-\log([HA]) = -\log[HA]$$

Component-by-component take the negative log of the equilibrium expression and change the multiplication to addition. (They are logs now.) You get:

$pH = pK_A + \log[A^-] - \log[HA]$, which is the same as;

$pH = pK_A - \log\left([HA]/[A^-]\right)$, the usual way you see the H-H equation.

There are four perfectly correct ways to write the H-H equation. They are:

$$pH = pk_A - \log\frac{[HA]}{[A^-]}$$

or

$$pH = pk_A + \log\frac{[A^-]}{[HA]}$$

or

$$pOH = pk_B + \log\frac{[\text{conjugate cation}]}{[\text{base}]}$$

or

$$pOH = pk_B - \log\frac{[\text{base}]}{[\text{conjugate cation}]}$$

An ***equimolar*** buffer is one in which the concentration of the weak acid (or base) is the same as the concentration of the conjugate ion. This may not seem particularly significant to you, but there are several important ideas that can be easily seen from it. Start with the ionization equilibrium expression and cancel the [HA] with the [A^-]. This shows that in an equimolar buffer kA = [H^+].

$$kA = \frac{[H^+]\cancel{[A^-]}}{\cancel{[HA]}}$$

$$\text{if } [HA] = [A^-]$$

$$kA = [H^+]$$

This shows how a buffer works. As acid or base is added to a buffer solution, the buffer equilibrium will trade off [HA] with [A^-] to come to a new equilibrium. When that happens, there will be a much smaller change in the hydrogen ion concentration than if the acid or base were added to an unbuffered solution.

Now let's do a similar trick with the H-H equation. If [HA] = [A^-], the term [HA]/[A^-] = 1 and log 1 = 0, so pH = pKA.

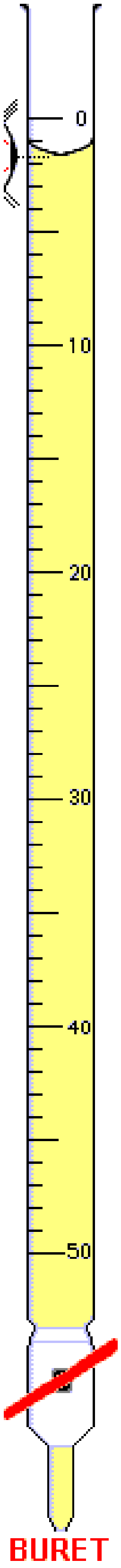
$$pH = pKA - \log \frac{\cancel{[HA]}}{\cancel{[A^-]}}$$

$$pH = pKA$$

This indicates that in an equimolar buffer the pH = pKA and that the RATIO of the [HA] to the [A^-] will determine the pH of the solution. The further the ratio gets from one to one, the further the pH gets from the pKA. The buffer has its greatest buffering power at the pKA of the weak acid (or base). The higher the concentration of both the weak acid and its conjugate ion, the more buffering power is available.

Back to the beginning of Acids and Bases.

TITRATION



The word "titration" rhymes with "***tight nation***," and refers to a commonly used method of (usually) finding the concentration of an unknown liquid by comparing it with a known liquid. An acid-base titration is good to consider when learning the method, but there are more uses for the technique. The measure of oxalate ion using potassium permanganate in a warm acid environment is a good example of a redox titration. The Mohr titration is a determination of chloride concentration using known silver nitrate solution and sodium dichromate an indicator.

A measured amount of the unknown material in a flask with indicator is usually combined with the known material from a buret (rhymes with "sure bet"). The buret is marked with the volume of liquid by a scale with zero on top and (usually) fifty milliliters on the bottom. The buret has some type of valve at the bottom that can dispense the contained liquid.

It is not necessary to start the titration with the known liquid level in the buret at the zero mark, but the level must be within the portion of the buret that is marked. The buret on the left shows about 1.8 ml of the yellow liquid in it. Most laboratory burets can be read to an accuracy of one hundredth of a milliliter. (The drawing on the left is a bit crude. Most burets show the ten divisions of a milliliter and you can interpolate between the marks.) One reads the buret by getting at eye level to the bottom of the meniscus (curve in the liquid) and comparing the bottom of the meniscus to the marks on the glass. A reading of the buret is taken before and at the end of the titration. The amount of know-concentration liquid used is the difference of the beginning and ending buret reading.

The ***endpoint*** of the titration is usually shown by some type of indicator. A ***pH indicator*** is a material, usually an orgainc dye, that is one color above a characteristic pH and another color below that pH. There are many materials that can serve as pH indicators, each with its own ph range at which it changes color. Some have more than one color change at distinct pH's. Litmus and phenolphthalein are common pH indicators. Litmus is red in acid (below pH 4.7) and blue in base (above pH 8.1). Phenolphthalein (The second 'ph' is silent and the 'a' and both 'e's are long, if that is any help.) is clear in acid (below pH 8.4) and pink- purple in base (above pH 9.9). These ranges may seem large, but near the ***equivalence point***, the point at which the materials are equal, there is a large change in pH. The equivalence point may not occur at pH 7, neutral pH, so the appropriate pH indicator must be chosen for the type of acid and base being titrated.

The volume of the material of unknown concentration is known by how much is put into the reaction vessel. The concentration of the standard is known, and its volume is known from the measurement of liquid used in the titration.

If you have a monobasic base and a monoprotic acid, you can simplify the formula for titration to: if C_A = the concentration of the acid and C_B = the concentration of the base and V_A = the volume of acid solution and V_B = the volume of base, then,

$$C_A V_A = C_B V_B$$

Back to the beginning of Acids and Bases.

SALTS

A ***salt*** is the combination of an anion (- ion) and a cation (a + ion). Another way to think of a salt is the combination of the anion of a certain acid combined with the cation of a certain base. The neutralization of potassium hydroxide with hydrochloric acid produces water and the salt, potassium chloride. In a solid salt, the ions are held together by the difference in charge. Solid salts usually make crystals, sometimes including specific molar amounts of water, called ***water of hydration*** into the crystal. If a salt dissolves in water solution, it usually dissociates (comes apart) into the anions and cations that make up the salt.

Salts dissolved in water may not be at neutral pH. Table salt, NaCl, has a neutral pH in water, but baking soda, $NaHCO_3$ is very alkaline when dissolved in water. Take a teaspoonful of baking soda on your hand, wet it, and completely wash your hands with it. (Baking soda is a really fine material for cleaning hands!) There is the hint of the slipperiness of bases on your hands that had to come from the baking soda.

How can you predict the pH of a salt dissolved in water? The actual pH will depend on the type of anion and cation, the solubility of the salt, the temperature of the solution, and concentration of the salt if less than saturated. salt. Here are the general rules:

- Salts made of the anion of a strong acid and the cation of a strong base will be neutral salts, that is, the water solution with this salt will have a pH of seven. (example - sodium chloride)

- Salts made of the anion of a strong acid and the cation of a ***weak*** base will be acid salts, that is, the water solution with this salt will have a pH of less than seven. (example - ammonium chloride)

- Salts made of the anion of a ***weak*** acid and a strong base will be an alkali salt. The pH of the solution will be over seven. (example - sodium bicarbonate)

- It can be a bit more difficult to tell the pH of a salt solution if the salt is made of the anion of a weak acid and the cation of a weak base. Usually, the main determining factor is whether the weak acid is weaker than the weak base, but that is not always the case. For the purpose of the problems in the review section, you may say that the pH of a 'weak-weak' salt is indeterminate.

Back to the beginning of Acids and Bases.

TITRATION AND pH PROBLEMS

THE FOLLOWING SALTS IN WATER SOLUTION WILL HAVE A pH OF 7, -7(less than 7), +7(more than 7), OR INDETERMINATE (I). FOR EACH PREDICT THE pH OF THE SOLUTION. Explanations

1. Na_2CO_3
2. $FeCl_3$
3. KNO_3
4. $NH_4C_2H_3O_2$
5. $ZnSO_4$
6. $Ba(NO_3)_2$
7. RbF
8. $CaBr_2$

FIND THE pH OF THE FOLLOWING SOLUTIONS. Find kA's, pKA's, kB's, and pKB's on the tables above.

9. 0.0115 M HCl
10. 0.0815 M NaOH
11. 0.00372 M $Ba(OH)_2$
12. 0.12 M $HC_2H_3O_2$
13. 1.35 E-5 H_3BO_3
14. 0.255 M NH_4OH
15. 0.578 M H_3PO_4
16. 0.16 M HCl and 0.072 M phosphoric acid.
17. 1.25 M acetic acid and 0.75 M potassium acetate.
18. 0.788 M lactic acid and 1.27 M calcium lactate.
19. 0.590 M ammonium hydroxide and 1.57 M ammonium chloride.
20. Explain how to make 5 L of 0.15 M acetic acid-sodium acetate buffer at pH 5.00 if you have 1.00 Molar acetic acid and crystaline sodium acetate.

FOLLOWING ARE TITRATION PROBLEMS. ASSUME THAT THE pH INDICATOR WILL BE THE RIGHT ONE TO BALANCE THE AMOUNT OF ACID AND BASE. SOME OF THE TITRATIONS ARE NOT ACID - BASE TITRATIONS. AGAIN ASSUME THERE IS AN INDICATOR THAT WILL TELL WHEN MOLAR AMOUNTS ARE MATCHED.

21. 23.45 mL of 0.275 M sodium hydroxide was used to titrate against mL of acetic acid. What was the concentration in M of acetic acid?

22. 17.05 mL of 0.247 M barium hydroxide was used to titrate against 10 mL of nitric acid. What was the concentration in M of nitric acid?

23. 35.79 mL of 0.275 M sodium hydroxide was used to titrate against 15 mL of sulfuric acid. What was the concentration in M of sulfuric acid?

24. 24.92 mL of 0.00199 M silver nitrate was used to titrate against 5 mL of sodium chloride solution. What was the concentration of NaCl?

ANSWERS TO PROBLEMS

1. +7
2. -7
3. 7
4. I
5. -7
6. 7
7. +7
8. 7
9. 1.9
10. 12.9
11. 11.9
12. 2.8
13. 6.8
14. 11.3
15. 1.2
16. 0.8
17. 4.5
18. 3.6
19. 8.8

20. Weigh 39.1 g of sodium acetate, measure 274 ml of the 1.00 Molar acetic acid and place into a 5 liter volumetric flask. Dissolve, then fill the volumetric flask to the line with distilled water and mix.

21. 1.29 M **<22. 0.842 M>** **23. 0.328 M** **24. 9.92 E-3 M**

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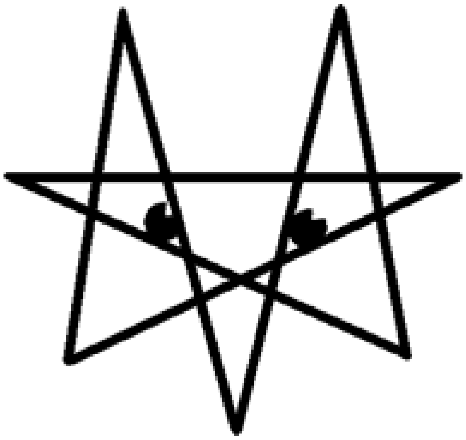

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USE OF GRAPHING CALCULATOR FOR pH BOX MATH

[H$^+$] = 2.75 E-6

Start with [H$^+$] = 2.75 E-6. Input (-) (This is the 'change sign' button.), log (not *ln*, the natural log) 2 . 7 5 E (-) 6 and enter. The pH will be displayed as 5.560667306. It is dreadfully unrealistic to consider that number as a final answer of the pH of the solution because pH is not generally accurately measurable beyond two places to the right of the decimal. If this were a final answer, I would round it to 5.56, but if you want to continue around the pH box, you should keep as many of the digits as you can.

pH = 5.560667306

Punch (-) to change the sign and ans to call up the previous answer. (This inserts the 5.60667306 into the new calculation.) Punch +, the plus sign and 1 4 enter to add 14 to the negative pH. This will give you the pOH of 8.439332694. (Round to 8.44 if this is your final answer.)

pOH = 8.439332694

To get to the [OH$^-$] from the pOH, punch in the antilog (usually INV or shift and log), change sign (-), and the pOH from the previous answer ans

$[OH^-]$ = 3.636363636 E-9

To get back to the $[H^+]$ from the $[OH^-]$, enter the Kw, 1 E -14, and divide by the previous answer. Punch 1 E (-) 1 4 ÷ ans enter

$[H^+]$ = 2.75 E-6

Now for practice, go around the pH box the other way.

The rules are:

- To get pH from $[H^+]$ or to get pOH from $[OH^-]$, use the negative log.
- To go from $[OH^-]$ to pOH or from $[H^+]$ to pH, use antilog of the negative number.
- To go from $[H^+]$ to $[OH^-]$ or back, first put in the Kw, 1E-14 and divide by the one you are leaving.
- To go from pH to pOH or back, subtract the number you have from 14.

Proficiency in pH box calculations requires practice. There is no Chemtutor Quickquiz on the pH box because you can make your own exercises, but you will use the calculations in many problems in this acid-base section.

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ALLOTROPES

The word *allotrope* just means different type or alternate type. A number of elements appear naturally in more than one form at room temperature. The allotropes are usually due to the crystal shape, or lack of crystal shape, or the attachments of more than one atom of an element.

One of the easiest materials to see and play with in this respect is sulfur. Most pharmacies will have containers of flowers of sulfur. This dull yellow element is not only non- poisonous, but it is ingestable. (You can EAT it!). Is there any good reason for eating it? Yes! A spoonful eaten an hour before going out into a pine forest will keep off the no-see-ums, or chiggers, as they are called in the southern US. The sulfur supposedly comes out of your body in your sweat and discourages the insects. It would likely not be a good idea to eat sulfur before a big date, unless your date ate some also. It doesn't smell very good. Don't eat any of the sulfur from your chemistry lab. No telling what other laboratory chemicals have contaminated it.

Sulfur also has an allotrope that is easily seen. Into a test tube put an amount of flowers of sulfur that is a depth of about twice the diameter of the test tube. Heat this over a flame until the sulfur is all melted. The melting point of sulfur is just a few degrees above the boiling point of water. Pour out the melted sulfur onto a clean disposable piece of paper. (Careful. The liquid is hot and sticky. It will burn you if it gets on you.) The sulfur quickly cools into a rubbery mass. It is still sulfur. Very slowly as it sits, the rubbery mass will turn back into a crystalline material. There are two crystalline shapes of sulfur, a monoclinic and a rhombic along with this amorphous (without crystalline shape) form.

Oxygen has two common allotropes. The familiar O_2 is the common oxygen in the air. O_3 is ozone, an allotrope of oxygen. The most common way for ozone to be made is from natural lightning. Ozone accounts for the "smell of rain" that occurs around lightning strikes. The difference between them is that the O_2 molecule has two atoms of oxygen attached to each other and the O_3 molecule has three atoms of oxygen attached to each other. Ozone is a higher energy form of free elemental oxygen. Generally after a while the ozone gradually changes back to O_2 in the air.

Carbon also has allotropes, but it is not so easy to change the carbon from one allotrope to the other. In fact, if you know of a good easy way to change carbon black into gem quality diamonds, tell me about it. The three allotropes of carbon are carbon black or lampblack, diamond, and graphite. Carbon black is unattached carbon atoms. The black coloring material in automobile tires, the blackening in shoe polish, etc. are all carbon black. The soot from an oxygen-starved flame has a lot of carbon black in it. Coal is mostly carbon black.

Pencil lead at one time was made with the element lead, but no more. Graphite mixed with a very fine clay is molded into a thin cylinder and placed in a wooden splint to make most common pencils. You can see purer graphite in some locksmith's lubricant. As a naturally occurring mineral, graphite is a dark gray, greasy-feeling material. This greasiness comes from the shape of the carbon. In graphite the carbon is attached in large sheets of hexagonally bonded atoms.The sheets can easily move over one another, giving it that greasy feeling.

The bonds of diamond are tetrahedral. Each atom in a diamond is linked to four other carbon atoms tetrahedrally in three-space. Since the bonds are strong and the atoms of carbon are small, diamond is very hard. It is a crystal, though. If you tap a diamond in just exactly the right place, it will cleave along the crystal face.

Now that you know something about allotropes, is the change from one allotrope to the other a chemical change? Most chemists would say, "No," but there is a material made that has new properties. In the case of carbon or oxygen, there are even some new chemical bonds made, even if it is between all atoms of the same type.

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IONIZATION

Ionic compounds, those attached by an ionic bond, come apart in water into the two ions. Sodium chloride is a good example of an ionic material. Most ionic materials, as sodium chloride, are in the form of crystals in solid form and in the form of ions in the dissolved form in aqueous solution. You have seen dissolving of sodium chloride before. A pinch of table salt in a cooking pot half full of water very quickly changes to the ions. How do we know the ions are in the solution? The solution of table salt (or any other dissolved ionic compound) can conduct an electric current by the movement of the ions. The equation for this process is:

$$NaCl \longrightarrow Na^+ + Cl^-$$

The sodium ions are attracted to the negative end (the oxygen end) of the water molecules, and the chloride ions are attracted to the positive end (the hydrogen end) of the water molecule.

Is this a genuine reaction or not? We say that a physical change is one in which there is no change in the chemical makeup of the reactant and the original reactant(s) may be reclaimed by a physical process. A chemical change is one in which there is a new material made.

Solid sodium chloride is definitely chemically different from sodium ions-plus-chloride ions. The ions conduct electricity and can react in ionic reactions. On the other hand, the material can completely reclaimed by the process of evaporation of the water. This is commonly done with sea water to get the salt. Have bonds been broken? Yes, if you were to tag specific sodium ions (radioactive tagging) to go with other tagged chloride ions and dissolve them with non-tagged ions, you would find that upon reclaiming the solid material the tagged ions mixed with the untagged ions. The bonds of the crystal have detached. The ions are loose in solution and make bonds again as the crystal reappears. The ions do not return to any previously determined position. The crystal itself is only a conglomerate of ions in relative positions and not a solid made of discrete molecules.

Some ionic materials, such as acetic acid, are only partly ionized in water. We know this from the way the acetate ion frees itself from the hydrogen ion. Acetic acid is a weak acid, that is, the material may be completely dissolved, but there is only evidence of a certain distinctive portion of the hydrogen ion.

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BIOCHEMISTRY

Biochemistry is the chemistry of living things. The number of fascinating chemical changes that go on inside any living thing is enormous. The variety of large, complex, extremely intricate systems in a living thing are mind-boggling. Death of a living thing is both a cessation of the biochemical processes and a large number of biochemical reactions itself. Even before the attack of the micro-organisms on a tree, the very stopping of the everyday reactions cause a new set of chemical changes to happen.

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BLUE VITRIOL

Blue vitriol is an old common name for cupric sulfate pentahydrate. That name comes from the color, of course, which is a strikingly beautiful blue, and 'vitriol' from the glassy appearance of the crystals rather than any vituperative. (Run for that Webster's!) Blue vitriol is one of a number of hydrated crystals. These crystals, often sulfates or carbonates, attract and semi-attach a definite number of water molecules to each of the non-water parts to form a crystal lattice. A dot is usually used in the formula to represent the association of the water to the ionic part of the formula.

As with most hydrated crystals, gentle heating will free the water from the copper sulfate. Upon heating, blue vitriol will change from the glassy blue (about the color of the title of this page) to a powdery light robin's egg blue, releasing water in the form of vapor*. The equation for this process is:

$$CuSO_4 \cdot 5H_2O \longrightarrow CuSO4 + 5H_2O$$

The association of the water to the copper sulfate is in exactly one to five mole ratio. The dehydrated crystal is hygroscopic, that is, it fiercely grabs up water from the atmosphere to replace into the crystal. If you place a drop of liquid water onto the dehydrated crystal, it grabs up the water with a sizzling sound, produces a bit of heat, and changes to a color closer to the hydrated crystal.

Is this a genuine reaction or not? The exchange of heat, the exact proportions of water and copper sulfate, and the change of properties make good arguments for it being a genuine reaction. On the other hand, the water stays water and the copper sulfate formula does not change. The process is reversible by simple physical process, either adding water or heating to drive off the water.

*Copper sulfate is poisonous due to the copper ion. Copper and other "heavy metals" such as lead and mercury are a problem in cells of living things. Blue vitriol can present a problem in doing this little dehydrating experiment because larger crystals can explode from the heat and spray copper sulfate all around. The powdery dehydrated crystal is also dangerous. It is possible to breathe in enough of the powder to poison yourself.

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CARBON DIOXIDE

Carbon dioxide is a gas at room temperatures. It is an important part of the respiration of living things and the carbon cycle. Carbon dioxide in our atmosphere is a colorless, odorless gas that is heavier than air. Put a piece of dry ice into a deflated balloon and tie the open end of the balloon. The dry ice will change into gaseous CO_2 and fill the balloon. This balloon will drop quickly in the air. Carbon dioxide is a product of complete combustion of any material that contains carbon.

Dry ice is solid carbon dioxide. It goes directly from a solid to a gas at atmospheric pressures. (It takes higher pressure for the liquid to appear.) This process, along with the reverse process of the gas going directly to become a solid, is called sublimation. Sublimation of CO_2 at atmospheric pressure occurs at -78.5 °C. Any wispy bit of white haze around dry ice as it sublimes is not carbon dioxide, but water. The crystals of water come about from the solidification of the water in the atmosphere. Stage or movie productions needing a gentle haze on the ground have long relied on dry ice in water. The dry ice sends up ice crystals into the air as the dry ice bubbles under the water The ice crystals melt in the air to make a wonderful little cloud. The carbon dioxide gas dissolved in the water and around the water droplets tends to make the cloud cling to the ground.

I know of someone who entered a High School Science Club float in the Fourth of July parade with a large paper cylinder on the float in the shape of a beaker. Under the beaker was a pan of water and some pellets of dry ice to put into it to form an evil-looking mist. The individual in question became over enthusiastic about creating mist and put a large amount of dry ice into the pan. By the time the float passed the reviewing stand, the water had frozen.

One of the best ways to get a good refreshing drink in front of a chemistry class is to place a pellet of dry ice into an Erlenmeyer flask with about a third of the flask filled with water. It is best to lean on the top of the flask with the palm of one hand. This increases the pressure on the carbon dioxide to push it into the water. Stirring helps, so every so often mix the flask around. As the liquid cools from the dry ice, even more of the gas can be dissolved into the water. The result, after a dramatic presentation and a calm swig of the liquid, is called seltzer water. This is the same material that gives any carbonated drink its fizz. Oh, one warning. Don't drink the dry ice pellet down with the water. The result is even worse than swallowing a whole undissolved Alka Seltzer tablet. Swallowing dry ice is dangerous. You can freeze a part of your stomach doing that. Just try to explain that to an emergency room doctor without laughing.

As carbon dioxide dissolves in water, there is another change. The water becomes very slightly acid. Carbonated drinks have a bit of a sour taste or 'bite' that comes from the carbon dioxide. Once the 'fizz' has gone from such a drink, the taste is 'flat.' The solution of carbon dioxide in water can neutralize a base, so it is appropriate to call it 'carbonic acid,' but there is no compound that can be isolated. The equation for this process is:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

The reaction is written with a double-sided arrow because it is reversible. This has all the qualifications of a genuine chemical reaction, except there is no way to isolate the product. Carbonic acid only exists as ions in a water solution of carbon dioxide.

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AMMONIA

Ammonia, NH_3, is a gas with a distinctive odor. There is no way to describe the smell to you any more than there is a way to describe the smell of a pear. But you have likely smelled ammonia. Many household cleaners contain ammonia. Cats eat a large amnout of protein. The protein has nitrogen in it that must be excreted from the body. The contents of a cat pan will give off a strong odor of ammonia as the deterioration process of the waste goes on.

Ammonia has a number of uses. Some of the first refrigeration units used ammonia as a coolant. It makes a fine coolant material, but in the event of leakage from a cooling system, ammonia is dangerous. In the amounts one would get from a leaking cooling system ammonia can be a noxious gas. Ammonia can be made directly from the nitrogen in the air and hydrogen gas by the Haber process. It is used to make fertilizers and explosives.

Due to the amazing properties of water to dissolve materials and the added properties of ammonia as a polar covalent material with a very notable separation of charge, ammonia water makes a wonderful cleaning material for glass and other materials.

In a reaction that has some similarities to the reaction of carbon dioxide and water, ammonia dissolves in water to produce ammonium hydroxide. We know there is some ammonium hydroxide in the solution because we can make ammonium salts from it and the solution is alkaline, but there is no such compound as ammonium hydroxide. As the water evaporates from the solution, the ammonium hydroxide escapes as water vapor and ammonia gas. The name 'ammonia water' is a good way to describe a solution of ammonia in water.

Does pressing ammonia gas into water produce a chemical reaction? This is just as tough a question as the similar one with carbon dioxide. We can not isolate pure ammonium hydroxide, but the solution is alakli and further reactions can happen with the ammonium ion in solution.

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METHANE

Methane, CH_4, is the smallest of the hydrocarbons, those organic materials made of only carbon and hydrogen.

It has been known as 'swamp gas,' a name that comes from the most obvious place to see it. The bottom of swampy areas, where much organic material from dead plants and animals sinks, is the place where bacterial action breaks down the complex biological materials to smaller molecules. The bacteria make their living that way. Many of these bacteria are anaerobic, that is, they are either inhibited or killed by the presence of free oxygen. Methane is one of the products of the metabolism of the bacteria. If you see a release of gas from the bottom of a swamp, light it. If it burns, it is likely methane. Once swamp air was thought to be the cause of malaria (*mal* - bad, and *aria* - air in Italian) and there was a considerable effort to study methane from the swamps. As you know, methane does not cause malaria, but is a pretty good fuel.

Swamps are not the only source of methane. Some materials that do not easily digest in people and animals may be handled by bacteria in the intestines. Legumes (beans) are notorious for having indigestible portions that react this way, somewhat idiosyncraticly, with people. Some dogs have a difficult time digesting the cereals in inexpensive dog foods, and they may develop a case of the winds from it.

Cattle have four stomachs for the fermentation and digestion of even more difficult foods. Even so, there are many things that the digestive system of cattle cannot handle, so bovine burps have a high percentage of methane in them. Methane from cow burps has been called a major pollutant of the earth's atmosphere. It seems there ought to be a way to collect that and not only have a new source of fuel and clean the atmosphere in the process. Methane is slightly lighter than air, so collection bags on the backs of cattle would stand up from the beasts, but methane is not so much lighter than air that we have to fear floating cattle. |8-)

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PROTEIN

The white of an egg is almost all water and protein. The water does not change significantly on cooking. The protein does. What is a protein? Here is a rather simplified answer. A protein is a very large molecule of repeating base units on which are attached various side units. A single amino acid has an amino side (-NH2 with the nitrogen attached to a carbon) and a carboxylic acid side (-COOH with the carbon attached to another carbon). The amino end of one amino acid is attached to the acid end of the next amino acid. The 'backbone' of this huge molecule is the -N-C-C-O- series of each amino acid. Each protein has a bare minimum of thirty amino acids in it, usually several hundreds, if not thousands, of amino acids. If a string of amino acids has less than thirty or so amino acids, biochemists call the string a polypeptide. There are about twenty different types of amino acid. Every protein made by an individual has exactly the same amino acids in exactly the same place. The pattern for each protein in the body of a living thing is one of the important bits of information passed down from generation to generation in genetic material.

The main idea we need to understand is that each protein is very large, and that each protein has to be exactly right or it will not do what it needs to do. Cooking does not usually destroy the actual molecular formula for a protein, but it destroys the shape of the protein from how it was folded and re-connected and related to the environment around it. The process of destroying the useful shape of a protein is called denaturing. Cooking is only one of the ways to denature protein. Adding acid or salt or lye (base) to the protein can also denature the protein and these processes also tend to kill bacteria and other things that would attack the protein. Salting pork or fish were the best ways to preserve these foods at one time. The proteins of milk curdle as they denature in the acid of cheese. The starch is opened up and the protein, what little bit there is, is denatured in corn when it is mixed with lye for hominy. After denaturing, proteins are not useful for whatever they were made, but only as food for something else. The animal that eats the protein breaks it down (digests it) into the individual amino acids and can use the amino acids as a source of energy or as a source of raw materials (amino acids) for building its own proteins. (Most plants make their own amino acids.)

Is cooking an egg (denaturing a protein) a chemical reaction? Possibly, but it certainly is a biochemical reaction. The same obviously goes for a steak or any other source of protein.

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SOAP

Soap is made from neutral fat and lye. Sodium lye (sodium hydroxide solution) or potash lye (potassium hydroxide in solution) when boiled with neutral fats make glycerine and soap. A molecule of neutral fat is split into one molecule of glycerine and three molecules of fatty acids, twelve to twenty-two carbon chains of fat-soluble end and an organic acid end that attracts the sodium or potassium in an ionic bond.

Soap making is an old technology from home chemistry. The fire place of a home would be the source of heat and the cooking area. The meat cooked over the flame would drip fat into a collecting pan. Ashes from the fire have a small amount of lye in them. The ashes were washed with water and the lye was concentrated by boiling most of the water out. The fat and lye were put into a large kettle and boiled to make soap. It takes some experience for a soapmaker to get it right. If too much fat is added, the soap can be too oily to use. If too much lye is added, the soap will be caustic on skin and hair. The strong alkalai of lye destroys protein. Now you know the origin of the famous, 'Grandma's lye soap that will eat your face off.'

Glycerine is a by-product of the soap-making reaction. (A by-broduct is another material made that is not the main material desired from the reaction.) Glycerine is an edible, sweet-tasting, oily liquid that dissolves in water and many oils. Glycerine may be used as an antifreeze or as a hair dressing.

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GELATIN

Have you ever seen soup bones for sale at the meat counter of a market? Meat soups are made by gently simmering some of the less meaty abatoir products. Bones, sinew, cartilege, and some meat make excellent soup.

Simmering is cooking in water by heating to just below the boiling point, usually for several hours. Hot water leaches out proteins from bones and cartilege that make a colloidal suspension in the liquid. If you take that liquid with enough suspended protein and refrigerate it, the mixture becomes a gel. The semi-solid nature of the gel suggests that at one point there has been a change in the mixture from the protein being the dispersant and the water a dispersing agent to the water being trapped within a loose protein structure. In short, the gel has set. The gel made this way is called *gelatin*. You can find gelatin in the drippings of meat cooked in other ways also.

Gelatin desserts are just the leached protein, some coloring, flavoring, and some sugar. Is it true, then, that gelatin desserts are good sources of protein? Well, maybe.

The proteins of bones and cartilege are structural proteins. In bone the protein serves as a support lattice-work for the hardening crystals of (mostly) calcium compounds that give more rigidity to bones. This type of protein has only a few of the amino acids that occur in proteins useful for such things as enzymes and muscles. The amino acids in gelatin are all produced by the human body. The *essential amino acids*, those that can not be produced by the human body are not present in gelatin in any significant quantity. For this reason, we call gelatin a source of x x x protein.

Gels are interesting mixtures. You might say that the liquid and solid phase of a colloidal suspension undergo a change wherein the roles of the phases have reversed. The solid becomes the strucural entity and the liquid becomes the dispersed portion. A true gel will have a 'ring' to it. You can see this in the 'wiggle' of gelatin. Many commercial toothpastes, hand cleaners, and shampoos are gels. Firmly slap these into the palm of your hand to feel the gel ring. The reason for offering the public these commercial preparations in the form of a gel is that there is less likelyhood of separation of the materials or settling of the suspended portions.

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ALKALI FLATS

Many years ago there was a large shallow salt sea in the western portion of what is now the United States. The Bonneville Salt Flats and the Great Salt Lake are almost all that remains of that sea. There are a few other places, mostly in desert areas in which a small amount of water may remain with a lot of the concentrated salts from that ancient sea. They are flat areas because they were the bottom of the sea. There is an excess of the alkaline salts in these areas called "alkali flats."

During the last two centuries of expansion of the United States toward the west, many land travellers and explorers have found themselves attempting to cross the desert areas on foot or by animal transport, only to run across the alkali flats. The water from the pools in these areas are full of poisonous alkali salts. The caricature drawing of these alkali pools has a sun-dried skeleton or a sun-dried skull lying about near the pool, but such obvious warning was not always there. Many a thirsty traveller learned too late that the alkali pools were dangerous.

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EXPLANATION OF ACID - BASE PROBLEMS

TITRATION AND pH PROBLEMS

THE FOLLOWING SALTS IN WATER SOLUTION WILL HAVE A pH OF 7, -7(less than 7), +7(more than 7), OR INDETERMINATE (I). FOR EACH PREDICT THE pH OF THE SOLUTION.

1. Na_2CO_3 is a basic salt because NaOH is a strong base and H_2CO_3 is a weak acid. pH is above 7.

2. $FeCl_3$ is an acid salt because $Fe(OH)_3$ is weak base and HCl is a strong acid. pH is less than 7.

3. KNO_3 is a neutral salt. Both HNO_3 and KOH are strong. pH = 7.

4. $NH_4C_2H_3O_2$ is indeterminate. Both NH_4OH and $HC_2H_3O_2$ are weak. pH is actually only a very little above 7.

5. $ZnSO_4$ is an acid salt. The first ionization of H_2SO_4 is strong and $Zn(OH)_2$ is weak. pH is less than 7.

6. $Ba(NO_3)_2$ is neutral because both $Ba(OH)_2$ and HNO_3 are strong. pH = 7.

7. RbF is an alkaline salt because RbOH is strong and HF is weak. pH is over 7.

8. $CaBr_2$ is neutral because both $Ca(OH)_2$ and HBr are strong. pH = 7.

Back to the Acid and Base math problems.

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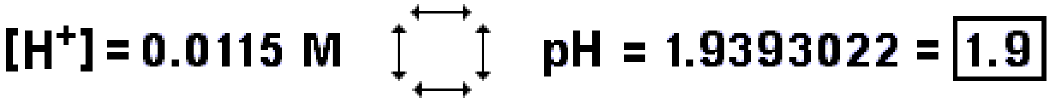
9. What is the pH of a 0.0115 M HCl solution?

The only two materials in the solution are water and HCl. The water alone would provide 1 E-7 Molar hydrogen ion. The HCl is a strong and soluble acid, so all of the acid is in the form of ions, providing 0.0115 Molar hydrogen ion. There is no need to consider the hydrogen ion from water as it is much less than five percent of the total hydrogen ion concentration. The concentration of hydrogen ion is adequately estimated at 0.0115 M. This is only a pH box problem. (Note the symbol Chemtutor uses for pH box math.) As a final answer, Chemtutor suggests rounding pH values to one decimal place. Few pH meters are that accurate.



$$[H^+] = 0.0115\ M \qquad pH = 1.9393022 = \boxed{1.9}$$

Back to Acid and Base math problem #9.

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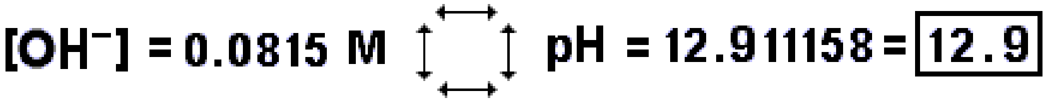
10. Find the pH of 0.0815 M NaOH solution.

The only two materials in the solution are water and NaOH. The water alone would provide 1 E-7 Molar hydroxide ion. The NaOH is a strong and soluble base, so all of the base is in the form of ions, providing 0.0815 Molar hydroxide ion. The hydroxide ion is most important in this problem. The hydroxide ion from the dissociation of water is much less than five percent of the hydroxide ion from sodium hydroxide, so the concentration of hydroxide ion is 0.0815 M. This is only a pH box problem. The answer has been rounded to one decimal place.



$$[OH^-] = 0.0815\ M \qquad pH = 12.911158 = \boxed{12.9}$$

Back to Acid and Base math problem #10.

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11. Find the pH of 0.00372 M $Ba(OH)_2$ solution.

$Ba(OH)_2$ is a strong base, that is, up to its solubility limits the compound will be completely ionized in water solution. $[(OH)^-]$ is twice the $[Ba(OH)_2]$ because for each mol of $Ba(OH)_2$ there are two mols of hydroxide ion. The ionization of water, the only other possible source of hydroxide ions, produces nowhere near five percent of the hydroxide ion available from $Ba(OH)_2$, and so:

$$[(OH)^-] = 2\,[Ba(OH)_2] = 2\,(0.00372\text{ M}) = 0.00744\text{ M}$$

Now that we know the $[(OH)^-]$, this is only a pH box problem. The answer is in pH, so it is rounded to one decimal place.

$$[OH^-] = 0.00744\text{ M} \leftrightarrow \text{pH} = 11.871573 = \boxed{11.9}$$

Back to Acid and Base math problem #11.

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12. Find the pH of 0.12 M $HC_2H_3O_2$

The only two things in this solution are water and acetic acid, a weak acid. The k_A of acetic acid is 1.74 E-5. Water and acetic acid could contribute hydrogen ion to this mixture. If water were the only possible contributor, it would give 1 E-7 M hydrogen ion. If the acetic acid were the only contributor, we could calculate it from the equilibrium expression. Since the hydrogen ion from the acetic acid would be exactly the same concentration as the acetate ion, $[H^+] = [(C_2H_3O_2)^-]$. And we can simplify by substituting $[H^+]^2$ for $[H^+]\,[(C_2H_3O_2)^-]$.

original equilibrium expression — simplified

$$k_A = \frac{[H^+][(C_2H_3O_2)^-]}{[HC_2H_3O_2]} = \frac{[H^+]^2}{[HC_2H_3O_2]}$$

solved for the square of H ion concentration

$$[H^+]^2 = k_A\,[HC_2H_3O_2]$$

solved for H ion concentration

$$[H^+] = \sqrt{k_A\,[HC_2H_3O_2]}$$

Now we can substitute our numbers for the k_A and $[HC_2H_3O_2]$ to find that $[H^+]$ = the square root of (0.12 x 1.74 E-5). The $[H^+]$ due to acetic acid is 1.4450 E-3 M.

substitute numbers for symbols — do the math

$$[H^+] = \sqrt{(1.74\text{ E-5})(0.12)} = 1.4450\text{ E-3 M}$$

The $[H^+]$ from the acetic acid is less than five percent of the [acetic acid], so there is no need to get a more accurate answer by subtracting the $[H^+]$ from the [acetic acid]. After finding the $[H^+]$, we calculate the pH by using the pH box. The pH is 2.840134, rounded to 2.8.

$$[H^+] = 1.4450\text{ E-3 M} \leftrightarrow \text{pH} = 2.840134 = \boxed{2.8}$$

Back to Acid and Base math problem #12.

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13. Calculate the pH of 0.0000135 M H_3BO_3

Oh, no. We have a complication. H_2CO_3 has such a small k_A (5.37 E-10 for the first ionization) and the acid is in such small concentrations that the $[H^+]$ from the acid will be not much more than the $[H^+]$ from the ionization of water. The other possible sources of $[H^+]$ are the second and third ionizations of the boric acid, but they both have k_A's that are far from the first ionization, so they should not be of any significance.

What you would find, if you assume the ionization of water to be negligible, is a silly answer. You try it. Use the standard square root of (k_A times $[H_3BO_3]$). You get a pH OVER seven. (pH = 7.1) Ridiculous. Boric acid is an acid and should result in a pH of less than seven.

There are several ways to do this. One way is by successive approximations. First use the ionization constant formula to calculate the $[H^+]$ from the acid, then use that $[H^+]$ to find the $[OH^-]$. Since the $[H^+]$ from water equals the $[OH^-]$, you can add that number back to the $[H^+]$ from the acid to get a first round total $[H^+]$. Use the first round total $[H^+]$ in the acid dissociation equation to find the concentration of acetate ion and that would be equal to the second round estimation of the $[H^+]$ from acid. Keep going around that circle until you get three stable significant digits for the total $[H^+]$.

Another way is by substitutions into known equations. Your equations are the formula for the k_W, the formula for the $[H^+]$ of a weak acid, the equality of the $[H^+]$ from water with the $[OH^-]$, and the statement that the total $[H^+]$ equals the $[H^+]$ from water plus the $[H^+]$ from the ionization of the acid.

equation for $[H^+]$ of a weak acid

$$[H^+_A] = \sqrt{k_A\,[H_3BO_3]}$$

total $[H^+]$ = $[H^+_T] = [H^+_W] + [H^+_A]$

and

$[H^+]$ from water = $[H^+_W] = [OH^-]$

equation of the Kw $[H^+_T][OH^-] = 1E\text{-}14$

substitute for the $[H^+_T]$

$$\left(\sqrt{k_A\,[H_3BO_3]} + [OH^-]\right)[OH^-] = 1E\text{-}14$$

and you have a quadratic equation in $[OH^-]$

$$[OH^-]^2 + \sqrt{k_A\,[H_3BO_3]}\,[OH^-] - 1E\text{-}14 = 0$$

Or you could substitute in for the $[OH^-]$ ion and solve for the $[H^+]$.

Drop the numbers in and do the math. It is messy and tedious and disgusting to have to use the quadratic equation, but it will give you and answer of $[OH^-]$ = 6.6115 E-8 which results in a pH of 6.8203, rounded to 6.8, a likely answer.

Back to Acid and Base math problem #13.

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14. pH of 0.255 M NH_4OH

The k_B of NH_4OH is 1.78 E-5.

The ionization equilibrium expression for NH_4OH or any other weak base is similar to the ionization equilibrium expression for a weak acid, but this time the equation will be solved for the hydroxide ion concentration.

The hydroxide ion is in excess. The two sources of hydroxide ion are the $[H^+]$ and water, but the contribution from the water is negligible.

The other assumption, that the amount of dissociated ion is negligible, is also valid because the concentration of base is so large. (Try it if you don't believe it.)

original equilibrium expression simplified

$$k_B = \frac{[NH_4^+][OH^-]}{[NH_4OH]} = \frac{[OH^-]^2}{[NH_4OH]}$$

solved for the square of OH ion concentration

$$[OH^-]^2 = k_B\,[NH_4OH]$$

solved for OH ion concentration

$$[OH^-] = \sqrt{k_B\,[NH_4OH]}$$

Now substitute the numbers and do the math.

substitute numbers for symbols do the math

$$[OH^-] = \sqrt{(1.78\text{ E-}5)(0.255)} = 2.1305\text{ E-}3\text{ M}$$

$$[OH^-] = 0.0021305\text{M} \longleftrightarrow \text{pH} = 11.3285 = \boxed{11.3}$$

Back to Acid and Base math problem #14.

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15. 0.578 M H_3PO_4

In a solution that has only water and phosphoric acid there are four possible sources of hydrogen ion, the water and the three ionizations of the phosphoric acid. Each ionization has a different k_A.

$H_3PO_4 \longrightarrow (H_2PO_4)^- + H^+$	first ionization	$k_A = 6.92\text{ E-}3$
$(^- \longrightarrow (HPO_4)^{2-} + H^+$	second ionizaton	$k_A = 6.17\text{ E-}8$
$(HPO_4)^{2-} \longrightarrow (PO_4)^{3-} + H^+$	third ionization	$k_A = 2.09\text{ E-}12$

It is clear that the first ionization of phosphoric acid at this concentration is much greater than the third ionization of phosphoric acid, but the big questions are whether we need to consider the second ionization of phosphoric acid or the ionization of water.

The hydrogen ion concentration from the first ionization can be calculated by the usual square root of ([acid]k_A) to get an initial estimate.

$$[H_1^+] = \sqrt{k_{A1}[H_3PO_4]}$$

$$[H_1^+] = \sqrt{(0.578)(6.92E\text{-}3)} = 0.063243656$$

From the initial estimate, the $[H^+]$ from the first ionization (0.063243656 M) will be more than 5% of the acid concentration (0.578 M). We will have to use the more accurate form of the equation that includes the decrease in unionized acid concentration by the ionized forms.

Will we have to also account for the second ionization? The number we found as first estimate for the $[H^+]$ can also serve as estimate of the $[H_2PO_4)^-]$, the anion in the first ionization. But the anion of the first ionization is the original acid in the second ionization and the estimate of the $[H^+]$ can also be used in the second ionization equation. If we solve for the anion of the second ionization equation, we would get an estimate of the hydrogen ion that the second equation would produce.

$$k_{A2} = \frac{[H_1^+][(HPO_4)^=]}{[(H_2PO_4)^-]}$$

$$[H_2^+] = [(HPO_4)^=] = \frac{k_{A2}[(H_2PO_4)^-]}{[H_1^+]}$$

$$\text{since } [H_1^+] \cong [(H_2PO_4)^-]$$

$$[H_2^+] \cong k_{A2} \cong 6.17\ E\text{-}8$$

This is an interesting result. Notice the $[H^+]$ from the second ionization is very close to the second k_A when there is nothing but water and phosphoric acid in the solution. What would happen at other concentrations of phosphoric acid? At other pH's whith the same initial concentration of phosphoric acid?

The concentration estimate of the hydrogen ion from the second ionization is far below 5% of the hydrogen ion from the first ionization, so the second ionization does not need to be considered. But we do need to consider the decrease in acid concentration from ionization of the first reaction, so we use the quadratic form of the equation substituted into the quadratic equation.

$$[H^+]^2 + k_A[H^+] - k_A[HA] = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$[H^+] = x \qquad k_{A1} = b$$

$$-k_{A1}[HA] = c \qquad 1 = a$$

When you substitute the numbers, the math looks like:

$$[H^+] = \frac{-(6.92E-3) \pm \sqrt{(6.92E-3)^2 + 4(0.578)(6.92E-3)}}{2}$$

As you can see when you do the math, the $[H^+]$ is 0.059878231, more than 5% different from the original estimate. Now we can confidently change that $[H^+]$ to the pH by the pH box.

$$[H^+] = 0.059878231 \quad \leftrightarrow \quad pH = 1.22273 = \boxed{1.2}$$

If you are really sharp, you noticed that the original estimate using the simplified method of calculating the $[H^+]$ produces the number 0.063243656, and that the pH of that $[H^+]$ is the SAME as the number from the more complex calculation when rounded to one decimal point.

Back to Acid and Base math problem #15.

16. What is the pH of 0.16 M HCl and 0.072 M phosphoric acid?

There are five sources of hydrogen ion in this solution. Count them. Water, HCl, and the three ionizations of the phosphoric acid. Likely the water and the lesser two of the three ionizations of phosphoric acid will not significantly contribute to the hydrogen ion concentration.

Since the HCL is a strong acid, it contributes 0.16 Molar hydrogen ion to the solution, but the phosphoric acid is a weak acid and the $[H^+]$ from it can not calculated by the square root of (k_A $[H_3PO_4]$) because the $[H^+]$ is not equal to the $[H_2PO_4]$. We must go back to the ionization equilibrium equation for the first ionization of phosphoric acid.

$$k_{A1} = \frac{[H_T^+][(H_2PO_4)^-]}{[H_3PO_4]}$$

We can look up the k_A. The $[H^+]$ is the same as the [HCl], and the concentration of phosphoric acid is given. The $[H_2PO_4]$ will be equal to the concentration of hydrogen ion contributed by the first ionization of the phosphoric acid.

$$k_{A1} = \frac{[H_T^+][(H_2PO_4)^-]}{[H_3PO_4]}$$

$$[H_1^+] = [(H_2PO_4)^-] = \frac{k_{A1}\ [H_3PO_4]}{[H_T^+]}$$

$$[H_1^+] = \frac{(6.92E-3)(0.072)}{0.16} = 3.114E-4$$

So the pH depends only on the [HCl].

$$[H^+] = 0.16 \Leftrightarrow \text{pH} = 0.79588 = \boxed{0.8}$$

Back to Acid and Base math problem #16.

---

17. Find the pH of 1.25 M acetic acid and 0.75 M potassium acetate.

Acetic acid k_A = 1.74 E-5 pK_A = 4.76.

This is a genuine buffer problem. Added to the water are a weak acid and a salt containing the anion of the acid.

There are two good ways to work buffer problems, with the Henderson- Hasselbach equation or with the ionization equilibrium expression of the weak acid or base. I personally have a mental block against the H-H equation because I can never remember whether it uses a positive or negative log and which concentration goes on top. You can use it if you wish. Particularly if you need to calculate buffers often, you should engrave it upon your gray matter. If you really need it and can't remember it, you can derive it from the ionization equlilbrium expression.

There are three cautions you need to observe with either equation: (1) Make sure you are using the correct concentration for each variable, (2) check to see if the numbers you propose to use are going to be within the

5% rule for simplification, and (3) estimate the answer from what you know and make sure your final answer is reasonable.

Before actually doing the problem, estimate the answer from your own reasoning. In this case, the pkA of acetic acid is 4.76. The rule is that an equimolar buffer has a pH equal to the pkA and in this problem there is less potassium acetate than acetic acid, so the pH must be lower (more acid) than the pkA within a pH unit or so. If the acetic acid were the only solute, the pH estimate would be the square root of (acid concentration times kA).

$$[H^+] = \sqrt{k_A\,[HC_2H_3O_2]} = \sqrt{(1.74\ E\text{-}5)(1.25)}$$

$$[H^+] = 0.00466369 \ \longleftrightarrow\ pH = 2.3313$$

The answer should be somewhere between pH of 2.3 and 4.8

The majority of the acetate ion will be from the potassium acetate. Is it right that the total acetate ion concentration will be equal to the concentration of the potassium acetate? Or will the acetate ion concentration from the ionization of the acetic acid contribute more than 5%? The potassium acetate concentration is 0.75 M. The acetate ion concentration from acetic acid would be 0.00466 M, less than 5% of 0.75 M even without the common ion effect. We can safely use 0.75 as the concentration of acetate ion.

Will the concentration of unionized acid be a problem? The measured concentration is 1.25 M and the ionized amount is 0.00466 M, far less than 5% of 1.25 M.

As threatened, we can use the ionization equilibrium expression of acetic acid for the main equation for this problem, substituting for the kA, substituting the concentration of potassium acetate for the concentration of acetate, substituting the concentration of acetic acid, and solving for the hydrogen ion concentration to get the pH.

original equilibrium expression

$$k_A = \frac{[H^+][(C_2H_3O_2)^-]}{[HC_2H_3O_2]}$$

$$[H^+] = \frac{k_A\,[HC_2H_3O_2]}{[(C_2H_3O_2)^-]} = \frac{(1.74\ E\text{-}5)(1.25)}{0.75}$$

$$[H^+] = 0.000029 \ \longleftrightarrow\ pH = 4.5376 = \boxed{4.5}$$

The answer of pH = 4.5 is a reasonable one by our estimation because it is more acid than the pkA of 4.76.

It is a little easier to do this problem by the Henderson- Hasselbach equation, if you are sure you know it. You must still make sure you are substituting correctly and that your assumptions for simplification are valid (within

5%). The H-H equation is not much good for solutions in which either the acid or ion concentrations are more than ten times one another or in which the concentration of either material is less than one hundred times the kA because it doesn't easily adapt to a quadratic form.

$$pH = pK_A - \log\frac{[HA]}{[A^-]}$$

$$pH = 4.76 - \log\frac{1.25}{0.75}$$

$$pH = 4.76 - 0.222$$

$$pH = 4.538 = \boxed{4.5}$$

Back to Acid and Base math problem #17.

---

18. 0.788 M lactic acid and 1.27 M calcium lactate.

Lactic acid kA = 8.32 E-4   pKA = 3.08.

Here is another acid - conjugate base buffer pair. This time there is more conjugate anion than acid concentration, so we expect the pH to be somewhat higher (more alkali) than the pKA. As in the previous problem, there seems to be no complication with either of the components being of too small a concentration or the concentrations being too close to the KA, so there should be no need for a quadratic equation.

The concentration of calcium lactate needs to be doubled (!) to represent the lactate ion concentration because the calcium is divalent and has two lactate ions per formula of calcium lactate. The concenration of acid is more than 100 times the KA, so the concentration of acid is close enough to the concentration of unionized species.

By the ionization equilibrium equation:

equilibrium expression

$$k_A = \frac{[H^+][L^-]}{[HL]} \qquad L^- = \text{lactate ion}$$

$$[H^+] = \frac{k_A[HL]}{[L^-]} = \frac{(8.32E\text{-}4)(0.788)}{2.54}$$

$$[H^+] = 0.0002581 \updownarrow \overset{\longleftrightarrow}{\underset{\longleftrightarrow}{\quad}} \updownarrow pH = 3.5882 = \boxed{3.6}$$

Or by the H-H equation, you get the same answer.

$$pH = pK_A + \log \frac{[L^-]}{[HL]}$$

$$pH = 3.08 + \log \frac{2.54}{0.788}$$

$$pH = 3.08 + 0.50831$$

$$pH = 3.58831 = \boxed{3.6}$$

Back to Acid and Base math problem #18.

---

19. 0.590 M ammonium hydroxide and 1.57 M ammonium chloride.

ammonium hydroxide k_B = 1.78 E-5 pK_B = 4.75.

Here we have a weak base and its conjugate cation. We can use the ionization equilibrium expression, but it is different from the acid ionization expression. The ammonium hydroxide ionizes into hydroxide ion and ammonium ion, so it would be best to find the concentration of the hydroxide ion.

The ionization equilibrium expression must have the k_B rather than a k_A, or the Henderson- Hasselbach equation has to have all its components adapted to alkali, but it is completely analagous to the acid calculation. In either way of doing the problem, you will have to change the answer to the pH by the pH box.

Will we be able to use our standard shortcuts? The concentration of base is more than 100 times the k_A, so the measured amount of ammonium hydroxide in solution is a good enough number for the concentration of unionized species. The concentration of weak base and conjugate ion will be within 1:10 of each other, so the amount of conjugate ion can be adequately estimated by the concentration of ammonium chloride. There is high enough concentration of the base so that the ionization of water does not significantly change the hydroxide concentration.

original equilibrium expression

$$k_B = \frac{[NH_4^+][OH^-]}{[NH_4OH]}$$

$$[OH^-] = \frac{k_B\,[NH_4OH]}{[NH_4^+]} = \frac{(1.78\,E\text{-}5)(0.590)}{1.57}$$

$$[OH^-] = 6.68917\,E\text{-}6 \;\rightleftarrows\; pH = 8.8254 = \boxed{8.8}$$

Or by the H-H equation, you get the same answer.

$$pOH = pk_B + \log\frac{[\text{conjugate cation}]}{[\text{base}]}$$

$$pOH = 4.75 + \log\frac{1.57}{0.59}$$

$$pOH = 4.75 + 0.4250476$$

$$pOH = 5.17505 \;\rightleftarrows$$

$$pH = 8.82495 = \boxed{8.8}$$

Does the answer make sense? The combination is a base buffer and the pH is slightly base. There is almost three times the concentration of ammonium chloride than ammonium hydroxide, so the pH of the mixture is more acidic than it would be if the buffer had been equimolar. (pH = 9.25)

Back to Acid and Base math problem #19.

---

20. Explain how to make 5 L of 0.15 M acetic acid-sodium acetate buffer at pH 5.00 if you have 1.00 Molar acetic acid and crystaline sodium acetate.

Here is a problem you may have to actually use one day. In biochemistry some enzymes need to be at a particular pH to work at maximum. You would choose a weak acid with a pkA close to the pH you need. (The pkA of acetic acid is 4.76.) The osmolarity (the total molar amount of dissolved materials) may be specified. (It is here. The total of acetic acid and sodium acetate should be at 0.15 Molar.)

It is most convenient to use the Henderson - Hasselbach equation for this, as it has a term that can be the ratio of the two materials. The form of the H-H equation does not matter, but the concentration of the conjugate ion will have to be greater than the concentration of the acid because the pH is greater than the pk_A of the weak acid.

$$pH = pk_A + \log\frac{[A^-]}{[HA]}$$

$$pH - pk_A = \log\frac{[A^-]}{[HA]}$$

$$\log\frac{[A^-]}{[HA]} = 5 - 4.76$$

taking the antilog of both sides

$$\frac{[A^-]}{[HA]} = 1.7378$$

What we get from the H-H equation is the ratio of the two constituents. We can use that ratio as one of the equations in a two - equation - two - unknown setup to substitute one into the other and calculate the concentration of acetic acid, [HA], and the concentration of sodium acetate, $[A^-]$.

$$\frac{[A^-]}{[HA]} = 1.7378$$

$$[A^-] + [HA] = 0.15$$

$$1.7378[HA] + [HA] = 0.15$$

$$2.7378[HA] = 0.15$$

$$[HA] = 0.0547885\ M$$

$$[A^-] = 0.0952115\ M$$

But we still have not answered the question, "Explain how to make 5 L of pH 5, 0.15 M acetic acid-sodium acetate buffer." We have a 1.00 Molar solution of acetic acid and crystals of (solid) sodium acetate. The way we have to measure the acetic acid is by measuring the volume of the more concentrated solution. The way to measure the sodium acetate is to weigh it. We would need (54.7885 x 5 = 273.9425) ml of acetic acid and (82.04 x 0.0952115 x 5 = 39.055757) grams of sodium acetate.

$$\left(\frac{0.0952115\,\cancel{\text{mol}}}{\cancel{\text{L}}}\right)\left(\frac{82.04\,\text{g}}{\cancel{\text{mol}}}\right)\left(\frac{5\,\cancel{\text{L}}}{1}\right) = 39.055757\,\text{g} = \boxed{39.1\,\text{g}}$$

$$\left(\frac{0.0547885\,\cancel{\text{mol}}}{\cancel{\text{L}}}\right)\left(\frac{\cancel{\text{L}}}{1\,\cancel{\text{mol}}}\right)\left(\frac{5\,\text{L}}{1}\right) = 0.2739425\,\text{L} = \boxed{274\,\text{mL}}$$

The real answer is that you need to weigh 39.1 g of sodium acetate, measure 274 ml of the 1.00 Molar acetic acid and put them into a 5 liter volumetric flask with enough water to dissolve the sodium acetate. Then fill the volumetric flast to the line with distilled water and mix the solution.

Back to Acid and Base math problem #20.

FOLLOWING ARE TITRATION PROBLEMS. ASSUME THAT THE pH INDICATOR WILL BE THE RIGHT ONE TO BALANCE THE AMOUNT OF ACID AND BASE. SOME OF THE TITRATIONS ARE NOT ACID - BASE TITRATIONS. AGAIN ASSUME THERE IS AN INDICATOR THAT WILL TELL WHEN MOLAR AMOUNTS ARE MATCHED.

21. 23.45 mL of 0.275 M sodium hydroxide was used to titrate against mL of acetic acid. What was the concentration in M of acetic acid?

22. 17.05 mL of 0.247 M barium hydroxide was used to titrate against 10 mL of nitric acid. What was the concentration in M of nitric acid?

23. 35.79 mL of 0.275 M sodium hydroxide was used to titrate against 15 mL of sulfuric acid. What was the concentration in M of sulfuric acid?

24. 24.92 mL of 0.00199 M silver nitrate was used to titrate against 5 mL of sodium chloride solution. What was the concentration of NaCl?

ANSWERS TO PROBLEMS

21. 1.29 M **<22. 0.842 M>** **23. 0.328 M** **24. 9.92 E-3 M**

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the quadratic equation

where $ax^2 + bx + c = 0$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

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Sachertorte, or the Chocolate Cake That Ate Cincinnati

The sachertorte is a rich cake that originated in the Hotel Sacher in Vienna, Austria in the late eighteenth century. It asks to be eaten with a generous dollop of REAL whipped cream on a thin slice of the cake and a cup of coffee. You may take the coffee with or without sugar, but the Viennese tradition is to lighten the coffee with another generous dollop of the same whipped cream. It has absolutely no calories if you eat it quickly enough. $|8-)

1 cup (one-half pound)(250 ml) real butter
1 cup (250 ml) table sugar
8 large eggs
1 cup (250 ml) flour
8-9 oz (250 g) semisweet chocolate
    (Buy two 12 oz (340g) packages for one cake and the icing. Or three for two cakes.)
half tablespoon (5 grams) baking powder
8-9 oz (250 g) apricot preserves
    (Buy a large (half liter) jar for two cakes. You can't let a cake become lonely.)

Separate the eggs. (Do not let ANY of the egg yellow get into the white.) In an absolutely clean (free of fat) mixing bowl and with a clean beater, whip the egg whites until the peaks are stiff. Set the beaten egg whites aside (not over 20 minutes).

Warm the chocolate in a double boiler. Cream the butter in the mixer. Add the sugar to the mixing bowl and mix. Add the egg yellows one at a time into the mixing bowl as the beater continues. Add the melted chocolate, continuing to mix. Sift the flour with the baking powder in it.

Butter and flour a springform baking pan. Preheat the oven to 350 ° F (175 ° C). When the oven is heated, gently stir in the flour and baking powder mixture. Do not over-stir. GENTLY and quickly fold the beaten egg white into the dough. Pour the mixture into the prepared springform pan. Bake at 350°F (175 ° C) for one hour. Remove the cake from the oven and place upside down onto a dinner plate. Leave the springform on the cake, but gently loosen the cake from the sides of the pan by opening the springform and gently tapping the (upside down) bottom. Leave the cake to cool or almost cool.

When the cake is relatively cool, remove the springform, cut the cake in half (make two thin cylinders), and slather the apricot preserves onto the lower half still in the plate. Reattach the top half of the cake and apply frosting.

If you have cut the cake to serve it and you wish to save the rest of the cake for another day, it is a good idea to rewarm any leftover frosting you might have and apply it to the cut surfaces of the cake.

Chocolate Icing (Frosting)

This recipe makes icing for 1.5 cakes with generous icing or two cakes with thin frosting.

1 cup (250 ml) table sugar
15 oz (450 g) semi-sweet chocolate
2 pats butter

Warm the chocolate in a double boiler. To exactly a cup (or exactly 250 ml) of sugar in a Pyrex® measuring cup, add just enough very hot or boiling water to bring the volume back up to the original mark of the sugar volume. Stir until most of the sugar dissolves. Heat in a microwave on high for several minutes or until all the sugar has been dissolved. The sugar should be slightly supersaturated at room temperature, but you should never let it get there. There should be slightly less syrup than your original measurement of sugar. Let the syrup cool a bit to be just about the same temperature as the chocolate. With a whisk, briskly stir the chocolate as you pour in the syrup, very slowly at first. Continue to heat the chocolate on the double boiler as you mix. By the time you finish pouring the syrup, the mixture should be smooth and consistent. If it is not smooth after some mixing with a whisk, add SMALL amounts (drops) of water and mix until it becomes smooth. Add the two pats of butter when it is smooth and continue to stir. When the icing begins to skin over when you quit stirring, it is ready to coat the cake.

Move quickly with the icing. Pour it over the top of the cake and very quickly move it around to cover the top. By that time, the icing should be a little more viscous and ready to adhere to the sides of the cake. Dribble the icing down from the top of the cake or pat it onto the sides of the cake, but completely cover the cake in icing. The icing does not swirl or mix around very much. It should harden in place fairly quickly.

When the icing is thoroughly hardened (about six hours), slice thin pieces and serve with real whipped cream and coffee.

Return to cake recipe.

Whipped Cream

The real secret to making good whipped cream is to start with COLD whipping cream. If there are a few ice crystals in the cream, that's good. If you can cool the mixing bowl and beater in the freezer before whipping, that helps also. If you whip the cream in the classic style, in a bowl with a whisk, you can place the bowl on a bed of ice.

To make Viennese whipped cream, add about 20 grams of table sugar to a half liter of cream as it just begins to froth. (That is two heaping tablespoons of sugar to a pint of cream.)

Return to cake recipe.

Mixing the Chocolate with the Syrup

Here is an interesting operation. You will be adding a water solution of sucrose (table sugar) into an oil solution or suspension of melted chocolate.

As you pour in the first few drops of syrup into the chocolate, it takes some stirring to make the two liquids mix. Once they are mixed, the two liquids seem to make a stable mixture. As you continue to pour small amounts of syrup into the chocolate, you will see a thickening of the mixture. At some point, the mixture may become semi-solid. Keep adding syrup and stirring. After the semi-solid state, the mixture will need stirring to become more liquid. You may have to break up the pieces of semi-solid into the fluid mixture. One of the secrets to good mixing is to keep the chocolate and syrup as warm as possible in the top of the double boiler.

The change is from a small amount of a water solution being suspended into an oily fluid to a water solution with the oily chocolate being suspended in it. The mixture is mostly held together by the sugar, a material that will dissolve in either water or oil. I needed to sneak in a chemistry lesson here.

Return to the frosting recipe.

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ANSWER AND DISCUSSION

PROBLEM #1, SET 1 - MOLS

1. How many pennies are in a mole of pennies? How many thousand-dollar bills (k-notes!) is that mole of pennies equal to?

The first part of the problem is easy based on the definiton that a mol of ANYTHING is 6.023 E23 of them. A mol of pennies is 6.023 E23 pennies. This is what is GIVEN in the second part of the question. The second part is just a DA problem because we are going from one amount of money to another.

Pennies (E-2 dollars) to k-notes (E3 dollars) is a metric conversion. Just from the definitions of penny and k-note, we can say that 1kK-note = E5 pennies.

As for any DA problem, begin with what you know. There is no denominator for "GIVEN," so use "1." Use the definition as a conversion factor so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{6.023\ \text{E23 pennies}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{K-note}}{\text{E5 pennies}}\right)} = \overset{\text{ANSWER}}{\boxed{6.023\ \text{E18 K-notes}}}$$

E5 is 100,000. The calculator math is: 6.023 E23 ÷ 100000 =

The math for this problem is not spectacular. Aside from being a good reminder of how to do DA problems, the answer is important for its magnitude. Consider that if we had a mol of pennies, the value of them would be six billion (E9) times a billion (E9) thousand dollar bills(E5 pennies). This gives you some idea that the number for mol is so large that it is incomprehensible to most people. The ease of writing Avogadro's number in the scientific notation system gives us a sense of understanding that number that is really not there.

calculator

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #2, SET 1 - MOLS

2. NO_2 is the molecular formula for nitrous dioxide (also known as nitrogen dioxide). List the information available to you from this formula.

The small formula NO_2 has a lot of information in it. The most basic is that: (a) each formula of nitrous dioxide has one nitrogen atom and two oxygen atoms, (b) the formula weight is 46 g/mol (16 g/mol for each oxygen and 14 g/mol for the single nitrogen in each formula), and (c) the material makes molecules in which the atoms are attached by covalent bonds (because it is two non - metal elements).

(In answer to part a) Each element has one and only one capital letter. Nobelium has the symbol, "No." One capital letter, one element. Carbon monoxide, a compound of one carbon atom and one oxygen atom, is CO, but cobalt, the single atom of an element, is Co. The smaller subscript "2" after the "O" for oxygen indicates that there are two oxygen atoms in the formula. The numbers written in this way refer ONLY to the element just before it OR the group of elements inside the parentheses just before it, such as: $Al_2(SO_4)_3$. In the aluminum sulfate formula the "2" shows two aluminum atoms, the "4" shows four oxygen atoms, and the "3" outside the parehtheses indicates three phosphates, that is, the entire contents of the parentheses must be multiplied by three. The total atom count for aluminum phosphate is two aluminum atoms, three sulfur atoms, and twelve (three times four) oxygen atoms.

(In answer to part b) One of the important lessons of this chapter is the finding of a formula weight. The formula weight is the mass in Atomic Mass Units of one entire formula or the number of grams of material based on the sum of the atomic weights of the atoms in a formula. (The phrase, "formula weight" is the more general term that inculdes the term, "molecular weight." Some materials just don't come in molecules.) The formula weight of a material can be found by adding the atomic weights of the atoms in the a formula of the material. In the case of NO_2, there is one nitrogen at an atomic weight of 14.0 and two oxygen atoms at atomic weights of 16.0 each. When the formulas become larger, such as the blue vitriol in problem #4 m in this set, it might be a good idea to make a list of the atoms in the material such as:
1 Cu ---- 1 x 63.5 = 63.5 g/mol
1 S ------ 1 x 32.1 = 32.1 g/mol
4 O ----- 4 x 16.0 = 64.0 g/mol
10 H --- 10 x 1.0 = 10.0 g/mol
5 O ----- 5 x 16.0 = 80.0 g/mol
____

totals of 21 atoms and 249.6 g/mol in each formula.

(In answer to part c) A metal and a non-metal will usually form an ionic bond. An electron or several electrons from the metal leave the metal, forming a positive ion, and an electron or several electrons can be taken up by the non - metal to form a negativ ion. The resulting (+ and -) ions attract each other in what is called an ionic bond. But NO_2 has not metal element in it. The two non - metals can only bond by sharing electrons in a covalent bond.

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #3, SET 1 - MOLS

3. C_2H_2 is the molecular formula for ethylyne (A.K.A. acetylene). (a) How many atoms are in one molecule? (b) Which atoms make up acetylene? (c) How many moles of atoms are in one molecule of acetylene? (d) How many molecules are in 5.3 moles of acetylene? (e) How many atoms are in a mole of acetylene?

(a) Acetylene has four atoms in each formula, two carbons and two hydrogens. It is a true molecule because it is held together by covalent bonds.

(b) Carbon and hydrogen only.

(c) There are four atoms in each molecule of acetylene, so there are 4/Avogadro's number of mols of atoms per molecule.
The math is: 4 ÷ 6.023 E 23 = 6.6412 E-24 mols of atoms per molecule

(d) Each mol of acetylene is 6.023 E23 molecules, so 5.3 mols is 5.3 X 6.023 E23 molecules of acetylene.
The math is: 5.3 x 6.023 E 23 = 3.1922 E 24 molecules

(e) Each mol of acetylene is 6.023 E23 molecules, and each molecule has four atoms, so there are 4 x 6.023 E23 atoms in a mol.
The math is: 4 x 6.023 E 23 = 2.4092 E 24 atoms per mol of acetylene

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #4, SET 1 - MOLS

4. Calculate the molar mass of a mole of the following materials: (a) Al (b) Ra (c) Co (d) CO (e) CO_2 (f) HCl (g) Na_2CO_3 (h) $Ca(NO_3)_2$ (i) $(NH_4)_3(PO_4)$ (j) H_2O (k) Epsom salts - $Mg(SO_4)\cdot 7H_2O$ (m) blue vitriol - $Cu(SO_4)\cdot 5H_2O$

All of these molar masses can be calculated with the help of a periodic chart with the atomic weight. The formula weight is the sum of the atomic weights of the atoms in a formula of the material. The units of formula weight or atomic weight or molecular weight is "grams per mol." Chemtutor calculates the formula weights by using the atomic weight of elements with ONE DIGIT to the right of the decimal point. Your instructor may use two or three digits to the right of the decimal point or some other method. It is common to calculate to the nearest whole number, but many elements have fractional numbers a significant portion of a whole number. In calculating one decimal to the right, the most significant deviation is that of hydrogen in organic compounds, not so much due to the significance of deviation of one atom, but that there are usually so many hydrogen atoms in oranic compounds.

(a) Al --- 1 x 27.0 = 27.0 g/mol

(b) Ra --- 1 x 226.0 = 226.0 g/mol

(c) Co --- 1 x 58.9 = 58.9 g/mol

(d) CO --- C --- 1 x 12.0 = 12.0 g/mol
O --- 1 x 16.0 = 16.0 g/mol

----

totals ----- 1 C and 1 O ---- 28.0 g/mol

(e) CO_2 --C --- 1 x 12.0 = 12.0 g/mol
O --- 2 x 16.0 = 32.0 g/mol

----

totals ---- 1 C and 2 O ---- 44.0 g/mol

(f) NaCl -- Na --- 1 x 23.0 = 23.0 g/mol
Cl --- 1 x 35.5 = 35.5 g/mol

----

totals ---- 1 Na and 1 Cl ---- 58.5 g/mol

(g) Na_2CO_3 -- Na --- 2 x 23.0 = 46.0 g/mol
C --- 1 x 12.0 = 12.0 g/mol
O --- 3 x 16.0 = 48.0 g/mol

----

totals ----- 2 Na, 1 C, 3 O ----- 106.0 g/mol

(h) $Ca(NO_3)_2$ -- Ca --- 1 x 40.1 = 40.1 g/mol
N --- 2 x 14.0 = 28.0 g/mol
O --- 6 x 16.0 = 96.0 g/mol

----

totals ------ 1 Ca, 2 N, 6 O ------ 164.1 g/mol

(i) $(NH_4)_3(PO_4)$ -- N -- 3 x 14.0 = 42.0 g/mol
H ----- 12 x 1.0 = 12.0 g/mol
P ----- 1 x 31.0 = 31.0 g/mol
H ----- 4 x 16.0 = 64.0 g/mol

----

totals --------- 1 N and 3 H -------- 149.0 g/mol

(J) H_2O -- H --- 2 x 1.0 = 2.0 g/mol
O --- 1 x 16.0 = 16.0 g/mol

----

totals ---- 2 H and 1 O ---- 18.0 g/mol

(k) Epsom salts, $Mg(SO_4)\cdot 7H_2O$
Mg --- 1 x 24.3 = 24.3 g/mol
S ----- 1 x 32.1 = 32.1 g/mol
H ----- 14 x 1.0 = 14.0 g/mol
O ----- 11 x 16.0 = 176.0 g/mol

----

totals ---- 1 Mg, 1 S, 14 H, 11 O --- 246.4 g/mol

There is no "l," just as in Christmas.

(k) blue vitriol - $Cu(SO(PO_4)\cdot 5H_2O$
Cu --- 1 x 63.5 = 63.5 g/mol
S ----- 1 x 32.1 = 32.1 g/mol
H ----- 10 x 1.0 = 10.0 g/mol
O ----- 9 x 16.0 = 144.0 g/mol

\-

totals ----- 1 Cu, 1 S, 10 H, 9 O ---- 249.6 g/mol

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #5, SET 1 - MOLS

5. Calculate the number of moles in: (a) 2.3 # of carbon (b) 0.014 g of Tin (c) a 5 Oz silver bracelet (d) a pound of table salt (e) a 350 Kg cast iron engine block (f) a gal. of water (8.3 #) (g) a ton of sand (SiO_2) (h) 6.2 grams of blue vitriol (i) a pound of Epsom salts

Here for the first time we will be using DA method to change between mass and mols of a material. The conversion factor will be the formula weight of the material. There may be a little more DA to get the amount of material into units of grams, but that is just added to the main idea, that being that the formula weight is the way to get from mass to mols or from mols to mass of any material. Remember that the units of formula weight are grams per mol. Use the units in your calculations to keep your math straight.

Another way of thinking of the using the formula weight for a conversion factor is that for every material, the formula weight of it in grams is equal to a mol of that material.

The only real differences among these problems are the different formula weights of the materials and different ways to express the given amount of the material in grams so that they can be converted to mols.

a GIVEN DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{2.3\ \cancel{\#}\ \text{carbon}}{1}\right)\left(\frac{453.6\ \cancel{g}}{\cancel{\#}}\right)\left(\frac{\text{mol}}{12.0\ \cancel{g}}\right) = \boxed{86.94\ \text{mols C}} = \boxed{86.9\ \text{mols C}}$$

b GIVEN F.W. RAW ANSWER ANSWER

$$\left(\frac{0.014\ \cancel{g}\ \text{tin}}{1}\right)\left(\frac{\text{mol}}{118.7\ \cancel{g}}\right) = \boxed{1.1794\text{E-4 mols Sn}} = \boxed{1.18\text{ E-4 mols Sn}}$$

c GIVEN DEF. DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{5\ \cancel{Oz}.\ \text{Ag}}{1}\right)\left(\frac{\cancel{\#}}{16\ \cancel{Oz}}\right)\left(\frac{453.6\ \cancel{g}}{\cancel{\#}}\right)\left(\frac{\text{mol}}{107.9\ \cancel{g}}\right) = \boxed{1.3137\ \text{mols Ag}} = \boxed{1.31\ \text{mols Ag}}$$

d GIVEN DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{1\cancel{\#}\ \text{NaCl}}{1}\right)\left(\frac{453.6\ \cancel{g}}{\cancel{\#}}\right)\left(\frac{\text{mol}}{58.5\ \cancel{g}}\right) = \boxed{7.7538\ \text{mols NaCl}} = \boxed{7.75\ \text{mols NaCl}}$$

e GIVEN DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{350\cancel{Kg}\ \text{Fe}}{1}\right)\left(\frac{\text{E3}\ \cancel{g}}{\cancel{Kg}}\right)\left(\frac{\text{mol}}{55.8\ \cancel{g}}\right) = \boxed{6272.4\ \text{mols Fe}} = \boxed{6.27\text{E3 mols Fe}}$$

f GIVEN DENSITY! DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{1\cancel{gal}\ H_2O}{1}\right)\left(\frac{8.345\ \cancel{\#}}{\cancel{gal}}\right)\left(\frac{453.6\ \cancel{g}}{\cancel{\#}}\right)\left(\frac{\text{mol}}{18.0\cancel{g}}\right) = \boxed{210.3\ \text{mols}\ H_2O} = \boxed{210\ \text{mols}\ H_2O}$$

g GIVEN DEF. DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{1\cancel{ton}\ SiO_2}{1}\right)\left(\frac{2\text{E3}\ \cancel{\#}}{\cancel{ton}}\right)\left(\frac{453.6\ \cancel{g}}{\cancel{\#}}\right)\left(\frac{\text{mol}}{60.1\cancel{g}}\right) = \boxed{1.5095\ \text{mols}\ SiO_2} = \boxed{1.51\ \text{mols}\ SiO_2}$$

h GIVEN F.W. RAW ANSWER ANSWER

$$\left(\frac{6.2\ \cancel{g}\ \text{blue vitriol}}{1}\right)\left(\frac{\text{mol}}{249.6\ \cancel{g}}\right) = \boxed{0.024840\ \text{mols bv}} = \boxed{0.0248\ \text{mols bv}}$$

i GIVEN DEF. F.W. RAW ANSWER ANSWER

$$\left(\frac{1\cancel{\#}\text{epsom salts}}{1}\right)\left(\frac{453.6\ \cancel{g}}{\cancel{\#}}\right)\left(\frac{\text{mol}}{246.4\ \cancel{g}}\right) = \boxed{1.841\ \text{mols es}} = \boxed{1.84\ \text{mols es}}$$

Problem 5 f has an interesting part to it. The amount of material was given in volume rather than mass. An English volume, at that. The way shown here is via the English weight density of the water. There are several ways to do this, but I knew the number to make it quicker. The metric density of water is 1 g/cc, but getting the volume from gallons to cc's can be a pain. Try it yourself.

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #6, SET 1 - MOLS

6. Calculate the number of atoms in: (a) 100 g of Argon (b) 1.21 Kg aluminum foil (c) a 28 # lead brick (d) the E7 Kg of water in an olympic swimming pool (e) 7 Kg of hydrogen gas (f) a tonne of calcium nitrate

Now we can investigate the relationship between mols and number of molecules or atoms. You could call the units of Avogadro's Number atoms per mol or molecules per mol or just formulas per mol, depending upon how the material in question naturally comes. A mol of the element tin is Avogadro's number of atoms because elements come in atoms. A mol of water is Avogardo's number of molecules because water doesn't come any other way. A mol of blue vitriol, $Cu(SO_4)\cdot 5H_2O$, is Avogogadro's number of the whole formula, to include the water parts. Even though the formula comes apart into ions in solution and the water parts are not chemically attached, the entire group of atoms makes up a formula."

a

$$\overset{\text{GIVEN}}{\left(\frac{100\ \cancel{\text{g}}\ \text{Ar}}{1}\right)}\overset{\text{F.W.}}{\left(\frac{\cancel{\text{mol}}}{39.9\ \cancel{\text{g}}}\right)}\overset{\text{A.N.}}{\left(\frac{6.023\text{ E23 atoms}}{\cancel{\text{mol}}}\right)}=\overset{\text{RAW ANSWER}}{\boxed{1.509\text{ E24 atoms}}}=\overset{\text{ANSWER}}{\boxed{1.51\text{ E24 atoms}}}$$

b

$$\overset{\text{GIVEN}}{\left(\frac{1.21\ \cancel{\text{Kg}}\ \text{Al}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E3}\ \cancel{\text{g}}}{\cancel{\text{Kg}}}\right)}\overset{\text{F.W.}}{\left(\frac{\cancel{\text{mol}}}{27.0\ \cancel{\text{g}}}\right)}\overset{\text{A.N.}}{\left(\frac{6.023\text{ E23 atoms}}{\cancel{\text{mol}}}\right)}=\overset{\text{RAW ANSWER}}{\boxed{2.6992\text{ E25 atoms}}}=\overset{\text{ANSWER}}{\boxed{2.69\text{ E25 atoms}}}$$

c

$$\overset{\text{GIVEN}}{\left(\frac{28\ \cancel{\#}\ \text{Pb}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{453.6\ \cancel{\text{g}}}{\cancel{\#}}\right)}\overset{\text{F.W.}}{\left(\frac{\cancel{\text{mol}}}{207.2\ \cancel{\text{g}}}\right)}\overset{\text{A.N.}}{\left(\frac{6.023\text{ E23 atoms}}{\cancel{\text{mol}}}\right)}=\overset{\text{RAW ANSWER}}{\boxed{3.692\text{ E25 atoms}}}=\overset{\text{ANSWER}}{\boxed{3.69\text{ E25 atoms}}}$$

d

$$\overset{\text{GIVEN}}{\left(\frac{\text{E7}\ \cancel{\text{Kg}}\ H_2O}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E3}\ \cancel{\text{g}}}{\cancel{\text{Kg}}}\right)}\overset{\text{F.W.}}{\left(\frac{\cancel{\text{mol}}}{18\ \cancel{\text{g}}}\right)}\overset{\text{A.N.}}{\left(\frac{6.023\text{ E23 }\cancel{\text{molecules}}}{\cancel{\text{mol}}}\right)}\overset{\text{DEF.}}{\left(\frac{3\text{ atoms}}{\cancel{\text{molecule}}}\right)}=\overset{\text{ANSWER}}{\boxed{1.00\text{ E33 atoms}}}$$

e

$$\overset{\text{GIVEN}}{\left(\frac{7\ \cancel{\text{Kg}}\ H_2}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E3}\ \cancel{\text{g}}}{\cancel{\text{Kg}}}\right)}\overset{\text{F.W.}}{\left(\frac{\cancel{\text{mol}}}{2.0\ \cancel{\text{g}}}\right)}\overset{\text{A.N.}}{\left(\frac{6.023\text{ E23 }\cancel{\text{molecules}}}{\cancel{\text{mol}}}\right)}\overset{\text{DEF.}}{\left(\frac{2\text{ atoms}}{\cancel{\text{molecule}}}\right)}=\overset{\text{ANSWER}}{\boxed{4.22\text{ E27 atoms}}}$$

f

$$\overset{\text{GIVEN}}{\left(\frac{1\ \cancel{\text{tonne}}\ Ca(NO_3)_2}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E6}\ \cancel{\text{g}}}{\cancel{\text{tonne}}}\right)}\overset{\text{F.W.}}{\left(\frac{\cancel{\text{mol}}}{164.1\ \cancel{\text{g}}}\right)}\overset{\text{A.N.}}{\left(\frac{6.023\text{ E23 }\cancel{\text{formulas}}}{\cancel{\text{mol}}}\right)}\overset{\text{DEF.}}{\left(\frac{9\text{ atoms}}{\cancel{\text{formula}}}\right)}=\overset{\text{ANSWER}}{\boxed{3.30\text{ E28 atoms}}}$$

You can see that we have to calculate the number of UNITS of the material, whatever units it naturally comes in, and then consider the number of atoms in each unit of the material. (I have not given the raw answers in some of the problems above to save space.)

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #7, SET 1 - MOLS

7. What is the percentage composition of oxygen in each of the following materials: (a) CO (b) CO_2 (c) $(NO_3)^-$ (d) isopropyl alcohol C_3H_8O (e) calcium nitrate (f) blue vitriol $Cu(SO_4)\cdot 5H_2O$

Percentage is defined as: the target over the total times 100. Percentage composition is a common statistical treatment for a subset of a material within a larger material, for instance the percentage of sand in a concrete mixture or the percentage of males under twelve years old in the population of the United States populaion.

a % oxygen in CO

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{16.0\ \cancel{\frac{g}{mol}}}{28.0\ \cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\textbf{RAW ANSWER}}{\boxed{57.14\%}} = \overset{\textbf{ANSWER}}{\boxed{57.1\%}}$$

b % oxygen in CO_2

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{32.0\ \cancel{\frac{g}{mol}}}{44.0\ \cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\textbf{RAW ANSWER}}{\boxed{72.72\%}} = \overset{\textbf{ANSWER}}{\boxed{72.7\%}}$$

c % oxygen in $(NO_3)^-$

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{48.0\ \cancel{\frac{g}{mol}}}{62.0\ \cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\textbf{RAW ANSWER}}{\boxed{77.42\%}} = \overset{\textbf{ANSWER}}{\boxed{77.4\%}}$$

d % oxygen in IPA(C_3H_8O)

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{16.0\ \cancel{\frac{g}{mol}}}{60.0\ \cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\textbf{RAW ANSWER}}{\boxed{26.6\overline{6}\%}} = \overset{\textbf{ANSWER}}{\boxed{26.7\%}}$$

e % oxygen in $Ca(NO_3)_2$

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{96.0\ \cancel{\frac{g}{mol}}}{164.1\ \cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\textbf{RAW ANSWER}}{\boxed{58.50\%}} = \overset{\textbf{ANSWER}}{\boxed{58.5\%}}$$

f % oxygen in b.v.

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{144.0\ \cancel{\frac{g}{mol}}}{249.6\ \cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\textbf{RAW ANSWER}}{\boxed{57.69\%}} = \overset{\textbf{ANSWER}}{\boxed{57.7\%}}$$

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #8, SET 1 - MOLS

8. What is the percentage composition of phosphate in each of the following materials: (a) phosphoric acid (b) sodium carbonate (c) ammonium phosphate (d) aluminum phosphate

a % phosphate in phosphoric acid

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{95.0\,\cancel{\frac{g}{mol}}}{98.0\,\cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\text{RAW ANSWER}}{\boxed{96.94\%}} = \overset{\text{ANSWER}}{\boxed{96.9\%}}$$

b % phosphate in sodium carbonate

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{0\,\cancel{\frac{g}{mol}}}{103.0\,\cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\text{RAW ANSWER}}{\boxed{00.00\%}} = \overset{\text{ANSWER}}{\boxed{00.0\%}}$$

c % (PO_4) in $(NH_3)\ PO_4$

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{95.0\,\cancel{\frac{g}{mol}}}{146.0\,\cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\text{RAW ANSWER}}{\boxed{65.07\%}} = \overset{\text{ANSWER}}{\boxed{65.1\%}}$$

d % (PO_4) in $Ca_3(PO_4)_2$

$$\left(\frac{\text{target}}{\text{total}}\right) \times 100 = \left(\frac{190.0\,\cancel{\frac{g}{mol}}}{310.3\,\cancel{\frac{g}{mol}}}\right) \times 100 = \overset{\text{RAW ANSWER}}{\boxed{61.23\%}} = \overset{\text{ANSWER}}{\boxed{61.2\%}}$$

Back to mol problems.

ANSWER AND DISCUSSION

PROBLEM #9, SET 1 - MOLS

9. What is the percentage composition of sulfate in each of the following materials: (a) sulfuric acid (b) sodium sulfate (c) Epsom salts (d) aluminum sulfate

a % (SO_4) in H_2SO_4

$$\left(\frac{\text{target}}{\text{total}}\right)\text{x}100=\left(\frac{96.1\cancel{\frac{g}{mol}}}{98.1\cancel{\frac{g}{mol}}}\right)\text{x}100=\overset{\text{RAW ANSWER}}{\boxed{97.96\%}}=\overset{\text{ANSWER}}{\boxed{98.0\%}}$$

b % (SO_4) in Na_2SO_4

$$\left(\frac{\text{target}}{\text{total}}\right)\text{x}100=\left(\frac{96.1\cancel{\frac{g}{mol}}}{142.1\cancel{\frac{g}{mol}}}\right)\text{x}100=\overset{\text{RAW ANSWER}}{\boxed{67.63\%}}=\overset{\text{ANSWER}}{\boxed{67.6\%}}$$

c % (SO_4) in $MgSO_4{\cdot}7H_2O$

$$\left(\frac{\text{target}}{\text{total}}\right)\text{x}100=\left(\frac{96.1\cancel{\frac{g}{mol}}}{246.4\cancel{\frac{g}{mol}}}\right)\text{x}100=\overset{\text{RAW ANSWER}}{\boxed{39.00\%}}=\overset{\text{ANSWER}}{\boxed{39.0\%}}$$

d % (SO_4) in $Al_2(SO_4)_3$

$$\left(\frac{\text{target}}{\text{total}}\right)\text{x}100=\left(\frac{288.3\cancel{\frac{g}{mol}}}{342.3\cancel{\frac{g}{mol}}}\right)\text{x}100=\overset{\text{RAW ANSWER}}{\boxed{84.22\%}}=\overset{\text{ANSWER}}{\boxed{84.2\%}}$$

Back to mol problems.

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How to do these problems STP gas and mass stoichiometry problems in general.

All of the problems in this set are stoichiometry problems with at least one equation participant as a gas at STP. (a) Write and balance the chemical equation. (2) Do the math in DA style using 1 mole gas at STP = 22.4 liters as a factor. In the following problems ALL GASES ARE AT STP.

In this set of problems for the first time you will be using the idea of stoichiometry. These problems always refer to a chemical reaction. The chemical reaction must be first written and balanced. You will be given an amount of one of the materials and be expected to find out how much that corresponds to another one of the materials in that chemical reaction. Because we are beginning with an amount of a material and we are looking for another amount of (another) material, the DA method is standardly used for this type of problem.

Begin each problem with what you know, the GIVEN material and the GIVEN amount in whatever units it is given.

Change the GIVEN amount of material to units of mols. In the case of gases at STP, the conversion factor is: 1 mol of gas = 22.4 liters at STP. In the case of masses, you must use the formula weight of the material to change from mass to mols.

Use the mol ratio to change from one material to another. The mol ratio is the name (or symbol) of the material and the coefficient of that material in the balanced chemical reaction.

Change the mols of the new material to whatever units are asked for.

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #1, SET 2 - STP GAS AND MASS STOICHIOMETRY

1. How many moles of nitrogen gas is needed to react with 44.8 liters of hydrogen gas to produce ammonia gas?

$$3H_2 \quad + \quad N_2 \longrightarrow \quad 2NH_3$$

GIVEN: 44.8 L of H_2 at STP.

FIND: mols of N_2.

Here the sequence is: GIVEN liters of H_2 at STP, CHANGE liters of H_2 at STP to mols of H_2, MOL RATIO to change from H_2 to N_2. There is no need to go any further to change the N_2 into mols, because the mol ratio leaves the material in that unit anyway.

$$\overset{\text{GIVEN}}{\left(\frac{44.8\ \cancel{\text{L@STP}}\ \cancel{\text{H}_2}}{1}\right)}\overset{\text{MVG}}{\left(\frac{1\ \cancel{\text{mol}}}{22.4\ \cancel{\text{L@STP}}}\right)}\overset{\text{MR}}{\left(\frac{1\ \text{mol N}_2}{3\ \cancel{\text{mol}}\ \cancel{\text{H}_2}}\right)} = \overset{\text{ANSWER}}{\boxed{0.667\ \text{mol N}_2}}$$

The MVG is the "molar volume of gas at STP." The MR is the mol ratio. Notice the numbers in blue in the mol ratio. Those numbers come from the coefficients in the balanced chemical equation.

The math is: 44.8 ÷ 22.4 ÷ 3 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #2, SET 2 - STP GAS AND MASS Stoichiometry

2. How many liters of ammonia are produced when 89.6 liters of hydrogen are used in the above reaction?

The "above reaction" from problem #1 is: $N_2 + 3H_2 \longrightarrow 2NH_3$

GIVEN: 89.6 L of H_2 at STP.

FIND: Volume of ammonia (in liters at STP)

Take the GIVEN quantity, use the Molar Volume of Gas at STP (MVG) to change it to mols, change the material with the mol ratio (MR), and change the mols of new material to the requested liters at STP using the MVG again.

$$\overset{\text{GIVEN}}{\left(\frac{89.6\cancel{\text{LSTP}}\ \cancel{\text{H}_2}}{1}\right)}\overset{\text{MVG}}{\left(\frac{1\cancel{\text{mol}}}{22.4\cancel{\text{LSTP}}}\right)}\overset{\text{MR}}{\left(\frac{2\cancel{\text{mol}}\,\text{NH}_3}{3\cancel{\text{mol}}\ \cancel{\text{H}_2}}\right)}\overset{\text{MVG}}{\left(\frac{22.4\text{LSTP}}{1\cancel{\text{mol}}}\right)} = \overset{\text{ANSWER}}{\boxed{59.7\text{ L NH}_3\text{ STP}}}$$

The math is: 89.6 ÷ 22.4 ÷ 3 x 2 x 22.4 =
or, if the MVG's cancel, 89.6 ÷ 3 x 2 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #3, SET 2 - STP GAS AND MASS STOICHIOMETRY

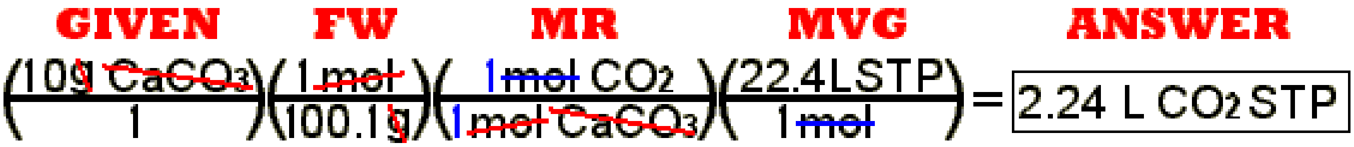
3. Ten grams of calcium carbonate was produced when carbon dioxide was added to lime water (calcium hydroxide in solution). What volume of carbon dioxide at STP was needed?

$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3 + H_2O$$

GIVEN: 10.0 g = mass of calcium carbonate

FIND: Volume of carbon dioxide (in liters at STP)

Take the GIVEN quantity, a mass, use the Formula Weight of the given quantity to change it to mols, change the material with the mol ratio (MR), and change the mols of new material to the requested liters at STP using the MVG. Find this pathway on the Stoichiometry Roadmap



$$\left(\frac{10\,\cancel{g}\ \cancel{CaCO_3}}{1}\right)\left(\frac{1\,\cancel{mol}}{100.1\,\cancel{g}}\right)\left(\frac{1\,\cancel{mol}\ CO_2}{1\,\cancel{mol}\ \cancel{CaCO_3}}\right)\left(\frac{22.4\,L\,STP}{1\,\cancel{mol}}\right)=\boxed{2.24\ L\ CO_2\ STP}$$

The math is: 10 ÷ 100.1 x 22.4 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #4, SET 2 - STP GAS AND MASS STOICHIOMETRY

4. When 11.2 liters of hydrogen gas is made by adding zinc to sulfuric acid, what mass of zinc is needed?

$$Zn + H_2SO_4 \rightarrow H_2 + ZnSO_4$$

GIVEN: 11.2 L of H_2 at STP

FIND: mass of Zn

Take the GIVEN quantity, a volume at STP, use the MVG to change it to mols, change the material with the mol ratio (MR), and change the mols of new material to the mass using the formula weight of the new material. Find this pathway on the Stoichiometry Roadmap

GIVEN **MVG** **MR** **FW** **ANSWER**

$$\left(\frac{11.2\,\cancel{L}\,\cancel{H_2}\,\cancel{STP}}{1}\right)\left(\frac{1\,\cancel{mol}}{22.4\,\cancel{L}\,\cancel{STP}}\right)\left(\frac{1\,\cancel{mol}\,Zn}{1\,\cancel{mol}\,\cancel{H_2}}\right)\left(\frac{65.4\,g}{1\,\cancel{mol}}\right)=\boxed{32.7g\ Zn}$$

The math is: 11.2 ÷ 22.4 x 65.4 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #5, SET 2 - STP GAS AND MASS STOICHIOMETRY

5. What volume of ammonia at STP is needed to add to water to produce 11 moles of ammonia water?

The balanced chemical equation is:

$$NH_3 + H_2O \longrightarrow NH_4OH$$

GIVEN: 11.0 mols of ammonia water (NH_4OH)

FIND: Volume of ammonia gas (NH_3) in liters at STP.

Take the GIVEN quantity, a number of mols, and directly use the mol ratio (MR) to change to the other material. The mols of FIND material can be changed to the requested liters at STP using the MVG. Find this pathway on the Stoichiometry Roadmap

GIVEN **MR** **MVG** **ANSWER**

$$\left(\frac{11\,\cancel{mol}\,\cancel{NH_4OH}}{1}\right)\left(\frac{1\,\cancel{mol}\,NH_3}{1\,\cancel{mol}\,\cancel{NH_4OH}}\right)\left(\frac{22.4\,L\,STP}{1\,\cancel{mol}}\right)=\boxed{246\ L\ NH_3\ STP}$$

The math is: 11 x 22.4 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #6, SET 2 - STP GAS AND MASS STOICHIOMETRY

6. How many grams of carbonic acid is produced when 55 liters of carbon dioxide is pressed into water?

There is no such thing as solid carbonic acid. It only exists in ionic form in solution, but we can consider this exercise anyway.

The balanced chemical equation is:

$$CO_3 + H_2O \longrightarrow H_2CO_3$$

GIVEN: 55.0 mols of carbon dioxide (CO_2)

FIND: mass of carbonic acid (H_2CO_3).

Take the GIVEN quantity, a number of mols, and directly use the mol ratio (MR) to change to the other material. The mols of FIND material can be changed to the requested mass the formula weight of the FIND material. Find this pathway on the Stoichiometry Roadmap

GIVEN **MVG** **MR** **FW** **ANSWER**

$$\left(\frac{55\,L\,CO_2\,STP}{1}\right)\left(\frac{1\,\cancel{mol}}{22.4\,L\,STP}\right)\left(\frac{1\,\cancel{mol}\,H_2CO_3}{1\,\cancel{mol}\,CO_2}\right)\left(\frac{62\,g}{\cancel{mol}}\right)=\boxed{151.5\bar{5}\,g}=\boxed{152\,g}$$

The math is: 55 ÷ 22.4 x 62 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #7, SET 2 - STP GAS AND MASS STOICHIOMETRY

7. magnesium hydroxide + ammonium sulfate $\longrightarrow$ magnesium sulfate + water + ammonia

How much (grams) magnesium hydroxide do you need to use in the above reaction to produce 500 liters of ammonia?

First change the word chemical equation to a balanced symbol equation:

$$Mg(OH)_2 + (NH_4)_2SO_4 \longrightarrow 2H_2O + MgSO_4 + 2NH_3$$

GIVEN: 500 liters of ammonia gas (NH_3) at STP.

FIND: mass of magnesium hydroxide ($Mg(OH)_2$).

Take the GIVEN quantity, a volume of gas at STP, and find the mols given with the MVG, the molar volume of gas. Use the mol ratio (MR) to change to the other material. The mols of FIND material can be changed to the requested mass the formula weight of the FIND material. Find this pathway on the Stoichiometry Roadmap

GIVEN **MVG** **MR** **FW** **ANSWER**

$$\left(\frac{500\,L\,NH_3\,STP}{1}\right)\left(\frac{1\,\cancel{mol}}{22.4\,L\,STP}\right)\left(\frac{1\,\cancel{mol}\,Mg(OH)_2}{2\,\cancel{mol}\,NH_3}\right)\left(\frac{58.3\,g}{\cancel{mol}}\right)=\boxed{650.67\,g}=\boxed{651\,g}$$

The math is: 17xxxxxx4 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #8, SET 2 - STP GAS AND MASS STOICHIOMETRY

8. How much strontium bromide is needed to add to chlorine gas to produce 75 liters of bromine gas?

GIVEN: 75 liters of bromine gas (Br_2) at STP.

FIND: mass of strontium bromide ($SrBr_2$).

Take the GIVEN quantity, a volume of gas at STP, and find the mols given with the MVG, the molar volume of gas. Use the mol ratio (MR) to change to the other material. The mols of FIND material can be changed to the requested mass the formula weight of the FIND material. Find this pathway on the Stoichiometry Roadmap

GIVEN **MVG** **MR** **FW** **ANSWER**

$$\left(\frac{500\,\text{L}\ NH_3\ \text{STP}}{1}\right)\left(\frac{1\,\cancel{\text{mol}}}{22.4\,\text{L}\,\text{STP}}\right)\left(\frac{1\,\cancel{\text{mol}}\ Mg(OH)_2}{2\,\cancel{\text{mol}}\ NH_3}\right)\left(\frac{58.3\,\text{g}}{\cancel{\text{mol}}}\right)=\boxed{650.67\text{g}}=\boxed{651\text{g}}$$

The math is: 17xxxxxx4 =

calculator

Back to gas @ STP problems.

ANSWER AND DISCUSSION

PROBLEM #8, SET 2 - STP GAS AND MASS STOICHIOMETRY

9. What mass of ammonium chlorate is needed to decompose to give off 200 liters of oxygen?

10. Your car burns mostly octane, C_8H_{18}, as a fuel. How many liters of oxygen is needed to burn a kilogram of octane?

11. copper + sulfuric acid ⟶ copper II sulfate + water + sulfur dioxide

How many moles of copper are needed to produce 1000 L of SO_2?

12. What volume of oxygen is needed to burn a pound of magnesium?

13. How many grams of sodium do you have to put into water to make 30 liters of hydrogen at STP?

14. ammonia gas and hydrogen chloride gas combine to make ammonium chloride. What volume of ammonia at STP is needed to react with 47.7 liters of hydrogen chloride at STP?

15. How many liters of oxygen are needed to burn 10 liters of acetylene?

ANSWERS TO GAS STOICHIOMETRY PROBLEMS

1. 0.667 MOL
2. 59.7 L
3. 2.24 L
4. 32.7 g
5. 246 L
6. 152 g
7. 651 g
8. 828 g
9. 604 g
10. 2.46 KL
11. 44.6 MOL
12. 210 L
13. 61.6 g
14. 47.7 L
15. 25 L

Back to the beginning of Mols, Percents, and Stoichiometry.

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ANSWER AND DISCUSSION

PROBLEM #1, STATES OF MATTER

1. How much heat is needed to warm 25 grams of water from 10ºC to 20ºC?

See the graph below for a picture of what is happening in this problem. Heat is added and the temperature of the water increases. That is all that is happening. Leg "C" of the graph between 10ºC and 20ºC is the only part of the graph that is needed. There is only a straight line graph between these two points, meaning that this is the only thing happening and that the entire process can be described by one equation, Q = m c ΔT.

This problem is likely best done with W5P method because it asks for an amount of heat when you are given two temperatures, a mass, and a type of material. The measurements such as the specific heat, the heat of vaporization, or the heat of fusion, the properties of those materials, are all available if you know the type of material. In the special case of water, you should know all of those property quantities. The English units are not commonly used except in some industrial applications, such as air conditioners being rated in BTU's.

GIVEN: T_1 = 10ºC, T_2 = 20ºC, m = 25 g, and the material is water in the liquid state at the temperatures in this problem, so c = 1 cal/gram-degree.

FIND: a heat, Q

The question asks for a heat in calories.

FORMULA: $Q = m c \Delta T$ or $Q = m c (T_2 - T_1)$

You know two temperatures, a mass, and a specific heat. You are asked to find a heat. The formula comes from the formula section of Units in Chemtutor.

SOLVE: The formula is already solved for heat as it is memorized. Substitute the known values from GIVEN into the working equation, simplify, and do the math. No DA is needed, but carefully handle the units. The units can help find any math problems you may have.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: T_1 = 10ºC, T_2 = 20ºC, m = 25 g, c = 1 cal/g-deg

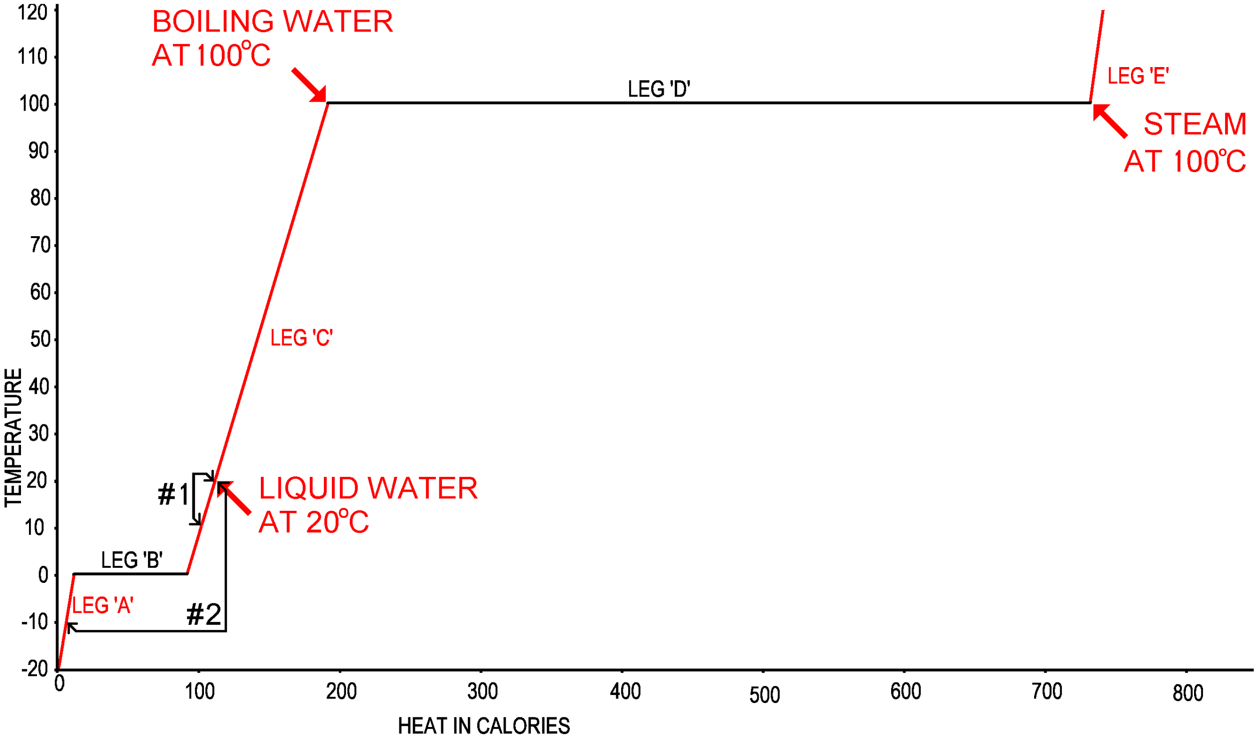
FIND: a heat, Q

The calculator math is: 20 - 10 x 25 =

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation or shortened to any fewer significant digits.

calculator

Back to Problems in States of Matter.



Back to Problems in States of Matter.

ANSWER AND DISCUSSION
PROBLEM #2, STATES OF MATTER

2. How much heat is needed to warm 25 grams of water (H_2O) from -10ºC to 20ºC?

This problem involves a change of state (ice to water) and heating as ice and heating as water. There are three legs to the temperature change of water from -10ºC to 20ºC labelled "A" as the first leg, the warming of ice to 0ºC, "B" as the melting of ice to water at 0ºC, and "C" as the warming of water from 0ºC to 20ºC. The two warming stages, as ice and as water, have the same formula, $Q = m\ c\ \Delta T$, relating the dimensions, but the numbers may be different. The specific heat of ice, "c_i," is 1/2 calorie per gram-degree whereas the specific heat of liquid water, "c_w," is one calorie per gram degree. The mass of the H_2O is the same in this case. The formula for the melting leg of the change is, $Q = m\ H_f$, where Q is the heat, m is the same mass as in the other legs, and H_f is the heat of fusion of water. The total formula for finding the amount of heat for this temperature and state change is the sum (total) of the three formulas as solved for Q.

The graph above shows the three legs of the change of water from ice at -10ºC to 20ºC, and the problem solution below labels the legs, i for ice, f for fusion, and w for water.

GIVEN: $T_{1i} = -10^\circ C$, $T_{2i} = 0^\circ C$, $m_i = 25$ g, $c_i = 1$ cal/gram-degree.
$T_{1w} = 0^\circ C$, $T_{2w} = 20^\circ C$, $m_w = 25$ g, $c_w = 1$ cal/gram-degree.
$m = 25$ g, $H_f = 80$ cal/g

FIND: a heat, Q
The question asks for a heat in calories.

FORMULAS: $Q = m\,c\,\Delta T$ and $Q = m\,H_f$
The formula for temperature increase with heat application ($Q = m\,c\,\Delta T$) will be used for the two legs A and C, the increase in temperature of the H_2O as ice and as water.

SOLVE: The formulas are already solved for heat as they are memorized. The heat of the legs must be added together to find the total heat, Q_T , or, because the mass is the same in all three equations, the equations may be rearranged as:

$$Q_T = m\,[\,(c_i\,\Delta T_i) + H_f + (c_w\,\Delta T_w)]$$

Where Q = heat in calories, c = specific heat, ΔT = the change in temperature, H_f = the heat of fusion, m = the mass, and the subscripts of "i" and "w" are for ice and water respectively. Substitute the known values from GIVEN into the working equation, simplify, and do the math.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $T_{1i} = -10^{o}C$, $T_{2i} = 0^{o}C$, $m_i = 25$ g, $c_i = 1$ cal/gram-degree.
$T_{1w} = 0^{o}C$, $T_{2w} = 20^{o}C$, $m_w = 25$ g, $c_w = 1$ cal/gram-degree.
$m = 25$ g, $H_f = 80$ cal/g

FIND: the total heat, Q_T

FORMULAS: $Q_f = m\,H_f$ $Q_i = m\,c_i\,(T_{2i} - T_{1i})$
$Q_w = m\,c_w\,(T_{2w} - T_{1w})$ $Q_T = Q_i + Q_f + Q_w$

SOLVED: $Q_T = m\,c_i\,(T_{2i} - T_{1i}) + m\,H_f + m\,c_w\,(T_{2w} - T_{1w})$

alternate: $Q_T = m\,[c_i\,(T_{2i} - T_{1i}) + H_f + c_w\,(T_{2w} - T_{1w})]$

SUBSTITUTION: $$Q_T = (25\,\cancel{g})(1/2\,\text{cal}/\cancel{g}\cdot\cancel{\text{deg}})(0^{\cancel{o}} - (-10^{\cancel{o}})) + (25\,\cancel{g})(80\,\text{cal}/\cancel{g}) + (25\,\cancel{g})(1\,\text{cal}/\cancel{g}\cdot\cancel{\text{deg}})(20^{\cancel{o}} - 0^{\cancel{o}})$$

OR $$Q_T = (25\,\cancel{g})[(1/2\,\text{cal}/\cancel{g}\cdot\cancel{\text{deg}})(0^{\cancel{o}} - (-10^{\cancel{o}})) + (80\,\text{cal}/\cancel{g}) + (1\,\text{cal}/\cancel{g}\cdot\cancel{\text{deg}})(20^{\cancel{o}} - 0^{\cancel{o}})]$$

ANSWER: 2625 cal OR 2.63 E3 cal OR 2.63 Kcal

ANSWER: Calculate the numerical answer and show your cancellation of the units.

It is fascinating that melting of ice takes a lot more energy in the form of heat than a small change in temperature. Even so, the 80 cal/gram heat of fusion is still a lot smaller than the 540 cal/gram heat of vaporization.

calculator

Back to Problems in States of Matter.

ANSWER AND DISCUSSION
PROBLEM #3, STATES OF MATTER

3. What is the specific heat of copper metal if 200 cal increases the temperature of 40.9 g of it from 21°C to 73°C?

With other temperatures that fit the properties of copper, the graph for water is similar to the graph for copper metal. At the temperatures in this problem, copper is on the first leg (Leg

"A") as a solid. There is no change in states. The formula must be Q = m c ΔT. The property quantities such as the value of the specific heat of copper are not commonly memorized measurements. Your instructor will not likely ask you to know such quantities.

GIVEN: Q = 200 cal, T_1 = 21°C, T_2 = 73°C, m = 40.9 g, and the material is copper in the solid state at the temperatures in this problem.

FIND: a specific heat, c
The question asks for a specific heat in calories per gram.

FORMULA: $Q = m\,c\,\Delta T$ or $Q = m\,c\,(T_2 - T_1)$
You know two temperatures, a mass, and a heat. You are asked to find a specific heat. The formula comes from the formula section of Units in Chemtutor.

SOLVE: The formula must be solved for specific heat from the memorized formula. Substitute the known values from GIVEN into the working equation, simplify, and do the math. No DA is needed.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: Q = 200 cal, T_1 = 21°C, T_2 = 73°C, m = 40.9 g, and the material is copper as a solid.

FIND: a specific heat, c

FORMULA: $Q = m c \Delta T$

ORIGINAL FORMULA SOLVED FOR	SUBSTITUTION	RAW ANSWER	ANSWER
$\frac{Q}{m(T_2 - T_1)} = \frac{\cancel{m}c\cancel{(T_2 - T_1)}}{\cancel{m}\cancel{(T_2 - T_1)}}$	$c = \frac{200 \text{ cal}}{(40.9 \text{ g})(52^\circ)} =$	$\boxed{0.094038 \text{ cal/g}\cdot\text{deg}} =$	$\boxed{0.0940 \text{ cal/g}\cdot\text{deg}}$

The calculator math is: 200 ÷ 40.9 ÷ 52 =

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation but does need to be shortened to three significant digits. How does this answer match the value for the specific heat of copper in the table?

calculator

Back to Problems in States of Matter.

ANSWER AND DISCUSSION
PROBLEM #4, STATES OF MATTER

4. How much heat is needed to increase the temperature of 12 grams of gold from 20 ºC to 95 ºC?

You know enough about the properties of gold to see that it would be a solid in all the temperatures in this example. Q = m c ΔT is the equation that describes this change. You are given a mass, two temperatures, and the material. You are asked for an amount of heat. Since the type of material is available, it is assumed that you have access to a table that would give you the specific heat, a property of the material.

GIVEN: T_1 = 20ºC, T_2 = 95ºC, m = 12 g, and the material is gold in the solid state, so from the table, c = 0.032 cal/gram-degree.

FIND: a heat, Q
The question asks for a heat in calories.

FORMULA: $Q = m\,c\,\Delta T$ or $Q = m\,c\,(T_2 - T_1)$
You know two temperatures, a mass, and a specific heat. You are asked to find a heat. The formula comes from the formula section of Units in Chemtutor.

SOLVE: The formula is already solved for heat as it is memorized. Substitute the known values from GIVEN into the working equation, simplify, and do the math. No DA is needed, but carefully handle the units. The units can help find any math problems you may have.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $T_1 = 20^oC$, $T_2 = 95^oC$, $m = 12$ g, $c = 0.032$ cal/gram-degree.

FIND: a heat, Q

ORIGINAL FORMULA SOLVED FOR	SUBSTITUTION	ANSWER
$Q = m\,c\,(T_2 - T_1)$	$Q = (12\ \cancel{g})(0.032\ \text{cal}/\cancel{g}\cdot\cancel{\text{deg}})(75\cancel{^{o}}) =$	$\boxed{28.8\ \text{cal}}$

The calculator math is: 12 x 0.032 x 75 =

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation or shortened to any fewer significant digits. It is fascinating that with only a very small amount of added heat the gold increases temperature so much compared to water.

calculator

Back to Problems in States of Matter.

ANSWER AND DISCUSSION
PROBLEM #5, STATES OF MATTER

5. What is the temperature of 40g of water at 45ºC added to 60g of water at 95ºC?

This is a neat little question about the second law of thermodynamics. The new temperature of the resulting material from a mix will all have the same temperature and that temperature will be the weighted average of the masses and temperatures and specific heats of the contributing materials. Since there is no change in phase, the problem goes without that complicating factor. We can treat the temperatures as absolute numbers, even though they are not. The first law of thermodynamics, that energy can be traded around but not lost, is the basis for the equation for this happening. The equations are:
$Q_1 + Q_2 = Q_T$ and $c_T = c_1 = c_2$ and $m_1 + m_2 = m_T$, so $[(m_1T_1) + (m_2T_2)]/(m_1 + m_2) = T_T$. If these were different materials added together, we would have to take into account the specific heat of each of them, but both materials here are water in the liquid state.

For many of these problems there will be a material that gains heat and a material that loses heat. Strictly speaking, a positive value for Q should indicate a gain of heat (since $T_2 - T_1$ is a positive number when there is an increase in temperature) or a greater amount of the looser phase, and a negative value for Q when there is a temperature loss or greater amount of the more tightly - bound phase. On the other hand, if we consider "heat lost" as a positive amount we can more easily construct formulas on the basis of, $Q_{\textbf{gained}} = Q_{\textbf{lost}}$ rather than the slightly more inconvenient $Q_{\textbf{gained}} = -(Q_{\textbf{lost}})$, where $Q_{\textbf{lost}}$ is a negative number.

GIVEN: $T_1 = 45^oC$ $T_2 = 95^oC$ $m_1 = 40$ g $m_2 = 60$ g
$m_1 + m_2 = m_T = 100$ g, $c_1 = c_2 = c_T = 1$ cal/g-deg
$Q_1 + Q_2 = Q_T$ - the equation of the first law of thermodynamics, and
$m_1 + m_2 = m_T$, the adding of the masses of water.

FIND: a temperature, T_T The question asks for a temperature in degrees.

FORMULAS: $Q = m\,c\,\Delta T$ or $Q = m\,c\,(T_2 - T_1)$ is an important formula, but there are some other formulas that must be put together especially for the perameters of this problem that are:
$Q_1 + Q_2 = Q_T$

SOLVE: With the several formulas, T_T must be solved for.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $T_1 = 45^oC$, $T_2 = 95^oC$, $m_1 = 40$ g, $m_2 = 60$ g,

FIND: T_T , the final temperature.

ORIGINAL FORMULAS	SOLVED FOR	SUBSTITUTION	ANSWER
$m_1+m_2=m_T$ and $Q_1+Q_2=Q_T$ and $m_1c_1T_1+m_2c_2T_2=m_Tc_TT_T$ and $c_1=c_2=c_T$ so $m_1T_1+m_2T_2=m_TT_T$	$T_T=\frac{m_1T_1+m_2T_2}{m_1+m_2}$	$=\frac{(40\cancel{g})(45^\circ)+(60\cancel{g})(95^\circ)}{100\,\cancel{g}}$	$=\boxed{75^\circ}$

The calculator math is: 40 x 45 = STO 60 x 95 + RCL = ÷ 100 =
where the "STO" is a storage function and "RCL" is a reclaim function. These may be "M+" for, "add to memory," and "m-" for, "retrieve from memory," or some other such set of buttons, depending on your calculator.

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation or shortened to any fewer significant digits.

calculator

Back to Problems in States of Matter.

ANSWER AND DISCUSSION
PROBLEM #6, STATES OF MATTER

6. What mass of live steam at 100ºC is needed to heat 27.5 Kg of water from 20ºC to 100ºC?

This problem is a good example of the idea that the formulas in this section are easy, but it often takes some skill and insight to construct the set of formulas in the correct way to reflect what is going on in the situation. See the graph for a good mental image of what is happening in this problem. The two materials, the steam at 100ºC is added to the water at 20ºC. The amount of heat gained by the water to get to be water at 100ºC has to be the same amount of heat lost by the steam to make the same water at 100ºC, the same temperature and phase as the other water.

Let's call the amount of heat gained by the 20ºC water Q_c because it is a heat, the heat on leg "c." Similarly, let's call the amount of heat lost by the steam Q_d because it involves leg "d." The formula is: $Q_c = Q_d$. So $m_c\ c_c\ \Delta T_c = m_d\ H_f$. We know m_c, c_c, ΔT_c, and H_f, and we are looking for m_d

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $T_1 = 20^\circ C$, $T_2 = 100^\circ C$, $m_c = 27.5$ Kg

From the properties of water table, $c_c = 1.00$ cal/gram-degree, $H_f = 540$ cal/g

FIND: a mass, m_d

ORIGINAL FORMULAS

$Q_c = Q_d$

$Q_d = m_d H_f$ and

$Q_c = m_c c_c \Delta T_c$ so

$m_d H_f = m_c c_c \Delta T_c$

SOLVED FOR

$$m_d = \frac{m_c c_c \Delta T_c}{H_f}$$

SUBSTITUTION **RAW ANSWER** **ANSWER**

$$m_d = \frac{(27.5\text{ Kg})(1\,\cancel{\text{cal/g}}\,\cancel{\text{deg}})(80\,\cancel{^\circ\text{C}})}{540\,\cancel{\text{cal/g}}} = \boxed{4.0741\text{ Kg}} = \boxed{4.07\text{ Kg}}$$

The calculator math is: 27.5 X 80 ÷ 540 =

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation or shortened to any fewer significant digits. It is fascinating that with only a very small amount of added heat the gold increases temperature so much compared to water.

calculator

Back to Problems in States of Matter.

ANSWER AND DISCUSSION
PROBLEM #7, STATES OF MATTER

7. A 641 gram horse shoe at 1100 ºC is dunked into a bucket containing 12.8 Kg of water at 22 ºC. Assume that no steam was lost from the bucket. When the horse shoe is taken out, it is at 100 ºC, just after it has quit boiling the water around it. What is the new temperature of the water?

Here the horse shoe loses $Q = m\ c\ \Delta T$ heat to the water and the water gains all that heat to increase the temperature of the water. The first important process is to see that going on and the second important process is to carefully label everything so we can analyze it. Let's call the amount of heat lost by the iron Q_i and the amount of heat gained by the water Q_w. Therefore, $Q_i = Q_w$.

GIVEN: $T_{1w} = 20^oC$, $T_{1i} = 1100^oC$, $T_{2i} = 100^oC$, $m_i = 641$ g,
$m_w = 12.8$ Kg, $c_i = 0.12$ cal/g-deg from the table, and $c_w = 1.00$ cal/g-deg from the list of water properties in the heat curve math table you should know.

FIND: the final temperature of water, T_{2w}

FORMULA: $Q = m\ c\ \Delta T$ or $Q = m\ c\ (\ T_2 - T_1\ )$
What is more important than the memorized equations is how to put them to use. Here for the iron horse shoe, $Q_i = m_i\ c_i\ \Delta T_i$ or $Q_i = m_i\ c_i\ (\ T_{2i} - T_{1i}\ )$
and for water, $Q_w = m_w\ c_w\ \Delta T_w$ or $Q_w = m_w\ c_w\ (\ T_{2w} - T_{1w}\ )$ We know the mass of iron, the

specific heat of iron, the initial and final temperatures of iron. We know the mass of water, the specific heat of water, and the initial temperature of water. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the final temperature of the water. Substitute the known values from GIVEN into the working equation, simplify, and do the math.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: T_{1w} = 20ºC, T_{1i} = 1100ºC, T_{2i} = 100ºC, m_i = 641 g, m_w = 12.8 Kg, c_i = 0.12 cal/g-deg , and c_w = 1.00 cal/g-deg.

FIND: the final temperature of water, T_{2w}

ORIGINAL FORMULAS	**SOLVE FOR**
$Q_w = Q_i$ and $\Delta T = T_2 - T_1$	$m_w c_w \Delta T_w = m_i\, c_i\, \Delta T_i$
$Q_i = m_i\, c_i\, \Delta T_i$	$m_w c_w T_{2w} - m_w c_w T_{1w} = m_i\, c_i\, \Delta T_i$
$Q_w = m_w c_w \Delta T_w$	$m_w c_w T_{2w} = m_i\, c_i\, \Delta T_i + m_w c_w T_{1w}$

WORKING EQUATION SOLVED FOR

$$T_{2w} = \frac{m_i\, c_i\, \Delta T_i + m_w c_w T_{1w}}{m_w c_w}$$

SUBSTITUTION

$$T_{2w} = \frac{(0.641\cancel{Kg})(0.12\cancel{cal/g^\circ C})(1000\,^\circ C) + (12.8\cancel{Kg})(1\cancel{cal/g^\circ C})(20\,^\circ C)}{(12.8\cancel{Kg})(1\cancel{cal/g^\circ C})}$$

RAW ANSWER **ANSWER**

$$\boxed{26.009^\circ C} = \boxed{26.0^\circ C}$$

The calculator math is: 0.641 x 0.12 x 1000 = STO 12.8 x 20 = + RCL = ÷ 12.8 =

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation, but it must be shortened to three significant digits.

calculator

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ANSWER AND DISCUSSION

PROBLEM #1, SET 1 - NUMBERS

1. What is 1.50 mm in km?

This problem is clearly a DA - only problem because it asks you to convert from one unit of distance to another, mm to km. Both of the units are metric units, so it needs a metric definiton. Either use the common definitions of kilometer to meter and meter to millimeter or use the metric staircase. Notice in each of the definitions that one of the larger unit comes first.

1 km = E 6 mm

or

1 km = E 3 m and 1 m = E 3 mm

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{1.5\,\cancel{\text{mm}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{km}}{\text{E6}\,\cancel{\text{mm}}}\right)} = \overset{\text{ANSWER}}{\boxed{1.5\text{ E-6 km}}}$$

OR

$$\overset{\text{GIVEN}}{\left(\frac{1.5\,\cancel{\text{mm}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{m}}}{\text{E3}\,\cancel{\text{mm}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{km}}{\text{E3}\,\cancel{\text{m}}}\right)} = \overset{\text{ANSWER}}{\boxed{1.5\text{ E-6 km}}}$$

E6 is 1,000,000. The calculator math is:
1.5 ÷ 1 E 6 = or 1.5 ÷ 1000000 =

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #2, SET 1 - NUMBERS

2. How many nanoseconds are in 1.50 days?

This problem is a DA - only problem because it asks you to convert from one unit of time to another, nanoseconds to days. Seconds to nanoseconds is a metric definition. See the metric staircase or the definition of "nano-." Seconds to days are commonly known definitions, seconds to minutes to hours to days. Notice in each of the definitions that one of the larger unit comes first.

1 sec = E 9 nanoseconds
1 min = 60 seconds
1 hour = 60 min
1 day = 24 hours

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{1.50\ \cancel{\text{days}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{24\ \cancel{\text{hrs}}}{\cancel{\text{day}}}\right)}\overset{\text{DEF.}}{\left(\frac{60\ \cancel{\text{min}}}{\cancel{\text{hr}}}\right)}\overset{\text{DEF.}}{\left(\frac{60\ \cancel{\text{sec}}}{\cancel{\text{min}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E9 ns}}{\cancel{\text{sec}}}\right)}=\overset{\text{RAW ANSWER}}{\boxed{1.296\ \text{E14}\,\text{nsec}}}=\overset{\text{ANSWER}}{\boxed{1.30\ \text{E14 nsec}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). It is best done with a calculator SEQUENTIALLY, in the following manner:

1.50 x 24 x 60 x 60 x 1 E 9 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math. On most scientific calculators it is easiest to put in E9 by first inserting a 1.

The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures. Your calculator will show you large numbers in the scientific notation style.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

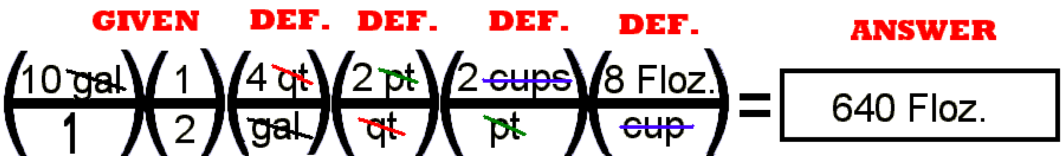
PROBLEM #3, SET 1 - NUMBERS

3. How many floz. of water do you have in exactly half of a ten gallon can?

This problem is a DA - only problem beacuse it asks you to convert from one unit of volume to another, gallons to fluid ounces. The definitions are all English. Notice in each of the definitions that one of the larger unit comes first.

1 gal = 4 qt.
1 qt. = 2 pints
1pint = 2 cups
1cup = 8 floz.

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do. This example begins with "half of a ten gallon can," so there is a number in the denominator of "given."



The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). On the calculator that is:
10 ÷ 2 x 4 x 2 x 2 x 8 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #4, SET 1 - NUMBERS

4. A car is going 60.0 MPH. How fast is that in ft/sec?

This problem is a DA - only problem beacuse it asks you to convert from one unit of velocity to another, miles per hour to feet per second. The definitions are all English. Notice in each of the definitions that one of the larger unit comes first.

1 mile = 5280 ft
1 hr = 60 min
1 min = 60 sec

Now is a good time to mention a common mistake. In changing hours to seconds I have seen many students use "1 hr = 60 sec" as a conversion factor. That's a mighty short hour.

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do. This example begins with "sixty miles per hour." "MPH" is just an abbreviation for "miles per hour," and the "hour" rightly goes in the denominator. The "miles" must be changed to "feet," and the "hours" must be changed to "seconds."

$$\overset{\text{GIVEN}}{\left(\frac{60\ \cancel{\text{miles}}}{\cancel{\text{hour}}}\right)}\overset{\text{DEF.}}{\left(\frac{5280\text{ ft}}{\cancel{\text{mile}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{hour}}}{60\ \cancel{\text{min}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{min}}}{60\text{ sec}}\right)} = \overset{\text{ANSWER}}{\boxed{88.0\text{ ft/sec}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). If you do it the long way, the calculator math is:
60 x 5280 ÷ 60 ÷ 60 =
If you want to shorten it, cancel one of the "60's" in the denominator with "60" in the numerator to make the math:
5280 ÷ 60 =

The answer shows three significant digits by showing the zero after the decimal point, even though that zero does not appear on the calculator.

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #5, SET 1 - NUMBERS

5. A car is going 62 MPH. How fast is that in KPH?

This problem is a DA - only problem because it asks you to convert from one unit of velocity to another, miles per hour to kilometers per hour. The definitions begin with English until we can get to a "bridge" to the metric system. The "bridge" is the definition "1 inch = 2.54 cm." After the "bridge" the metric definition is easy from the metric staircase.

What if you knew a definition that would take you directly from miles to kilometers? Could you use that as a one-step path from MPH to KPH? Yes, but (1) it would require you to know another definition, (2) the number 2.54 cm as one inch is an exact number by definition.

1 mile = 5280 ft
1 ft = 12 in
1 in = 2.54 cm
1 km = E5 cm

As any DA problem, begin with what you know and use the definitions as conversion factors so that you can cancel the units you don't want and leave the units you do. This example begins with "sixty miles per hour." "MPH" is just an abbreviation for "miles per hour," and the "hour" rightly goes in the denominator. The "miles" must be changed to "kilometers," and the "hours" do not need to be changed.

$$\overset{\text{GIVEN}}{\left(\frac{62\ \cancel{\text{miles}}}{\text{hour}}\right)}\overset{\text{DEF.}}{\left(\frac{5280\ \cancel{\text{ft}}}{\cancel{\text{mile}}}\right)}\overset{\text{DEF.}}{\left(\frac{12\ \cancel{\text{in}}}{\cancel{\text{ft}}}\right)}\overset{\text{DEF.}}{\left(\frac{2.54\ \cancel{\text{cm}}}{\cancel{\text{in}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{km}}{\text{E5}\ \cancel{\text{cm}}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{99.779328\ \text{KPH}}} = \overset{\text{ANSWER}}{\boxed{99.8\ \text{KPH}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
62 x 5280 x 12 x 2.54 ÷ 1 E5 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures. There is no need to put the answer into scientific notation because the number is less than 1000.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #6, SET 1 - NUMBERS

6. How many mm^2 are there in one square kilometer?

This problem is a DA - only problem because it asks you to convert from one unit of area to another, square kilometers to square millimeters. These are both metric measurements in units of squared distance. One mm^2 = (mm)(mm) and similarly, one km^2 = (km)(km). The metric definition from kilometer to millimeter is easy from the metric staircase, but the process must be DONE TWICE to account for the square.

1 km = E6 mm

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{1\ \cancel{\text{km}}^2}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E6 mm}}{\cancel{\text{km}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E6 mm}}{\cancel{\text{km}}}\right)} = \overset{\text{ANSWER}}{\boxed{1\ \text{E12 mm}^2}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done: 1 x 1 E6 x 1 E6 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

calculator

Back to DA problems.

ANSWER AND DISCUSSION OF PROBLEM

#7, SET 1 - NUMBERS

7. How many in^2 are there in an acre?

This problem is clearly a DA - only problem beacuse it asks you to convert from one unit of area to another, acres to square inches. These are both English measurements, so we need the definitons. An acre is recognizable as a unit of area not because it is in units of squared distance, but because the definition of acre is 43560 sq.ft.
$\text{in}^2 = (\text{in})(\text{in})$.

1 acre = 43560 ft^2
1 foot = 12 inches

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{1\ \cancel{\text{acre}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{43560\ \cancel{\text{ft}}^2}{\cancel{\text{acre}}}\right)}\overset{\text{DEF.}}{\left(\frac{12\text{ in}}{\cancel{\text{ft}}}\right)}\overset{\text{DEF.}}{\left(\frac{12\text{ in}}{\cancel{\text{ft}}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{6272640\text{ in}^2}} = \overset{\text{ANSWER}}{\boxed{6.27\text{ E6 in}^2}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
1 x 43560 x 12 x 12 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to scientific notation with three significant digits as the final answer.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #8, SET 1 - NUMBERS

8. How many mm^2 are there in 0.550 acre?

This problem is a DA - only problem beacuse it asks you to convert from one unit of area to another, acres to square millimeters. An acre is English, but square millimeters is metric, so we need a "bridge" from English to metric. The common definitions for changing system do not have a regularly used definition in the dimension of area, but in length. The length definition between the systems is "1 inch = 2.54 cm," so the pathway for this question is: acres to square feet to square inches to square centimeters to square millimeters. The squared distance changes have to be done twice.

1 acre = 43560 ft^2
1 foot = 12 inches
1 inch = 2.54 cm
1 cm = 10 mm

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{0.550\ \cancel{\text{acre}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{43560\ \cancel{\text{ft}}^2}{\cancel{\text{acre}}}\right)}\overset{\text{DEF.}}{\left(\frac{12\ \cancel{\text{in}}}{\cancel{\text{ft}}}\right)^2}\overset{\text{DEF.}}{\left(\frac{2.54\ \cancel{\text{cm}}}{\cancel{\text{in}}}\right)^2}\overset{\text{DEF.}}{\left(\frac{10\ \text{mm}}{\cancel{\text{cm}}}\right)^2}=\overset{\text{RAW ANSWER}}{\boxed{2.2258\text{ E9 mm}^2}}=\overset{\text{ANSWER}}{\boxed{2.23\text{ E9 mm}^2}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
0.550 x 43560 x 12 x 12 x 2.54 x 2.54 x 10 x 10 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to scientific notation with three significant digits as the final answer.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #9, SET 1 - NUMBERS

9.A car goes 0 to 60.0 MPH in 5.00 sec. Write that acceleration in m/sec2?

This problem is DA - only problem beacuse it asks you to convert from one unit of acceleration to another, miles per hour per second to meters per second squared. The miles must be changed to meters and the hours to seconds. The length definition between the systems is "1 inch = 2.54 cm," so the pathway for this part of the question is: miles to feet to inches to centimeters to meters. The changes in time are common definitions.

1 mile = 5280 ft
1 foot = 12 inches
1 inch = 2.54 cm
1 m = 100 cm
1 hour = 60 min
1 min = 60 sec

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
60 ÷ 5 x 5280 x 12 x 2.54 ÷ 100 ÷ 60 ÷ 60 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to scientific notation with three significant digits as the final answer.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #10, SET 1 - NUMBERS

10. Light travels at 3.00 E8 m/sec. How fast is that in MPH?

This problem is DA - only problem beacuse it asks you to convert from one unit of velocity to another, meters per second to miles per hour. The meters must be changed to miles and the seconds to hours, opposite of the the previous example. The length definition between the systems is "1 inch = 2.54 cm," so the pathway for this part of the question is: meters to centimeters to inches to feet to miles. The changes in time are common definitions.

1 mile = 5280 ft
1 foot = 12 inches
1 inch = 2.54 cm
1 m = 100 cm
1 hour = 60 min
1 min = 60 sec

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{3.00\text{ E8 }\cancel{\text{m}}}{\cancel{\text{sec}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E2 }\cancel{\text{cm}}}{\cancel{\text{m}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{inch}}}{2.54\ \cancel{\text{cm}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{ft}}}{12\ \cancel{\text{in}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{mile}}{5280\ \cancel{\text{ft}}}\right)}\overset{\text{DEF.}}{\left(\frac{60\ \cancel{\text{sec}}}{\cancel{\text{min}}}\right)}\overset{\text{DEF.}}{\left(\frac{60\ \cancel{\text{min}}}{\text{hour}}\right)}=\overset{\text{ANSWER}}{\boxed{\begin{array}{c}6.7108\text{ E8 MPH}\\ \text{or}\\ 6.71\text{ E8 MPH}\end{array}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
3.00E8 x 100 ÷ 2.54 ÷ 12 ÷ 5280 x 60 x 60 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to scientific notation with three significant digits as the final answer.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #11, SET 1 - NUMBERS

11. An elephront has a mass of 1.80 tonnes. What is its weight in ounces?

This problem is DA - only problem beacuse it asks you to convert from a unit of metric mass to a unit of English weight, perfectly understandable at one "g." The mass-to-weight definition between the systems is:
1 kg = 2.2 # or 1 # = 453 g
The pathway for this part of the question is: tonnes to kilograms to pounds to ounces or tonnes to kilograms to grams to pounds to ounces.

1 tonne = 1000 kg
1 kg = 2.54 #
1 # = 16 Oz

As for any DA problem, begin with what you know and use the definitions as conversion factors so that you can cancel the units you don't want and leave the units you do.

$$\begin{array}{cccccc} \text{GIVEN} & \text{DEF.} & \text{DEF.} & \text{DEF.} & \text{RAW ANSWER} & \text{ANSWER} \\ \left(\frac{1.80\,\cancel{\text{tonnes}}}{1}\right) & \left(\frac{\text{E3}\,\cancel{\text{kg}}}{\cancel{\text{tonne}}}\right) & \left(\frac{2.2\,\cancel{\#}}{\cancel{\text{kg}}}\right) & \left(\frac{16\text{ Oz}}{\cancel{\#}}\right) = & \boxed{63360\text{ Oz}} = & \boxed{6.34\text{ E4 Oz}} \end{array}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
1.80 x 1000 x 2.2 x 16 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to scientific notation with three significant digits as the final answer.

calculator

Back to DA problems.

ANSWER AND DISCUSSION

PROBLEM #12, SET 1 - NUMBERS

12. Mercury has a density of 13.6 g/cc. What is that in #/gal?

This problem is DA - only problem because it asks you to convert from a unit of metric mass density to a unit of English weight density, perfectly understandable at one "g." The mass-to-weight definition between the systems is: 1 kg = 2.2 # or 1 # = 453 g," so the pathway for this part of the question is: grams to pounds and cc's to milliliters to liters to quarts to gallons.

1 kg = 2.54 #
1 cc = 1 ml
1 liter = 1000 ml
1 liter = 1.06 qt

1 gal = 4 qt

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{13.6\ \cancel{\text{g}}}{\cancel{\text{cc}}}\right)}\overset{\text{DEF.}}{\left(\frac{\#}{453\ \cancel{\text{g}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{cc}}}{\cancel{\text{ml}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E3}\ \cancel{\text{ml}}}{\cancel{\text{liter}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\text{liter}}}{1.06\ \cancel{\text{qt}}}\right)}\overset{\text{DEF.}}{\left(\frac{4\ \cancel{\text{qt}}}{\text{gal}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{113.291\ \#/\text{gal}}} = \overset{\text{ANSWER}}{\boxed{113\ \#/\text{gal}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
13.6 ÷ 453 x 1000 ÷ 1.06 x 4 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to three significant digits as the final answer. It is not necessary to put the answer into scientific notation because it is a number less than 1000.

calculator

Back to DA problems.

ANSWER AND DISCUSSION #13, SET 1 - NUMBERS

13. A light year is the distance that light goes in a year. Using data from #10. how long is a light year in miles?

This example is the first time we show the use of DA as a problem - solving technique for simple problems. For this case, the velocity of light is given (from the answer in problem #10 in this set) in miles per hour. We can get a distance from this velocity by multiplying by the time (one year) right there in the DA framework.

If we use that velocity of light in the answer in #10 in miles per hour, the only unit that needs changing is the year to hours so that the hours in the denominator of the velocity can cancel. The number in the velocity of light is used with more significant digits than we will need. Rounding should only be done at the end of a problem.

1 year = 365.24 days
1 day = 24 hours

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{(6.7108\ \text{E8 mi})(\cancel{\text{yr}})}{\cancel{\text{hour}}}\right)}\overset{\text{DEF.}}{\left(\frac{365.24\ \cancel{\text{days}}}{\cancel{\text{year}}}\right)}\overset{\text{DEF.}}{\left(\frac{24\ \cancel{\text{hr}}}{\cancel{\text{day}}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{5.8825\ \text{E12 mi}}} = \overset{\text{ANSWER}}{\boxed{5.88\ \text{E12 mi}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). The math can be done:
6.7108 E8 x 365.24 x 24 =

There is no need to notice intermediate answers or to write anything down until you reach the end of the math.

The raw answer is then converted to scientific notation with three significant digits as the final answer.

calculator

Back to DA problems.

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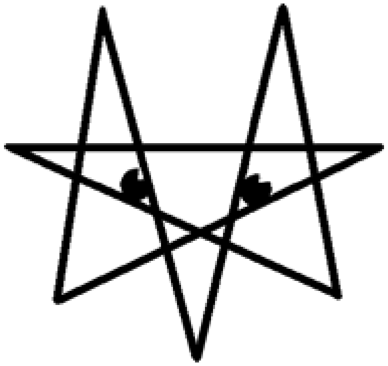


ANSWER AND DISCUSSION

PROBLEM #1, SET 2 - NUMBERS

1. How deep would the water in a trench three inches wide and sixteen feet long have to be to contain 24.0 cubic feet of water?

This problem is likely best done with W5P method because it asks for a length when you are given two other lengths and a volume. All units are in English system.

GIVEN: l_1 = 16 ft., l_2 = 3 in, l = 24.0 ft^3

You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a length, l

The question asks, "how deep," which asks for a length. You know the symbol for length from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $V = l\ l\ l$

You know two lengths and a volume. You are asked to find a length. The volume formula must be the one you need because it is the relationship among three lengths and a volume. You know this from the list of formulas in the formula section of Units in Chemtutor.

SOLVE: Using algebra, solve for the length you are looking for. Once you have one of the lengths on one side alone, substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 16$ ft., $l_2 = 3$ in, $V = 24.0\ ft^3$

FIND: a length, l

ORIGINAL FORMULA **SOLVED FOR** **SUBSTITUTION** **DA** **ANSWER**

$$V = l\,l\,l$$

$$\frac{V}{l\,l} = \frac{l\,\cancel{l}\,\cancel{l}}{\cancel{l}\,\cancel{l}}$$

$$l = \frac{24.0\,\overset{\cancel{(ft)}\cancel{(ft)}(ft)}{\cancel{ft^3}}}{(16\,\cancel{ft})(3\,\cancel{in})}\left(\frac{12\,\cancel{in}}{\cancel{ft}}\right) = \boxed{6\ ft}$$

The calculator math is: 24 ÷ 16 ÷ 3 x 12 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer(the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. In this case, no change is needed.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION

PROBLEM #2, SET 2 - NUMBERS

2. Cloth is four feet wide as it comes on the bolt. What length of cloth would you need to cover a surface of 58.0 square yards?

This problem is likely best done with W5P method because it asks for a length when you are given one other length and an area. All units are in English system.

GIVEN: $l_1 = 4$ ft., $A = 58.0\ ft^2$

You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a length, l

The question asks, "what length," which asks for a length. You know the symbol for length from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $A = l\,l$

You know one length and an area. You are asked to find a length. The area formula must be the one you need because it is the relationship among two lengths and a volume. You know this from the list of formulas in the formula section of Units in Chemtutor. State the original formula here.

SOLVE: Using algebra, solve for the length you are looking for. Once you have one of the lengths on one side alone, substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 4$ ft., $A = 58.0\ ft^2$

FIND: a length, l

ORIGINAL FORMULA **SOLVED FOR** **SUBSTITUTION** **DA** **ANSWER**

$$A = l\,l \qquad \frac{A}{l} = \frac{l\cancel{l}}{\cancel{l}} \qquad l = \frac{58\ \overset{\cancel{(yd)}(yd)}{\cancel{yd^2}}}{4\ \cancel{ft}}\left(\frac{3\ \cancel{ft}}{\cancel{yd}}\right) = \boxed{43.5\ yd}$$

The calculator math is: 58 ÷ 4 x 3 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. No change to the raw answer is needed in this problem.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION

PROBLEM #3, SET 2 - NUMBERS

3. It is 762 miles from here to Chicago. An obese Chemistry teacher jogs at a rate of one mile every twenty minutes. How long would it take him to jog to Chicago if he jogged continuously and REALLY wanted to get there?

This problem is likely best done with W5P method because it asks for a time when you are given a length and a velocity. All units are in English system.

GIVEN: d* = 762 miles, v = 1 mile/20 min

You know this from the units and dimensions table in the Units section of Chemtutor.

* I will admit to some sneakiness here. The dimension of distance has more than one symbol. Seeing the velocity and distance in the problem, I chose the symbol for distance that goes with the formula.

FIND: a time, t

The question asks, "How long would it take ...," which asks for a time. You know the symbol for time from the units and dimensions table in the Units section of Chemtutor.

FORMULA: v t = d

You know a length and a velocity. You are asked to find a time. The rate equation must be the one you need because it is the relationship among a rate (or velocity), a time, and a distance. You know this from the list of formulas in the formula section of Units in Chemtutor.

SOLVE: Using algebra, solve for the length you are looking for. Once you have the time on one side alone, substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the time units manageable.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: d = 762 miles, v = 1 mile/20 min

FIND: a time, t

ORIGINAL FORMULA	SOLVED FOR	SUBSTITUTION	ALGEBRA TO SIMPLIFY	DA	ANSWER
$v\,t = d$	$\frac{\cancel{v}t}{\cancel{v}} = \frac{d}{v}$	$t = \frac{762\text{ mi}}{\left(\frac{1\text{ mi}}{20\text{ min}}\right)} =$	$\frac{(762\,\cancel{\text{mi}})(20\,\cancel{\text{min}})}{1\,\cancel{\text{mi}}}$	$\left(\frac{\text{hr}}{60\,\cancel{\text{min}}}\right) =$	$\boxed{254\text{ hrs}}$

The calculator math is: 762 x 20 ÷ 60 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. Here, because of the W5P, there is no need to change the raw answer.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION

PROBLEM #4, SET 2 - NUMBERS

4. The density of lead is 11.4 g/cc. What is the mass of a block of lead two cm by ten cm by four cm?

This problem is likely best done with W5P method because it asks for a mass when you are given three lengths and a density. All units are in metric system.

GIVEN: l_1 = 2 cm, l_2 = 10 cm, l_3 = 4 cm, D = 11.4 g/cc

You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a mass, m

The question asks, "What is the mass ...," which asks for m, the mass. You know the symbol for mass from the units and dimensions table in the Units section of Chemtutor.

FORMULAS: $V = l\,l\,l$ $D = {}^{m}/V$

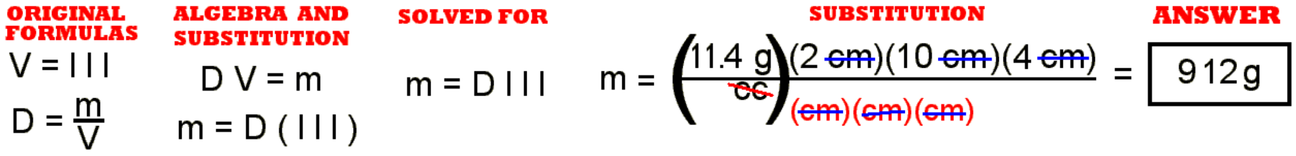
You know three lengths and a density. You are asked to find a mass. For this question, you need two of the equations from the formula section of Units in Chemtutor, the formula for volume and the density formula.

SOLVE: Using algebra, solve for the length you are looking for. Once you have the time on one side alone, substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 2$ cm, $l_2 = 10$ cm, $l_3 = 4$ cm, $D = 11.4$ g/cc

FIND: a mass, m



ORIGINAL FORMULAS

$V = l\,l\,l$

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

ALGEBRA AND SUBSTITUTION

$D\,V = m$

$m = D\,(l\,l\,l)$

SOLVED FOR

$m = D\,l\,l\,l$

SUBSTITUTION

$$m = \left(\frac{11.4\text{ g}}{\cancel{\text{cc}}}\right)\frac{(2\ \cancel{\text{cm}})(10\ \cancel{\text{cm}})(4\ \cancel{\text{cm}})}{(\cancel{\text{cm}})(\cancel{\text{cm}})(\cancel{\text{cm}})} =$$

ANSWER

$\boxed{912\text{g}}$

The calculator math is: 11.4 x 2 x 10 x 4 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. Once again there is no need to change the raw answer.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION

PROBLEM #5, SET 2 - NUMBERS

5. How many liters of water could you fit into a container measuring 10.0 ft by 13.0 ft by 8.00 ft?

This problem is likely best done with W5P method because it asks for a volume when you are given three lengths. The answer is asked for in metric system, but the information has been given in English system, so the units will need some DA.

GIVEN: l_1 = 10.0 ft, l_2 = 13.0 ft, l_3 = 8.00 ft,

You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a volume, V

The question asks for a volume, V. You know the symbol for volume from the units and dimensions table in the Units section of Chemtutor.

FORMULA: V = l l l

You know three lengths. You are asked to find a volume. For this question you need the volume equation from the formula section of Units in Chemtutor.

SOLVE: The equation is already solved for V, the volume. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: l_1 = 10.0 ft, l_2 = 13.0 ft, l_3 = 8.00 ft,

FIND: a volume, V

ORIGINAL FORMULA SOLVED FOR **SUBSTITUTION** **DA** **DA** **DA** **RAW ANSWER** **ANSWER**

$$V = l\,l\,l \qquad V = (10\ \cancel{ft})(13\ \cancel{ft})(8\ \cancel{ft})\left(\frac{12\ \cancel{in}}{\cancel{foot}}\right)^3\left(\frac{2.54\ \cancel{cm}}{\cancel{inch}}\right)^3\left(\frac{\text{liter}}{\text{E3}\ \cancel{cm^3}}\right) = \boxed{29449.52\ \text{L}} = \boxed{2.94\ \text{E4 L}}$$

By calculator it is: 10 x 13 x 8 x 12 x 12 x 12 x 2.54 x 2.54 x 2.54 ÷ 1000 =
Likely, you know some ways to make the math shorter.

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION

PROBLEM #6, SET 2 - NUMBERS

6. A box of qrtpsdfgh measures 24.0 x 4.00 x 12.0 inches. It has a density of 38.0 pounds per cubic foot. What is the weight of qrtpsdfgh in the box? (Notice the English system density!)

This problem is likely best done with W5P method because it asks for a weight when you are given three lengths and a weight density. The units are all English system.

GIVEN: l_1 = 24.0 in, l_2 = 4.00 in, l_3 = 12.0 in, D = 38.0 #/cu.ft.
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a weight, F_w
The question asks for a weight, Fw. You know the symbol for weight from the units and dimensions table in the Units section of Chemtutor.

FORMULAS: $D = F_w/V$ $V = l\,l\,l$
You know three lengths and a weight density. You are asked to find a weight. The formulas come from the formula section of Units in Chemtutor.

SOLVE: The equation is already solved for V, the volume. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: l_1 = 24.0 in, l_2 = 4.00 in, l_3 = 12.0 in, D = 38.0 #/cu.ft.

FIND: a weight, F_w

ORIGINAL FORMULAS	SOLVED FOR	SUBSTITUTION	DA	RAW ANSWER	ANSWER
$V = lll$ $D_w = \frac{F_w}{V}$	$F_w = D_w lll$	$F_w = \left(\frac{38\ \#}{\cancel{ft^3}}\right)(24\ \cancel{in})(4\ \cancel{in})(12\ \cancel{in})$	$\left(\frac{\cancel{foot}}{12\ \cancel{in}}\right)^3$	$= \boxed{25.\overline{3}\ \#}$	$= \boxed{25\frac{1}{3}\ \#}$

The calculator math is: 38 x 24 x 4 x 12 ÷ 12 ÷ 12÷ 12 = or just: 38 x 24 x 4 ÷ 12÷ 12 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION

PROBLEM #7, SET 2 - NUMBERS

7. My basement was flooded after a big rain. The basement is rectangular 12.0 ft by 17.0 ft. The water was measured as it drained out at 51.0 cubic feet. How deep was the water in the basement?

This problem is likely best done with W5P method because it asks for a distance when you are given two lengths and a volume. The units are all English system.

GIVEN: $l_1 = 12.0$ ft, $l_2 = 17.0$ ft, $V = 51.0$ cu.ft.

You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a length, l

The question asks for a length, l. You know the symbol for length from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $V = l\,l\,l$

You know two lengths and a volume. You are asked to find a length. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for one of the lengths. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 12.0$ ft, $l_2 = 17.0$ ft, $V = 51.0$ cu.ft.

FIND: a length, l

ORIGINAL FORMULA

$$V = l\,l\,l$$

SOLVED FOR

$$\frac{V}{l\,l} = \frac{l\,\cancel{l}\,\cancel{l}}{\cancel{l}\,\cancel{l}}$$

SUBSTITUTION **DA** **ANSWER**

$$l = \frac{51.0\ \overset{\cancel{(ft)}\cancel{(ft)}\cancel{(ft)}}{\xcancel{ft^3}}}{(12\ \cancel{ft})(17\ \cancel{ft})}\left(\frac{12\ in}{\cancel{foot}}\right) = \boxed{3\ in}$$

The calculator math is: 51 ÷ 12 ÷ 17 x 12 = or just: 51 ÷ 17 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. No change fsrom the raw answer is needed here.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION
PROBLEM #8, SET 2 - NUMBERS

8. A standard expressway lane is 11.0 ft wide. How long would a four lane expressway be if it had a square mile of pavement?

This problem is likely best done with W5P method because it asks for a distance when you are given one length and an area. The units are all English system.

GIVEN: l_1 = 44.0 ft(4 lanes at 11 ft each!), A = 1 sq. mi.
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a length, l
The question asks for a length, l. You know the symbol for length from the units and dimensions table

in the Units section of Chemtutor.

FORMULA: $A = l\,l$

You know one length and an area. You are asked to find a length. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for one of the lengths. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 44.0$ ft, $A = 1$ sq. mi.

FIND: a length, l

ORIGINAL FORMULA	SOLVED FOR	SUBSTITUTION	DA	ANSWER
$A = l\,l$	$\frac{A}{l} = \frac{l\,\cancel{l}}{\cancel{l}}$	$l = \frac{1\,\text{mi}^{\cancel{2}}}{44\,\cancel{\text{ft}}}$	$\left(\frac{5280\,\cancel{\text{ft}}}{\cancel{\text{mile}}}\right)$	$= \boxed{120\text{ mi}}$

The calculator math is: 5280 ÷ 44 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. The raw answer needs no change to it.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION
PROBLEM #9, SET 2 - NUMBERS

9. The density of gasoline is 720 g per liter. What is the mass of a jar of gasoline three cm by four cm by five cm?

This problem is likely best done with W5P method because it asks for a density when you are given three lengths and a mass. The units are all metric.

GIVEN: $l_1 = 3$ cm, $l_2 = 4$ cm, $l_3 = 5$ cm, D = 720 g/L
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: mass, m
The question asks for a mass, m. You know the symbol for length from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $V = l\,l\,l$ $D = m/V$
You know three lengths and a density. You are asked to find a mass. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the mass. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 3$ cm, $l_2 = 4$ cm, $l_3 = 5$ cm, D = 720 g/L

FIND: a length, l

ORIGINAL FORMULAS	SOLVED FOR	SUBSTITUTION	DA	ANSWER
$V = l\,l\,l$ $D = \frac{m}{V}$	$m = D\,l\,l\,l$	$m = \left(\frac{720\ \cancel{g}}{\cancel{cm^3}}\right)(3\ \cancel{cm})(4\ \cancel{cm})(5\ \cancel{cm})$	$\left(\frac{kg}{E3\ \cancel{g}}\right)$	$= \boxed{43.2\ kg}$

The calculator math is: 720 x 3 x 4 x 5 ÷ 1000 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. Once again, the raw answer does not need to be changed.

calculator

Back to W5P problems.

ANSWER AND DISCUSSION
PROBLEM #10, SET 2 - NUMBERS

10. How many liters of water could you fit into a hot tub that measures 1.50m deep and three meters in diameter? How many people? (1 cubic meter = 1000L)

This problem is likely best done with W5P method because it asks for the volume of a cylinder when you are given a length as height and another length as diameter. The units are all metric.

GIVEN: l = 11.0 ft, d = 3 m (so the radius, r = 1.5 m)
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a volume, V
The question asks for a length, l. You know the symbol for volume from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $V_c = \text{pi } r^2 \mathbf{l}$
You know the radius and height of a cylinder. You are asked to find the volume. The formula comes from the formula section of Units in Chemtutor.

SOLVE: The volume is already solved for in the memorized equation. GIVEN into equation and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: l = 11.0 ft, d = 3 m (so the radius, r = 1.5 m)

FIND: a volume, V

ORIGINAL FORMULA SOLVED FOR	SUBSTITUTION	DA	RAW ANSWER	ANSWER
$V_c = \text{pi}\ r^2\ l$	$V = (\text{pi})(1.5\ \cancel{m})^3$	$\left(\frac{E3\ L}{\cancel{m^3}}\right) =$	$\boxed{10602.875\ \text{liters}} =$	$\boxed{1.06E4\ L}$

The calculator math is: pi x 1.5 x 1.5 x 1.5 x 1000 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. You can leave the raw answer as it is.

The answer to the second question is: THE MORE, THE MERRIER

calculator

Back to W5P problems.

ANSWER AND DISCUSSION PROBLEM #11, SET 2 - NUMBERS

11. Mr. Richland has a swimming pool 10.0 ft by 20.0 ft. He had a wild party and they threw his son's Volkswagen into the pool. The VW has a volume of 10 cubic feet. It was sealed up, but it sank because of all the lead bricks in it.

(a) What is the area of the pool? (b) How much did the VW raise the water level?

A major idea here is that the volume of the VW is equal to the volume of displaced water. The displaced water can be measured as a layer on top of the other water in the pool.

Part (a) of the problem is easy and intuitive. Given two distances, what is the area?
Given l = 10 ft and l = 20 ft, A = l l = (10 ft)(20 ft) = 200 ft^2

The second part of this problem is likely best done with W5P method because it asks for a distance when you are given two lengths and a volume. The units are all English system.

GIVEN: l_1 = 10.0 ft, l_2 = 20.0 ft, V = 10 cu. ft.
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a length, l
The question asks for a length, l. You know the symbol for length from the units and dimensions table in the Units section of Chemtutor.

FORMULA: V = l l l
You know two lengths and a volume. You are asked to find a length. The formulas come from the formula section of Units in Chemtutor.

SOLVE: **Solve for one of the lengths. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some [DA](#) to get the units right.**

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 10.0$ ft, $l_2 = 20.0$ ft, V = 10 cu. ft.

FIND: a length, l

ORIGINAL FORMULA	SOLVED FOR	SUBSTITUTION	DA	ANSWER
$V = lll$	$\frac{V}{ll} = \frac{l\cancel{l}\cancel{l}}{\cancel{l}\cancel{l}}$	$l = \frac{10\ \overset{\cancel{(ft)}\cancel{(ft)}\cancel{(ft)}}{\cancel{ft^3}}}{(10\ \cancel{ft})(20\ \cancel{ft})}$	$\left(\frac{12\ in}{\cancel{foot}}\right)$	$= \boxed{0.6\ in}$

The calculator math is: 10 ÷ 10 ÷ 20 x 12 = or just: 12 ÷ 20 =

ANSWER: **Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.**

calculator

Back to W5P problems.

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ANSWER AND DISCUSSION

PROBLEM #1, SET 3 - NUMBERS

1. How many ounces is 45.0 tonnes?

This problem is clearly a DA - only problem because it asks you to convert from metric tonnes to English ounces. Here is a list of the definitions to use:
1 tonne = E3 kg
1 kg = E3 g
1 # = 453.6 g (the metric - to - English "bridge")
1 # = 16 Oz
OR 1kg = 2.2#

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{45\ \cancel{\text{tonnes}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E3}\ \cancel{\text{kg}}}{1\ \cancel{\text{tonne}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{E3}\ \cancel{\text{g}}}{\cancel{\text{kg}}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{\#}}{453.6\ \cancel{\text{g}}}\right)}\overset{\text{DEF.}}{\left(\frac{16\text{ Oz}}{\cancel{\#}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{1.5873\text{ E6 Oz}}} = \overset{\text{ANSWER}}{\boxed{1.59\text{ E6 Oz}}}$$

The calculator math is: 45 x 1000 x 1000 ÷ 453.6 x 16 =

The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures. Your calculator will show you large numbers in the scientific notation style.

The answer comes out only slightly different if you use the definition, "1 kg = 2.2 #" rather than going from kilograms to grams to pounds. You try it for yourself.

calculator

Back to Problem set #3, W5P and DA problems.

ANSWER AND DISCUSSION

PROBLEM #2, SET 3 - NUMBERS

2. How many liters are in 8.55 cubic miles of ocean water?

This problem is a DA - only problem because it asks you to convert from one unit of volume to another, cubic miles to liters. Cubic mile is an English unit and liter is a metric unit. There are at least two good ways do this problem with the information you have: cubic miles to cubic feet to cubic inches to cubic centimeters to milliliters to liters, or cubic miles to cubic feet to gallons to quarts to liters. The first sequence is more accurate because the definitions from cubic feet to gallons and from quarts to liters are not exact.

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\textbf{GIVEN}}{\left(\frac{8.55\ \cancel{mi^3}}{1}\right)}\overset{\textbf{DEF.}}{\left(\frac{5280\ \cancel{ft}}{\cancel{mi}}\right)^3}\overset{\textbf{DEF.}}{\left(\frac{12\ \cancel{in}}{\cancel{foot}}\right)^3}\overset{\textbf{DEF.}}{\left(\frac{2.54\ \cancel{cm}}{\cancel{inch}}\right)^3}\overset{\textbf{DEF.}}{\left(\frac{\cancel{ml}}{\cancel{cm^3}}\right)}\overset{\textbf{DEF.}}{\left(\frac{\text{liter}}{\text{E3}\ \cancel{ml}}\right)} = \overset{\textbf{RAW ANSWER}}{\boxed{3.5638\text{ E13 L}}} = \overset{\textbf{ANSWER}}{\boxed{3.56\text{ E13 liters}}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). Here is the calculator math:
8.55 x 5280 x 5280 x 5280 x 12 x 12 x 12 x 2.54 x 2.54 x 2.54 ÷ 1000 =

The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures. Your calculator will show you large numbers in the scientific notation style.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION

PROBLEM #3, SET 3 - NUMBERS

3. Water has a density of one gram (1.00g) per cubic centimeter. What is that in pounds per gallon?

This problem is a DA - only problem beacuse it asks you to convert from one unit of density to another, grams per cc to pounds per gallon. The problem is much easier if you think of changing grams to pounds and cubic centimeters to gallons. Again there are several ways to do this.

1 kg = 2.2 #
1 gal = 4 qt
1 liter = 1.06 qt
1 cc = 1 ml

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{1.00\ \cancel{g}}{\cancel{cc}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{cc}}{\cancel{ml}}\right)}\overset{\text{DEF.}}{\left(\frac{E3\ \cancel{ml}}{\cancel{liter}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{kg}}{E3\ \cancel{g}}\right)}\overset{\text{DEF.}}{\left(\frac{\cancel{liter}}{1.06\ \cancel{qt}}\right)}\overset{\text{DEF.}}{\left(\frac{4\ \cancel{qt}}{gal}\right)}\overset{\text{DEF.}}{\left(\frac{2.2\ \#}{\cancel{kg}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{8.302\ \#/gal}} = \overset{\text{ANSWER}}{\boxed{8.30\ \#/gal}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). Here is the calculator math:
1 ÷ 1.06 x 4 x 2.2 =

Notice that it is best to start the calculator math with a "1" to avoid a problem with having the first number in the numerator. The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures.

The number of about 8.3 pounds per gallon of water is a good one to remember as long as the US is going to insist upon using the unit of gallons. Many of the common materials we encounter, particularly in a grocery store, have densities in the vicinity of the density of water. At one time (when the British Empire could brag that the sun never set on it), there was a useful rule of thumb, "A pint is a pound the world 'round." That is about right for any material close to the density of water. One gallon is eight pints and one gallon of water has a weight of 8.3 pounds.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION

PROBLEM #4, SET 3 - NUMBERS

4. A roadsign posts a 50.0 MPH limit. What is that in KPH?

This problem is a DA - only problem beacuse it asks you to convert from one unit of velocity to another, miles per hour to kilometers per hour. The problem is much easier if you think of changing just the miles to kilometers. The hour unit in the denominator does not need changing.

1 mile = 5280 ft
1 ft = 12 inches
1 inch = 2.54 cm(English - to metric "bridge")
1 km = E5 cm

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{50\ \cancel{mi}}{hour}\right)}\overset{\text{DEF.}}{\left(\frac{5280\ \cancel{ft}}{\cancel{mile}}\right)}\overset{\text{DEF.}}{\left(\frac{12\ \cancel{in}}{\cancel{ft}}\right)}\overset{\text{DEF.}}{\left(\frac{2.54\ \cancel{cm}}{\cancel{in}}\right)}\overset{\text{DEF.}}{\left(\frac{km}{E5\ \cancel{cm}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{80.467\ KPH}} = \overset{\text{ANSWER}}{\boxed{80.5\ KPH}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). Here is the calculator math:
50 x 5280 x 12 x 2.54 ÷ 1 E 5 =

The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures. You can easily check this conversion by the speedometer of any recent model car. The MPH and KPH are displayed together on the speedometer readout. Look for yourself. Is 50 MPH about equal to 80 KPH?

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION

PROBLEM #5, SET 3 - NUMBERS

5. How large in square feet is a 525 square meter house?

This problem is a DA - only problem beacuse it asks you to convert from one unit of area to another, square meters to square feet. It is easy to think of this problem in terms of going from meters to centimeters to inches to feet and squaring each step.

1 ft = 12 inches
1 inch = 2.54 cm (the metric - to - English "bridge")
1 m = E2 cm

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{525\ \cancel{m^2}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{E2\ \cancel{cm}}{\cancel{m}}\right)^2}\overset{\text{DEF.}}{\left(\frac{\cancel{inch}}{2.54\,\cancel{cm}}\right)^2}\overset{\text{DEF.}}{\left(\frac{foot}{12\ \cancel{in}}\right)^2} = \overset{\text{RAW ANSWER}}{\boxed{5651.053\ ft^2}} = \overset{\text{ANSWER}}{\boxed{5.65\ E3\ ft^2}}$$

The math is done by multiplying everything on top (in the numerator) and dividing by everything on the bottom (in the denominator). Here is the calculator math:
525 x 100 x 100 ÷ 2.54 ÷ 2.54 ÷ 12 ÷ 12 =

The raw answer is the number taken directly off of the calculator and the correct units. The final answer is given here shortened to three significant figures and expressed in scientific notation.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION

PROBLEM #6, SET 3 - NUMBERS

6. How many square yards of paint are needed on the ceiling of a room that is 24.0 feet wide, 51.0 feet long and ten feet high?

This problem is likely best done with W5P method because it asks for an area when you are given two lengths. The units are all English system.

GIVEN: l_1 = 24.0 ft, l_2 = 51.0 ft, l_3 = 10.0 ft, (BUT NOT NEEDED)
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: an area, A
The question asks for an area, A in square yards. You know the symbol for area from the units and dimensions table in the Units section of Chemtutor.

FORMULA: A = l l
You know two lengths. You are asked to find an area. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for one of the lengths. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: l_1 = 24.0 ft, l_2 = 51.0 ft,

FIND: an area, A

ORIGINAL FORMULA SOLVED FOR	**SUBSTITUTION**	**DA**	**ANSWER**
$A = l\,l$	$A = (24\ \text{ft})(51\ \text{ft}) =$	$1224\ \cancel{\text{ft}^2}\left(\frac{\text{yard}}{3\ \cancel{\text{ft}}}\right)^2 =$	$\boxed{136\ \text{yd}^2}$

The calculator math is: 24 x 51 ÷ 3 ÷ 3 =

ANSWER: Calculate the numerical answer and show your cancellation of the units. The raw answer does not need to be changed into scientific notation or shortened to any fewer significant digits.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #7, SET 3 - NUMBERS

7. Gasoline has a density of 5.83 pounds per gallon. What volume tank would you need to store three tons of gasoline?

This problem is likely best done with W5P method because it asks for a volume when you are given a density and a weight. The units are all English system. Notice that the formula has to be for the English system weight density.

GIVEN: D_w = 5.83 #/gal, F_w = 3.00 tons
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a volume, V
The question asks for a volume, V. You know the symbol for volume from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $D = F_w/V$
You know the weight and the density. You are asked to find a volume. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the volume. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $D_w = 12.0$ ft, $F_w = 17.0$ ft.

FIND: a volume, V

ORIGINAL FORMULA **SOLVED FOR** **SUBSTITUTION** **DA** **RAW ANSWER** **ANSWER**

$$D = \frac{F_w}{V} \qquad \frac{V\cancel{D}}{\cancel{D}} = \frac{F_w\cancel{V}}{\cancel{V}D} \qquad V = \frac{F_w}{D} = \frac{(3\ \cancel{\text{tons}})\ \frac{\text{gal}}{\cancel{\#}}}{(5.83\ \cancel{\#/\text{gal}})}\left(\frac{2000\ \cancel{\#}}{\cancel{\text{ton}}}\right) = \boxed{1029.16\ \text{gal}} = \boxed{1.03\ \text{E3 gal}}$$

The calculator math is: 3 ÷ 5.83 x 2000 =

ANSWER: Notice the way the units of density in the denominator were handled (in red). The complex units presenting a fraction in the denominator can be simplified by inverting and placing in the numerator. The same set of units could be represented by the gallon unit in the numerator and the pound unit in the denominator. All of these are the same, but the less complicated the units appear, the less likely you are to make a mistake as you arrange the problem. Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #8, SET 3 - NUMBERS

8. The bathtub in the residential suite of the White House had to be enlarged for Warren G. Harding. He weighed 370 pounds. (Burp.) The bathtub is four feet wide, six feet long and three feet high. How many gallons of water are needed to fill the WGH Memorial Bathtub? (1 gal = 231 cu.in.)

This problem is likely best done with W5P method because it asks for a volume (in gallons) when you are given three lengths. The units are all English system.

GIVEN: $l_1 = 4.00$ ft, $l_2 = 6.00$ ft, $l_3 = 3.00$ ft,
You know this from the units and dimensions table in the Units section of Chemtutor.

We could list Warren G. Harding's weight here as part of the given material, but the equation does not need that information, so we would do just as well to leave it out.

FIND: a volume, V
The question asks for a volume, V. You know the symbol for volume from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $V = l\,l\,l$
You know three lengths. You are asked to find a volume. The formulas come from the formula section of Units in Chemtutor.

SOLVE: The known and memorized formula is already solved for the volume. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: $l_1 = 4.00$ ft, $l_2 = 6.00$ ft, $l_3 = 3.00$ ft,

FIND: a volume, V

ORIGINAL FORMULA SOLVED FOR	SUBSTITUTION	DA	RAW ANSWER	ANSWER
$V = lll$	$V = (4\cancel{ft})(6\cancel{ft})(3\cancel{ft})$	$\left(\frac{12\ \cancel{in}}{\cancel{foot}}\right)^3\left(\frac{gal}{231\ \cancel{in^3}}\right) =$	$\boxed{538.5974\ gal} =$	$\boxed{539\ gal}$

The calculator math is: 4 x 6 x 3 x 12 x 12 x 12 ÷ 231 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. The raw answer does not need to be in scientific notation, but must be rounded to three significant digits.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #9, SET 3 - NUMBERS

9. The density of water is 8.34 #/gal. What weight of water is needed to fill the WGH Memorial Bathtub?

This problem is likely best done with W5P method because it asks for a weight when you are given an English weight density and a volume from the previous question. The units are all English system.

GIVEN: D_w = 8.34 #/gal, V = 538.6 gal (from #8)
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a weight, F_w

The question asks for a weight, Fw. You know the symbol for weight from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $D_w = F_w/V$

You know a weight density and a volume. You are asked to find a weight. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the weight. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: D_w = 8.34 #/gal, V = 538.6 gallons

FIND: a weight, F_w

ORIGINAL FORMULA	SOLVED FOR	SUBSTITUTION	DA	RAW ANSWER	ANSWER
$D = \frac{F_w}{V}$	$DV = \frac{F_w \cancel{V}}{\cancel{V}}$	$F_w = DV = \left(\frac{8.34\ \#}{\cancel{gal}}\right)$	$\left(\frac{538.6\ \cancel{gal}}{1}\right)$	$= \boxed{4491.924\ \#}$	$= \boxed{4.49\ E3\ \#}$

The calculator math is: 8.34 x 538.6 ÷ 12 ÷ 17 x 12 = or just: 51 ÷ 17 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #10, SET 3 - NUMBERS

10. Mercury is 13.6 kg/liter. What mass of mercury is needed to fill the WGH Memorial Bathtub?

This problem is likely best done with W5P method because it asks for a mass when you are given a density and a volume (from #8 again). The units of mass and density are metric, but you know only an English volume for the bathtub.

GIVEN: D = 13.6 kg/liter, V = 53.86 gal
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a mass, m
The question asks for a mass, m. You know the symbol for mass from the units and dimensions table in the Units section of Chemtutor.

FORMULA: D = m/V
You know a volume and density. You are asked to find a mass. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the mass. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: D = 13.6 kg/liter, V = 538.6 gal

FIND: a mass, m

$$\begin{array}{cccccc} \textbf{ORIGINAL FORMULA} & \textbf{SOLVED FOR} & \textbf{SUBSTITUTION} & \textbf{DA} & \textbf{DA} & \textbf{ANSWER} \\ D = \frac{m}{V} & D\,V = m & m = \left(\frac{13.6\ \text{kg}}{\cancel{\text{liter}}}\right)\left(\frac{538.6\ \cancel{\text{gal}}}{1}\right) & \left(\frac{\cancel{\text{liter}}}{1.06\ \cancel{\text{qt}}}\right) & \left(\frac{4\ \cancel{\text{qt}}}{\cancel{\text{gal}}}\right) = & \boxed{\begin{array}{c} 2764.13585\ \text{kg} \\ \text{OR} \\ 2.76\ \text{E3}\ \text{kg} \end{array}} \end{array}$$

The calculator math is: 13.6 x 536.8 ÷ 1.06 x 4 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #11, SET 3 - NUMBERS

11. The velocity of light is 186,000 mi/sec. It takes radio signals 17.6 minutes to go from Earth to Jupiter at their closest approach. How far apart are the two planets at that time?

This problem is likely best done with W5P method because it asks for a distance when you are given a rate (or velocity) and a time. The units are English system from the miles. The time units are both metric and English.

GIVEN: v = 186,000 miles, t = 17.6 minutes
You know this from the units and dimensions table in the Units section of Chemtutor. Notice that the "v" for velocity is the lower case "v."

FIND: a length, d

The question asks for a length or distance, d. You know the symbol for length from the units and dimensions table in the Units section of Chemtutor. The symbol "d" is used for distance because the rate equation uses that.

FORMULA: v t = d

You know a velocity and a time. You are asked to find a distance. The formulas come from the formula section of Units in Chemtutor.

SOLVE: The distance is already solved for in the known equation. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: v = 186,000 miles/second, t = 17.6 minutes

FIND: a length, d

ORIGINAL FORMULA SOLVED FOR	SUBSTITUTION	DA	RAW ANSWER	ANSWER
$v\,t = d$	$d = \left(\frac{1.86\text{ E5 mi}}{\cancel{\text{sec}}}\right)\left(\frac{17.6\,\cancel{\text{min}}}{1}\right)$	$\left(\frac{60\,\cancel{\text{sec}}}{\cancel{\text{min}}}\right) =$	$\boxed{196{,}416{,}000\text{ mi}} =$	$\boxed{1.96\text{ E8 mi}}$

The calculator math is: 1.86 E 5 x 17.6 x 60 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #12, SET 3 - NUMBERS

12. A car takes on 22.7 L of gasoline. How many Floz is that?

Remember that a fluid ounce (Floz) is a unit of volume whereas an ounce (Oz) is a unit of force or weight.

This problem is clearly a DA - only problem because it asks you to convert from liters, a metric unit of volume to fluid ounces, an English unit of volume. Here is a list of the definitions to use:
1 liter = 1.06 quarts (the bridge to the English system in volume)
1 quart = 2 pints
1 cup = 8 Floz

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{22.7\ \cancel{\text{L}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{1.06\ \cancel{\text{qt}}}{\cancel{\text{liter}}}\right)}\overset{\text{DEF.}}{\left(\frac{2\ \cancel{\text{pt}}}{\cancel{\text{qt}}}\right)}\overset{\text{DEF.}}{\left(\frac{2\ \cancel{\text{cup}}}{\cancel{\text{pt}}}\right)}\overset{\text{DEF.}}{\left(\frac{8\ \text{Floz.}}{\cancel{\text{cup}}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{769.984\ \text{Floz.}}} = \overset{\text{ANSWER}}{\boxed{\begin{array}{l}77\bar{0}\ \text{Floz. OR}\\ 7.70\ \text{E2 Floz.}\end{array}}}$$

The calculator math is: 22.7 x 1.06 x 2 x 2 x 8 =
The treatment of the answer in this case is interesting. The number is actually too small to need to be written in scientific notation. (It is less than 1000.) But the number "770" just as it is suggests only two significant digits. There are two ways to make sure the three significant digits are recognized. Writing the number in scientific notation at the "E2" level or placing a bar over the training zero will show that the third digit, the zero, is significant.

calculator

Back to Problem set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #13, SET 3 - NUMBERS

13. Osmium metal is 22.0 g/mL. What's the volume of 2.50 kg of it?

If you recognize "22.0 g/mL" as a density, you know your units. If you don't notice it as a density, you might have some trouble knowing what to do with the entire problem. Once you see that, the problem is easiest done with W5P method because it asks for a volume when you are given a density and a mass. The units are all metric.

GIVEN: D = 22.0 g/mL m = 2.50 kg
You know this from the units and dimensions table in the Units section of Chemtutor.

FIND: a volume, V
The question asks for a volume, V. You know the symbol for volume from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $D = {}^{m}/V$
You know a density and a mass. You are asked to find a volume. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the volume. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: D = 22.0 g/mL m = 2.50 kg

FIND: a volume, V

ORIGINAL FORMULA	SOLVED FOR	SUBSTITUTION	ALG	DA	RAW ANSWER	ANSWER

$$D = \frac{m}{V} \qquad V = \frac{m}{D} \qquad V = \frac{(2.50\ \cancel{kg})}{(22.0\ \cancel{g/ml})}\left(\frac{ml}{\cancel{g}}\right)\left(\frac{E3\ \cancel{g}}{\cancel{kg}}\right) = \boxed{113.636\ ml} = \boxed{114\ ml}$$

The calculator math is: 2.5 ÷ 22 x 1000 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #14, SET 3 - NUMBERS

14. Concentrated sulfuric acid is 1.84 kg/L. What is the mass of 500 mL of it?

Again you need to see that 1.84 Kg/L is a density. Once you know that you have a density and a volume and need a mass, the problem seems a lot easier. W5P can be used here. The units are all metric.

GIVEN: V = 500 mL D = 1.84 kg/L
You know this from the units and dimensions table in the Units section of

Chemtutor.

FIND: a mass, m

The question asks for a mass, m. You know the symbol for mass from the units and dimensions table in the Units section of Chemtutor.

FORMULA: $D = {}^{m}/V$

You know a density and a volume. You are asked to find a mass. The formulas come from the formula section of Units in Chemtutor.

SOLVE: Solve for the mass. Substitute the known values from GIVEN into the working equation, simplify, and do the math. Here the math includes some DA to get the units right.

WHAT YOU WRITE DOWN SHOULD LOOK LIKE THIS:

GIVEN: V = 500 mL D = 1.84 kg/L

FIND: a mass, m

ORIGINAL FORMULA **SOLVED FOR** **SUBSTITUTION** **DA** **ANSWER**

$$D = \frac{m}{V} \qquad m = DV \qquad m = \left(\frac{1.84\ \mathrm{kg}}{\cancel{\mathrm{liter}}}\right)\left(\frac{500\ \cancel{\mathrm{ml}}}{1}\right)\left(\frac{\cancel{\mathrm{liter}}}{\mathrm{E3}\ \cancel{\mathrm{ml}}}\right) = \boxed{0.920\ \mathrm{kg}}$$

The calculator math is: 1.84 x 500 ÷ 1000 =

ANSWER: Calculate the numerical answer, show your cancellation of the units, and show the raw answer (the units that remain and the number on your calculator). Change the raw answer to the correct number of significant digits and change into scientific notation if the answer is greater than 1000 or less than 1/1000. No change from the raw answer is needed here if you leave it in units of kg.

calculator

Back to Problem Set #3, W5P and DA problems.

ANSWER AND DISCUSSION
PROBLEM #15, SET 3 - NUMBERS

15. A man is 5 ft. 11 inches tall. How many meters is that?

This problem is clearly a DA - only problem because it asks you to convert from feet and inches to meters. Notice the English measurement of length is a mixed number, that is, the distance is "5 feet plus eleven inches." In order to use this in the DA type of math, it will be necessary to convert it to either feet or inches. It is often useful to think in DA even for such a small operation.

5 ft (12 in/ft) = 60 inches and add the 11 inches to it to make 71 inches.

Here is a list of the definitions to use:
1 inch = 2.54 cm (the bridge from English to metric in length)
1 m = 100 cm

As for any DA problem, begin with what you know and use the definitions as conversion factors so you can cancel the units you don't want and leave the units you do.

$$\overset{\text{GIVEN}}{\left(\frac{71\ \cancel{\text{in}}}{1}\right)}\overset{\text{DEF.}}{\left(\frac{2.54\ \cancel{\text{cm}}}{\cancel{\text{in}}}\right)}\overset{\text{DEF.}}{\left(\frac{\text{m}}{100\ \cancel{\text{cm}}}\right)} = \overset{\text{RAW ANSWER}}{\boxed{1.8034\ \text{m}}} = \overset{\text{ANSWER}}{\boxed{1.80\ \text{m}}}$$

The calculator math is: 71 x 2.54 ÷ 100 =

calculator

Back to Problem set #3, W5P and DA problems.

Back to the beginning of Numbers and Math

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Chemtutor Clickwrap Agreement for Tutors

IMPORTANT - READ CAREFULLY: This Clickwrap Agreement is a legal agreement between you and Chemtutor, LLC, a limited liability company organized and existing under the laws of the State of Georgia, (“Chemtutor,” “we,” or “us”). You are a chemistry teacher or otherwise believe you are qualified to tutor students in chemistry. By clicking “accept” below you will be agreeing to the terms of this Agreement. Furthermore, by clicking "accept" you do confirm to us that you are “signing” this Agreement for all purposes under applicable law.

Chemtutor Agreement for Tutors

This Agreement constitutes the entire agreement between you and us with respect to your being listed as a “Tutor” on our website and supersedes any proposal or prior agreement, oral or written, and any other communication between you and us relating to the subject matter of this Agreement. By clicking the “accept” button you have accepted the terms of this Agreement.

1. **Background:** We own and operate the Chemtutor website with the URL www.chemtutor.com (the “Website”). The purpose of the Website is to provide information about high school and college chemistry to visitors to the Website and to provide a system for matching students with prospective tutors.

2. **Term:** The “Term” of this Agreement will begin on the date you click that you “accept” the terms of this Agreement and end upon thirty (30) days prior notice from one party to the other that the Term has ended except that the Term will end immediately if you breach or otherwise fail to comply with a term of this Agreement. If we terminate prior to the end of a period for which you have already paid other than for good cause, we will refund to you a pro

rata percentage of the amount you paid us based on the time that was remaining as of the date of termination. If either you terminate early, or we terminate early for good cause, you will not be entitled to any refund. . "Good cause" includes, but is not limited to, a material breach of this Agreement, a complaint from a student or any concern about your lack of ability as a tutor or danger to our students.

3. **Reservation of Right to Change Terms:** We reserve the right to change any term of this Agreement by either making the change available to be viewed on this Website and/or sending an email to the last email address you have given to us and such change will be effective immediately with respect to any renewal. With respect to any period for which you have already paid, such change will be effective unless you object to the change within thirty (30) days from the date of such notice. If you object, we will have the right to either terminate the Term hereunder or agree that the change does not apply to you. If we then terminate the Term early, we will owe you a pro rata refund of whatever sum you have paid us based on the percentage of the period for which you paid for which the Term will not apply.

4. **Account and Password:** You are responsible for maintaining the confidentiality of your account name and password. You are solely responsible for uses of your account, whether or not authorized by you. You agree to immediately notify us of any unauthorized use of your account.

5. **Listings:** If you meet our criteria and pay the required sum, you will be permitted to list your contact information with us. It is understood that your providing a listing with us does not guaranty any referrals. We reserve the right to decide the manner and method for determining which tutors will appear in any search solely at our discretion. In this regard we may decide that your information will not appear in any listings for any period of time, including, but not limited to, the remaining term of this Agreement, because of complaints we receive about you, concerns we have about you or for any other reason that we determine it would be in the best interest of the students that your information not appear.

6. **Charge for Listings:** You agree to pay us the sum set forth on the Web Site applicable to you for the period set forth therein.

7. **Representations and Warranties:** You represent and warrant to us that all of the information that you have submitted to us is true and correct and understand and recognize that we are relying on your representations in listing you in our data base.

8. **Disclaimer:** You recognize and agree that we are providing all the services we provide "as is" without warranties of any kind, either express or implied, including, but not limited to, warranties of title or implied warranties of merchantability, fitness for a particular purpose, compatibility, security, accuracy or non-infringement. To the fullest extent permitted by law, we and our members, managers, shareholders, directors, advisors, attorneys, agents, employees, officers, suppliers and subcontractors (the "Chemtutor Parties") make no warranties and shall not be liable for any use of or circumstances relating to the use of this Website including, but not limited to, for negligence. We do not represent or warrant that the purported students are actually students, that the students will pay for the services, or that it is safe to meet

them—we do not and have not taken any steps to verify that the students are in fact students or screen them for prior criminal or other acts.

9. **Indemnity:** You hereby agree to indemnity and hold us and the other Chemtutor Parties harmless from any and all losses, including, but not limited to, attorneys fees, that any one or more of the Chemtutor Parties may incur as a result of your violation of any of the terms and conditions of this Agreement, including, but not limited to, your breach of any of the warranties or representations. You further agree to indemnify and hold each of the Chemtutor Parties harmless from any and all losses, including, but not limited to, attorneys fees, that any one or more of the Chemtutor Parties may incur as a result of any claims by you against any one or more of the Chemtutor Parties even if such claim is based on the negligence of any one or more of such parties.

10. **Limitation of Liability:** You assume full responsibility and risk of loss resulting from your use of this website and any information on this website and relating to services you provide as a result of being contacted as a result of the information you provide on this website. under no circumstances shall we or any of the other chemtutor parties be liable for any indirect, punitive, special or consequential damages even if we or any of the other chemtutor parties have been advised of the possibility of such damages. our total liability in any event is limited to the amount, if any, you have actually paid us and you hereby release us and the other chemtutor parties from any and all obligations, liabilities and claims in excess of this limitation. the limitations set forth in this section are in addition to all of the other disclaimers and limitations of warranties and liabilities set forth in this agreement.

11. **Restrictions:** You agree to the following restrictions:

(a) You will not reprint, republish or distribute in any way, any information or materials found on our Website except as expressly permitted on the Website.

(b) You will not use any of the information on our Website for sending emails or for solicitation purposes or for any other purposes involving solicitation in any way.

(c) You will not provide to us or post on our Website any information that is incorrect, such as an incorrect name, address, email address or any other incorrect information in a resume or otherwise.

(d) You will not post any information that is defamatory, obscene, threatening, abusive or hateful.

(e) You will not access data not intended to be accessed by users of the site or attempt to probe, scan or test the vulnerability of our site or attempt to interfere with any service available on our site, change postings of others on our site, take other actions which impose an unreasonable or disproportionate load on our site, send unsolicited email, including promotions and/or advertising of products or services, to addresses obtained from our site, forge any email address, newsgroup or name in connection with this site and/or use a password, name or identification which is not your own in accessing our site.

(f) You will not attempt to decipher, decompile, disassemble or reverse engineer any of the software comprising or in any way used on our website.

(g) You will not post any materials on our site in violation of any other party's rights, including, but not limited to, copyrights or privacy and publicity rights.

12. Miscellaneous

12.1 Governing Law. This Agreement shall be governed by and construed in accordance with the law of the State of Georgia.

12.2 Further Actions. You agree to execute any and all documents and take any other actions reasonably required to effectuate the purposes of this Agreement.

12.3 Counterparts. This Agreement may be executed in counterparts, each of which shall be deemed an original but all of which shall constitute one and the same instrument.

12.4 Interpretation. The fact of authorship by or at the behest of a party shall not affect the construction or interpretation of this Agreement.

12.5 Relationship of the Parties.

(a) The parties agree that there is not and will not be any partnership, joint venture, employer-employee, master-servant, or franchisor-franchisee relationship between the parties hereto.

(b) In connection with the above, you agree and acknowledge that you are and will be responsible for paying any employees working for you, making deductions required by law, and reporting compensation for such employees as required by law. You hereby represent and warrant that you have to date filed and will in the future file all Federal and State income tax returns on your income when due. You further represent and warrant that you have to date paid, and will in the future pay, all taxes and assessments on your income required under applicable law including Federal and State income taxes and FICA.

(c) You hereby agree to indemnity and hold us harmless from any and all claims, including attorney’s fees, that may be incurred by you resulting from your failure to comply with any provision of this section of this Agreement including any violation of the warranties and representations set forth herein.

12.6 Amendments. No amendment or other change of this Agreement shall be effective unless and until set forth in writing and signed on behalf of each of the parties.

12.7 Entire Agreement. This Agreement embodies the entire agreement and understanding of the parties and supersedes all prior agreements, representations and understandings between the parties hereto relating to the subject matter hereof.

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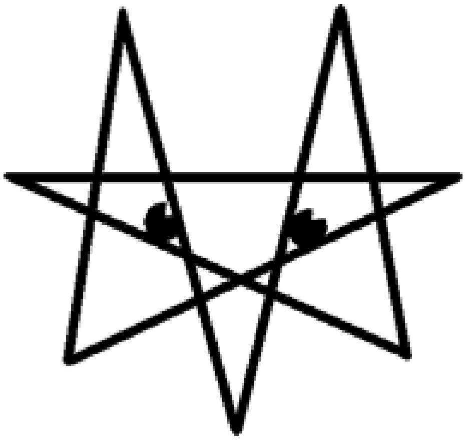

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