Solving Word Problems in Chemistry

Supplemental Notes

Most people spend more time and energy going around problems than in trying to solve them. – Henry Ford

"So when will I ever to use this stuff?"

It would be quite a challenge to find a teacher who has not heard that question at least once. Fundamentally, this is an important question to ask. When *will* you ever use ionic nomenclature, or Graham's Law, or the mole concept in everyday life? Statistically speaking, you never will. Only the fraction of students who ultimately pursue technical careers will even have a chance of using this stuff, and then most likely only if they pursue careers in chemistry or chemistry-related industries.

However, what you will use – to a greater extent than you will ever believe (coming from any teacher, anyway) – are the critical thinking and problem analysis abilities that come with mastery of chemistry content. You may never titrate another weak acid in your entire life, but you will have to approach complex (and sometimes multiple-step) problems. Chemistry courses make it comparatively easy - most of the information you need to solve a problem is right there on the paper in front of you, or at least as close as your notes. It is typically presented in a logical order (or, at least, is relatively organized). Since the course is chemistry, you can make certain metacognative assumptions about the direction the information provided is leading you. For the sake of getting a concept to sink in, many times the material is simplified from its real-life conditions. When you put all of these things into perspective, even the most complex chemistry problems can be solved with relative ease. And if you still have trouble, well, a little partial credit here, a few points for getting the right idea there, and suddenly you have a passing grade. The problem becomes, well, no problem.

Now consider a real-world problem, which will be complex and have multiple (generally, many) steps. The disciplines required for solving it will almost definitely not be restricted to chemistry, so most metacognative assumptions are irrelevant. Data or information that is provided (if there is any provided at all) may be incomplete, unnecessary, and is usually presented out of order. You will need to call on prior knowledge for almost anything that can be considered even remotely fundamental. Information is also found with arresting frequency to be inaccurate or completely false, or, in rare cases, *falsified* (and there are some people whose jobs are exclusively to determine when this has happened. There is no such thing is partial credit - if you build a bridge, and it collapses into the ravine just as the first hundred cars embark on it, you can safely bet that the families of the victims are not going to pat you on the back for giving it your best.

Solving problems is an everyday commitment – and as much as you hate to hear it over and over again, you only learn it by practicing. You solve a problem every time you figure your way around a traffic jam, select clothes for the day, or decide what to have to eat at the food court. You may hate chemistry, but the bottom line is that chemistry content simply provides a context for learning – you cannot solve a problem about nothing. The advantage of using science or math or psychology or whatever in context to solve problems is because, maybe, just maybe, you will find that you have some interest in one of those areas, and you will quickly find yourself heading down your life's path towards what you really love. And it's not always obvious – there are “professional” wrestlers who studied to be accountants, and funny car drivers who have advanced degrees in mathematics (true stories, both).

Learning to effectively solve word problems in chemistry requires you to polish three of the most important life skills you will ever acquire – mathematical competency, reading comprehension, and critical thinking. Mathematical competency speaks for itself – no amount of understanding of the problem will allow you to arrive at an answer without the ability to effortlessly perform the necessary computations. Reading comprehension skills are necessary to decipher the problem in the first place, to determine what is given, what it means, and what answer the question requires. Finally, critical thinking is necessary to bridge the gap between the other two skills – taking what you have been given, adding any prior knowledge that might be required, set up the steps of the problem, and follow each one to the final answer.

Once you have mastered these three general skills (and it not the intention of this paper to trivialize the time required and difficulty in doing just that), thinking your way through complex problems becomes far easier. Remember – practice is the key. Like a strong muscle, these skills do not mature overnight. This reference is intended only to serve as a framework for your thinking. Every problem is different, so no structured list of steps applies in every situation. You must practice solving problems, review the solutions, and learn to think in just the right way. Also like a muscle, these skills can atrophy with disuse, so stay current in your coursework and practice on your own. The reward will be well worth the effort.

Skills Requirements

There is a substantial set of basic skills that you, the student, must have mastery of prior to approaching any chemistry word problem. For reinforcement of any of these, materials and inquiry activities are available in this series of resource papers.

The following skills are **required** for all chemistry students:

- A strong grasp of the **metric system**, including:
  - The names of the **seven base units** and what they quantify
  - All of the common-usage **prefixes and their magnitudes**
  - How **derived, or compound, units** are determined and assembled
- Basic but confident **algebra** skills including the ability to **rearrange a multivariable equation** to represent a specific quantity
- Representing and manipulating **exponents** and **logarithms** will be required for more advanced chemistry topics
- Converting numbers from decimal to **scientific notation**, properly formatted, and back again
- The ability to determine the **precision** of a measurement or a reported value
- Knowledge of proper representation of **significant figures**
- The technique of **dimensional analysis** (also called the **factor-label** method) to convert units, which will also be important in stoichiometric and thermochemical calculations
- The concept of the **mole** in its various forms
- Know how to **use your calculator** to properly input exponents, scientific notation, and preserve the **correct order of operations**
- **Fundamental physical science vocabulary** – terms you should know before attempting any physical science course (see Appendix)

Finding the Answer

Summary of Problem-Solving Steps

No problem can stand the assault of sustained thinking. – Voltaire

1. **Get Your Bearings**
   - Look the problem over
   - Resist the urge to just start writing
   - Use stand-outs to get a sense of where the problem will take you
   - Be confident that you have the background to solve the problem

2. **Read, Read, Read!**
   - Put your pencil down
   - Read the problem several times to get strong familiarity
   - Determine the exact question
   - Take mental note of important information and key words

3. **Organize the Given Information and Develop a Plan**
   - Identify a starting point
   - Always head for the answer
   - Follow your instincts
   - Highlight important information
   - Assign values to variables

4. **Solve**
   - Use formulas that make sense
   - Use references whenever available
   - Be wary of significant figures and units
   - Be confident in your abilities

5. **Check Your Work**
   - Did you answer the question?
   - Does the scale and sign of the answer make sense?
   - Be confident in the work you have done

6. **Metacognition**
   - What were you thinking?

Step 1: Get Your Bearings

We are too busy mopping the floor to turn off the faucet. -- Unknown

First, put down you pen or pencil. You will not need it just yet. If you think having it in front of you might be too tempting, then put it somewhere that makes it a little harder to get to.

All too often, a problem is presented to a student, and, out of sheer terror at the prospect of a poor grade, the student proceeds to start somewhere in the middle and ultimately ends up with an ever-enlarging snowball that becomes more overwhelming and inescapable than the problem ever was to begin with.

It is important to resist the feeling of intimidation when first confronted with a word problem, especially one that covers a full page (or sometimes more – New Jersey standardized tests include constructed response questions that include data and information spanning four pages!). Word problems are designed in such a way that, to the untrained solver, they *are* intimidating, and rightly so - they are the ultimate test of your logical thinking and reading comprehension.

Resist the urge to immediately dig for the question and start plugging numbers into equations. Resist the urge, even, to start reading the problem! The purpose of this step is to give you a sense of what you are up against, not to start solving.

As with any large body of text or information, it is necessary to skim the entire question. Take a look at any data tables, graphs, or diagrams provided, and ask yourself a few questions. Does anything pop out? Is there anything in italicized or boldfaced text? Is there something in color among black and white items? Do any large (or small) numbers catch your attention? Are there any chemical formulas or equations immediately obvious? Do the graphs make immediate sense, or are they going to require some additional context from the problem?

Without reading the question thoroughly (which, to reiterate, you should not be doing yet!), the idea is to get some sense of what solving the question will entail. If (to use a simple example) a question provides data tables on water quality tests and statistics on suspicious illnesses in the northeastern United States, you can estimate that the question will involve a link between the two. While this technique is not foolproof, it is at least a way to get a look at everything provided quickly and all at once.

Lastly, your confidence plays a major role in your success when solving a word problem. If you glance at the sheet, get immediately intimidated by all of the graphs and data and formulas and cry out “I can’t do this!” chances are – you guessed it – you will not be able to do it. Be confident that you have done your part – studying, focusing on the lessons in class, and completing relevant assignments – because if you have, you have nothing to fear.

This entire step may take only a few seconds, or as long as a few minutes, but the general sense of the problem obtained is worth much more than the time spent.

Step 2: Read, Read, Read!

Do not pick up that pencil yet!

Now, read the problem. Once. Twice. Eight times, if you have to. You need intimate familiarity with the language of the problem, so read and reread it with this in mind. A passing familiarity will not, unfortunately, result in a passing grade. The familiarity to which I refer is the kind to which you might have with a close friend or relative's house – although you cannot necessarily describe every nook and cranny, you can explain the floor plan, the colors of the rooms, etc. So is it with word problems. You do not necessarily have to be able to recite that the mass of the polymer sample on the analytical balance was 21.3452 grams, but you should at least remember that there *was* a polymer sample.

When you read the problem, there are many things you must be aware of as you go. So many, in fact, that you generally will not pick everything up on the first pass (hence the command at the beginning of this section to read the problem more than once). At this point, the goal is to determine the question being asked (more on this below), given values or data (and their units!), provided equations or stated relationships, any implied relationships (more on this below, as well), and key words.

Key words can be hugely important – that is why they have their name. Most word problems contain key words intended to guide you in the direction of the correct procedure to solve the problem. For example, if a problem mentions that a particular compound "decomposes during the process," then it follows that the reaction involved for this compound must be a decomposition reaction. The key words could be more subtle; they could offer hints to the scale of the answer ("A large quantity of salt is recovered from the water."), the direction of heat flow ("The reaction vessel must be cooled..."), the quantity of reactants consumed or available ("Oxygen from the air is allowed to react..."), or perhaps some general condition or physical property ("…and the system is open to the air."). Whatever the situation, it is up to you to determine what terms are key words, and what their significance is to the problem's solution. This is a task that can be perfected only through experience, so the more practice you can do, the better at it you will become.

Step 3: Organize the Given Information and Develop a Plan

There's more than one way to look at a problem, and they all may be right. – Norman Schwarzkopf

Now that you have finished reading, you can retrieve your writing implement. Write down the question that the problem is asking you to answer. If the answer will be numerical, make a note of the unit (or, if this is not yet evident, the type of unit [mass, molarity, etc.]) that the answer must be reported in. If the answer will be non-numerical, make a note as to the exact scope of the answer and any key words it must contain. Read through the problem again, underlining or otherwise highlighting important information and assigning values to variables wherever you can.

The two parts of this – determining what the question asks for and assigning values to variables – are particularly critical because they will help you determine which formulas and equations are required to solve the problem. Also, things that you already know (called prior knowledge) will help you fill in gaps in the information – constants or molar masses, for example. Be sure to filter out the superfluous information. This might be as simple as ignoring a block of background information, or as difficult as determining pieces of information intentionally included but unnecessary to solve the problem.

Once you've determined the given information and the question being asked, identify a starting point. Do you need to convert the given values to different units? Do you need to derive or rearrange the proper equation? Or can you just plug in known values and begin solving? Is there a useful diagram included, or can you create one? Is there any information not given that you already know that might come in handy? Write down whatever comes to mind, but don't overdo it – info-dumping everything you can think of onto the page will just consume time and could confuse what's already given.

No matter what plan you use, what approach you take, what route you follow, there is one immutable, consistent truth that must exist no matter what: whatever steps you take, equations you solve, or assumptions you make, **they *must* take you one step closer to the solution**. Even if the work you do seems lateral in nature (that is, you're solving for something "on the side" that you need to be able to continue with your main plan), it should have some bearing on the solution. At no time should you be working on anything that has no relevance to your solution.

Step 4: Solve

Now that you have selected the formulas and equations that you think you will need, and you have decided on a sequence of steps (if the problem requires more than one step), grab your calculator and solve the problem.

Be aware of the requirements for significant figures, scientific notation, and unit conversions if any of these things are necessary. Be sure to transcribe properly the values that your calculator produces to the paper you are working on. Label *everything* with correct units, even values in simple formulas – this will help you keep track of your units as you go and help you check yourself if you make a mistake.

Write everything down – do not do any work just in your calculator or, worse, in your head. Students frequently do just this in an attempt to save time, or when they think the problem is too "easy." You may need to refer back to your work or the calculated values later, or, if you find an error down the road, you may need to refer to the setup and calculations to try to determine where the error began.

Most importantly, be confident in your math proficiency. The answer is out there – just think carefully and logically and you can find it.

Step 5: Check Your Work

When you finish solving, ask this simple question: Have you answered the *exact* question being asked? Solving equations, for example, and providing a numerical response, no matter how brilliant your work, does not answer the question "Will Jake have enough strong base to complete his titration?" This is a yes or no question, so answer it – yes, or no.

Do your units work out, based on the math you did? This is the simplest check to be sure you did not make a mechanical mistake when arriving at your answer.

Be confident that the work you've done supports the answers you get – even if they "seem wrong." Do not be intimidated by big or small numbers; sometimes, numbers are big, and sometimes, numbers are small. The unit you are working with will also have a substantial effect on the apparent magnitude of your numbers. For example, 3000 *grams* and 3000 *kilograms* are vastly different quantities, even though the magnitudes of their numerical components are identical.

With that said, your answer should make sense. It should fit into a scale that matches the scale of the given information. If the question asks "How many atoms thick is the galvanized coating on the steel plate?" you answer *must* be some whole number, since you cannot have a fraction of an atom. Therefore, an answer like 3.45×10^{-9} does not make much sense, since a negative power of ten indicates a number *less than one*. Similarly, an answer of 10 million liters for a question such as "What is the volume of the solution that results from diluting 1.35 L a 3.4 *M* solution until it is 0.2 *M* ?" should simply not make sense – imagine about how many beakers you would need to see 10 million liters in one place!

Lastly, if there is an alternative way to complete the problem (or at least parts of the problem), and time permits, use these alternative methods to check your answers. The beauty of chemistry is that many roads frequently lead to the same destination!

A Closing Note about Metacognition

While this will prove to be difficult in real world problems with no immediate context, metacognition, or thinking about thinking, can aid in solving a word problem in chemistry. For one thing, the problem is a chemistry problem, which generally narrows the possible topic areas that the problem will cover. If the problem is on an assessment for a particular unit, then the topics from that unit can, obviously, be expected to show themselves in the problem.

Keep in mind that using the context of the problem to artificially determine a way to solve it will only go so far. The cumulative nature of chemistry as a discipline often leads to multi-step problems that span a broad range of topics, and so even an exam that focuses on intermolecular forces might include thermochemistry, or stoichiometry, or any combination of topics. Narrowing your thinking by considering only the current topics being discussed in class may lead to an incomplete solution to the problem, or the inability to solve the problem at all.

Appendix

Important Physical Science Vocabulary

Below is a partial list of the most basic terms you will be responsible for in your Chemistry course. Some of these definitions are simplified and will be elaborated on during your coursework. Others are new and their uses not yet apparent; this will change as you progress through chemistry.

Absolute Zero	The temperature at which molecular motion ceases
Anion	An ion with a negative charge
Atom	The smallest particle that has the properties of an element
Atomic Number	The number of protons in an atom
Avogadro's Number	The specific number of particles in a mole, 6.02×10^{23}
Boiling Point	The temperature at which a liquid becomes a gas
Buoyancy	The force with which a more dense fluid pushes a less dense substance upward
Cation	An ion with a positive charge
Chemical Formula	The chemical symbols and numbers indicating the atoms contained in the basic unit of a substance
Chemical Change	When a substance changes composition by forming one or more new substances
Chemical Properties	The way a substance reacts with other substances
Chemistry	The study of matter and its changes
Compound	A substance made of atoms of more than one element bound together
Condensation	The change of a substance from a gas to a liquid
Controlled variables	All the factors which are kept constant in an experiment
Covalent	A compound formed when valence electrons are shared between two or more atoms to form bonds
Data	Numerical values recorded during an experiment
Data table	Used to organize data
Density	The characteristic of matter that denotes the amount of mass in a fixed volume
Dependent variable	The factor which responds to the change in the independent variable (also called the responding variable)
Electron	A subatomic particle with a negative charge found in the large cloud surrounding the nucleus
Element	A substance that cannot be broken down into simpler substances
Endothermic	A process, usually a chemical reaction, that requires a net intake of energy to occur
Energy	The ability to change or move matter
Evaporation	The change of a substance from a liquid to a gas
Exothermic	A process, usually a chemical reaction, that provides a net output of energy
Experimental error	Sources of deviation or problems that may cause the results of the experiment to be inaccurate – human mistakes are not sources of experimental error
Formula Unit	The smallest particle of an ionic compound

Freezing	The change of a substance from a liquid to a solid
Independent variable	The factor or variable being purposely changed (also called the manipulated variable)
Ion	An atom with a net charge
Ionic compound	A compound formed by the combination of two or more ions joined by powerful electromagnetic attraction
Isotope	Any one of several atoms of the same element with varying numbers of neutrons
Length	The straight-line distance between any two points
Mass	A measure of the quantity of matter in an object
Matter	Anything that has mass and takes up space
Melting	The change of a substance from a solid to a liquid
Melting Point	The temperature at which a solid becomes liquid
Metal	An element with the properties of shiny, lustrous, ductile, and malleable
Miscibility	The degree to which two or more liquids are able to dissolve into one another in various proportions
Mixture	A combination of more than one pure substance
Mole	A measurement of a specific number of particles of a substance
Molecule	The smallest particle of a covalent compound
Molecule	The smallest unit of a covalent substance that exhibits the properties of that substance
Neutron	A subatomic particle with a neutral charge that is found in the nucleus of an atom
Nonmetal	An element that has the properties of dull luster and are not ductile or malleable
Nucleus	The dense core of an atom containing protons and neutrons
Operational definition	Definition of a variable in an experiment (for example, the number of pounds a beam can carry before it breaks)
Percent Error	A measure of a value's deviation from the accepted or theoretical value (as a percentage) due to sources of experimental error, calculated as [(experimental - accepted)/(accepted)] x 100
Physical Change	When the physical form of a substance changes without changing its composition
Physical Property	A characteristic of a substance that can be measured, or changes without changing the composition of the substance
Pressure	Force exerted on a unit of area
Proton	A subatomic particle with a positive charge that is found in the nucleus of an atom
Pure Substance	Any matter that has a fixed composition and definite properties
Qualitative	Observations or descriptions of things noted during the experiment
Quantitative	Numerical measurements taken during an experiment, also called data
Radius	The distance from the center of a circle or sphere to its outer edge
Reaction	A process in which new substances with new chemical and physical properties are formed

Reactivity	The ability of a substance to react with other substances
Salt	Any ionic compound that is not an acid or a base
Sublimation	The change of a substance from a solid directly to a gas
Viscosity	A liquid's tendency to resist flow
Volume	A measure of the space that matter occupies
Weight	The force with which gravity acts on a quantity of matter
x-axis	Location of independent variable in a graph
y-axis	Location of dependent variable in a graph