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ABSTRACT

The concept of the mole and its relationship to chemical algebra is difficult for many high school chemistry students to master. This paper describes a study of the use of proportional reasoning when teaching mole relationships and its effect on developing critical thinking skills. The Test of Logical Thinking (TOLT) was used as a pre- and post-assessment of students' critical thinking skills. An experimental group (n=29) was taught to solve stoichiometry problems by proportional reasoning, while a control group (n=28) used dimensional analysis. From the results, it was concluded that teaching stoichiometric relationships through proportional reasoning had no apparent effect on developing critical thinking skills in the experimental group. There was, however, an apparent improvement in the students' ability to work together toward solutions, to express their thinking processes verbally, and to listen to and evaluate the comments of others. From a survey of 40 local high school chemistry teachers (return rate of 47%), it was found that two-thirds of the teachers used dimensional analysis as their method for teaching stoichiometry. Appended materials include the TOLT, a Critical Thinking and Self-Reflection Checklist, worksheets, laboratory sheets, a stoichiometry test, and a weekly progress questionnaire. (PR)

PROPORTIONAL REASONING IN THE SOLUTION OF PROBLEMS IN HIGH SCHOOL CHEMISTRY AND ITS IMPACT ON DEVELOPING CRITICAL THINKING SKILLS

by

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A Practicum Report

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Abstract

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The concept of the mole and its relationship to chemical algebra is difficult for many high school chemistry students to master. A large number of teachers use dimensional analysis as their method for teaching mole relationships. Other teachers employ proportional reasoning. Teachers prefer the methodology which would enhance students' understanding of mole relationships while developing latent problem solving skills. This study addresses the use of proportional reasoning when teaching mole relationships and its effect on developing critical thinking skills.

The Test of Logical Thinking (Tobin, 1981) was used as a pre and post assessment of students' critical thinking skills. In the interim, a Test group solved unit problems by proportional reasoning. Successful completion of the mole unit using proportions was expected to cause an improved logical thinking score. Analysis of evaluative tools, laboratory activities and unit test showed no significant improvement in logical thinking scores in students who employed proportionalities in the solution of mole problems. However, the development of proportional reasoning skills was an asset to the Test group in subsequent units of study. Appendices and recommendations are included.

Authorship Statement

I hereby testify that this paper and the work it reports are entirely my own. When it has been necessary to draw from the work of others, published or unpublished, I have acknowledged such work in accordance with accepted scholarly and editorial practice. I give this testimony freely, out of respect for the scholarship of other professionals in the field and in the hope that my own work, presented here, will earn similar respect.

Signed:

Janice M. Guthrie

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CHAPTER I

Purpose

Background

The site of this study was a 30-year old religious, coeducational, accredited, private school which has maintained a positive reputation in the community for its facilities, faculty and aggressive college preparatory education. Located on twenty-six acres of land in an upper middle class residential section of south Florida, this board-run school maintained fifteen educational buildings housing almost 1000 students kindergarten through grade twelve (Florida Department of Education, 1990).

At the time of this study, over 320 students in the high school were served by 35 faculty members. According to the 1990 school profile, 60 percent of this faculty possessed at least a masters degree. Classes were maintained at a maximum of 29 students with a student to faculty ratio of 15 to 1. Seventy-four percent of the students were of Caucasian descent, two percent

Black, 20 percent Hispanic and four percent of other nationalities. The school consistently has had 97-100 percent of the graduates attend a college or university. Monies received for the 71 students graduating in 1990 totalled almost $350,000 in academic, athletic and other scholarships (Townsend, 1991).

The researcher was responsible for four introductory chemistry classes, one organic chemistry class and one section of health. These assignments have varied on an annual basis with freedom to modify or offer new courses as deemed by the department head in conjunction with three other science teachers and confirmation by the administration. One of the seven periods each day was designated for planning and preparation. In addition to the teaching assignments, one class sponsorship and one committee chair were assigned. One paid club sponsorship was included in the researcher's responsibilities. The school day began at 7:40 a.m. and ended at 3:30 p.m. for the faculty. Each class was scheduled for 265 minutes per week.

It was the responsibility of the science department to provide the best college preparatory education at the high school level to prepare the graduates for any introductory college science course. Establishing a variety of course offerings and pursuing excellence in teaching methodology were essential for the students to be competitive with other academic students. The science department and administration supported the researcher, allowing freedom to alter teaching strategies or curricula to enhance academic productivity.

Problem Statement

One of the most challenging aspects of teaching introductory high school chemistry is helping students solve problems. These problems require mathematical skills such as solving computations, using formulas, gathering data, reading graphs, making data determinations in the laboratory and thinking critically. Often students bring into the classroom negative mathematics experiences which reinforce walls of anxiety in

chemistry problem-solving (Gabel, 1983). How the teacher handles this problem-solving anxiety would determine, in part, the degree of success in high school chemistry in addition to encouraging or discouraging students taking other higher level chemistry courses.

Problem-solving involves more than rote memorization of an algorithm, plugging in numbers and pressing buttons on a calculator. Such problems are no more than exercises with minimal practical application. Problem-solving is a critical thinking process by which students approach a problem, recognize relationships and plan a method for solution (Schrader, 1987). Successful development of these skills can then be transferred to new situations.

Years ago, after analyzing the responses of high school students to Piagetian tasks which required basic problem solving skills, Lawson and Renner (1977:546) found conclusively that "50 percent or more of the graduating senior high school students have not achieved formal operational ability." Recently, the April 9, 1990

issue of Newsweek confirmed this conclusion when America ranked eleventh out of thirteen countries involved in a chemistry achievement test, ninth in physics and last in biology.

An early stage of problem-solving begins when elementary students are exposed to their first arithmetic story problems in grade one. This is followed by years of a mixture of computation and problem-solving. Unfortunately, elementary teachers are often forced to evaluate primarily on computational skills and, consequently, slight problem-solving situations. The middle and high schools introduce the algebra series followed by geometry, trigonometry and beyond. It appears that problem-solving is not adequately developed at any of these levels (Mayberry, 1991).

In addition to limited problem-solving experience in math, seldom are these experiences applied to other subject areas. Problem-solving skills have been synonymous with mathematics. The life skill of critically thinking through a problem relates to subjects other than mathematics. Economics, history, English, and even trade courses

must involve their own application in developing problem-solving skills (Costa, 1983). The sciences, initially physical science and chemistry, epitomize the integration of math skills and the application of problem-solving strategies.

Beyond the factual information of the chemistry curriculum are a bevy of problem-solving situations. These problems may be in the context of density, gas laws, molarity and molality, equilibrium and other applications. Few, however, loom in teachers' minds as fearsome to students as stoichiometry problems. Here converge math skills, critical thinking and the abstract concept of the mole. Worthy (1989:49) aptly stated that the mole concept embodies "knowledge that is fundamental to all areas of chemistry...." All of the quantitative relationships in a chemical reaction pivot on understanding the mole and its uses in chemical algebra. The dilemma for the chemistry teacher is to relieve math anxiety, capitalize on critical thinking skills and incorporate mole relationships all in one fell swoop. The strategies used in teaching mole relationships and

subsequent stoichiometry problems merit investigation.

There are two widely accepted methodologies for teaching stoichiometric problems: dimensional analysis (factor-label method) and proportions. Some researchers (Bodner, 1987; Gabel, 1983) claim dimensional analysis is easier for teachers to teach and facilitates students arriving at the answer. Opponents of this theory (Cardulla, 1987; Coulter, 1981; Krajcik, 1987; Middlecamp, 1987; Schrader, 1987) claim that students do not use problem solving methods and therefore do not understand their own solutions.

The researcher has taught mole relationships proportionally for twelve of the fifteen years of experience. In the mid 1980's there was a change to dimensional analysis since the textbooks used this method exclusively. The researcher, after teaching the latter method, perceived increased confusion on the part of the students even though the simplicity of the method was stressed.

In examining past class records, the class average on a stoichiometry test given to 63

students in the 1989-90 school year was 72%. This represented a D+ on the school grading scale. In the 1988-89 school year, 51 students averaged 77% on a comparable test. This represented a C- on the school grading scale. Was the difficulty due to differences in teaching methods, low mathematics abilities or a lack of understanding of the mole concept requiring logical thinking? The same teaching methods and exercises had been used in past years with consistently better results. The students in the target school have statistically scored above the national average on mathematics achievement tests. The determining factor in the students' success in stoichiometry, therefore, seemed to lie in their ability to understand the concept of the mole and to use this concept in problem solving situations.

The decision as to the method used in teaching the solution of mole problems should, then, be based on how well the students understand the material. The purpose of this study was to test the effectiveness of proportionalities in teaching stoichiometric relationships. The appropriate

teaching methodology for the caliber of student at the target school resulted in an improved unit test score from the 74.5% (C-) average of the previous two years to 81% (C+).

The target group consisted of 57 students enrolled in introductory chemistry at the study site. The random distribution of these students into four classes was predetermined by computer scheduling. All were in the tenth, eleventh or twelfth grade and ranged in age from 15 to 18 years. Students were currently enrolled in or had completed second year algebra. The Test group of two classes was given instruction in solving stoichiometry problems using proportional reasoning. The other two classes served as the Control and were instructed in the use of dimensional analysis. Evidence of achievement was demonstrated by improved class scores on a unit test of questions and problems requiring understanding of the mole concept and critical thinking skills.

Outcome Objectives

The desired objectives fell into four major clusters. Each cluster dealt with a different aspect of the study.

1. The students will apply introductory logical thinking skills when balancing chemical equations and classifying types of reactions.

1.1 After one week of instruction and practice, 80% or 46 of the 57 chemistry students will correctly balance 8 out of 10 chemical equations as measured on a quiz.

1.2 After the second week of instruction and practice, 80% of the students will classify 20 reactions as belonging to one of four major types with 85% accuracy as measured on a quiz.

1.3 After two laboratory periods, 76% or 43 students will score an 84% or higher on a lab activity demonstrating types of chemical reactions.

1.4 After the fourth week of instruction, 80% of the students will predict the products of single and double replacement reactions with a score of 84% or more as measured on a quiz of 10 problems.

1.5 After four weeks of instruction and the completion of the introductory material on stoichiometry, 76% of the students will score a 75% or more on a test of 45 questions and problems which incorporate the above-mentioned skills.

2. The students will interpret and solve stoichiometry problems relating to moles.

2.1 After five weeks of instruction and practice in the stoichiometry unit, 80% or 46 of the 57 chemistry students will calculate the gram atomic mass and gram formula mass of ten compounds with a score of 80% or more as measured on a quiz of 10 problems.

2.2 After six weeks of instruction and practice, 80% of the students will perform one-step mole problems with a score of 75% or more as measured on a quiz of 10 problems.

2.3 After seven weeks of instruction, 50% of the students will determine experimentally the GAM of silver with a percent error of less than 50%.

2.4 After eight weeks of instruction and practice, 76% of the students will process two-step

mole problems with a score of 75% or more on a quiz of 10 problems.

2.5 By the ninth week of the instruction, 76% of the students will correctly interpret the coefficients of a balanced chemical equation with a score of 75% or more as measured by a quiz of 12 questions.

2.6 By the tenth week of instruction and practice, 76% of the students will derive quantitative information about reactants and products with a score of 75% or more as measured by a quiz of 10 questions.

2.7 By the eleventh week, all students will have completed two additional laboratory activities with a score of 75% or better as measured by the laboratory worksheets.

2.8 After completion of the unit, 76% of the students will earn a score of 75% or better on the unit test of 50 questions which incorporates all skills learned in the unit.

The objectives in cluster one and two will take 11 weeks to accomplish.

3. The students will improve critical thinking skills.

3.1 After completion of the unit, 65% of the students will increase their critical thinking skills by 7% (one point) or more as measured by the pretest and posttest scores on a paper and pencil test of logical thinking.

4. The students will maintain confidence in working mole problems.

4.1 Throughout the unit, 70% of the students will express either a consistent or improved attitude toward working mole problems as measured by weekly surveys of their personal progress.

CHAPTER II

Research and Solution Strategy

Researchers agree that abstract reasoning and problem solving are in the formative stage at the high school level (Coulter, 1981). This is further complicated by the difficult subject matter in chemistry. Possessing problem solving skills will aid greatly in the understanding of chemistry problems as much as understanding the underlying concepts in chemistry will improve students' problem solving skills. Methodology in teaching stoichiometry problems specifically polarizes into those who support dimensional analysis (factor-label method) for its ease of instruction against those who hold that proportional reasoning is the basis for critical thinking and problem solving.

'hat becomes the rationale for teaching one method over the other? Will dimensional analysis cause the students to develop critical thinking skills? If not, perhaps use of proportional reasoning would be preferred even if it is more challenging for students. Student competency can be tested but the effectiveness of the method can

only be demonstrated by the application of the newly learned skills to n w situations (Costa, 1983).

Dimensional analysis is identified as an *algorithm*, which is a well-defined process for the solution of a problem consisting of a set of rules which "can be followed more or less automatically..." (Bodner, 1987:502). As long as there are no exceptions to the rules, the algorithm can be used consistently with predictable accuracy. This method provides a single approach to all problems and is simple for students to master. Each factor represents a ratio or identity in which the numerator and denominator are equivalent. The quantity to be changed is multiplied by one or more of the known identities in such a way that all units cancel except the desired unit of the answer. Completion of the calculations indicated by the factors provides the numerical answer along with the proper units.

The following examples demonstrate the solution of three problems by dimensional analysis:

Example 1. A bag contains 12 marbles. How many marbles are in 2.5 bags?

The identity:

1 bag = 12 marbles

Unit analysis:

$$2.5 \text{ bags} \times \frac{12 \text{ marbles}}{1 \text{ bag}} = 30 \text{ marbles}$$

Example 2. How many inches are there in 2 miles?

Identities:

1 mile = 5280 feet

12 inches = 1 foot

Unit analysis:

$$2 \text{ miles} \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{12 \text{ inches}}{1 \text{ foot}}$$

= 126,720 inches

Example 3. How many grams in 10 liters of oxygen gas at STP?

Identities:

1 mole = 22.4 liters at STP

1 mole of O_2 = 32 grams

Unit analysis:

$$10 \text{ liters} \times \frac{1 \text{ mole}}{22.4 \text{ liters}} \times \frac{32 \text{ grams}}{1 \text{ mole}}$$

= 14.3 grams

Dimensional analysis is straightforward to teach and mechanical in problem set-up. Its

simplicity is beautiful. If the units do not cancel, leading to the desired unit of the answer, the student knows there has been an error in the problem set-up. Correct problem set-up through the analysis of the units automatically dictates whether the student multiplies or divides by the other numbers. Since a high percentage of students have not achieved the maturity to become formal operational, this method becomes "the best method in general... for the moles unit where less contamination could be expected" (Gabel, 1983).

Although dimensional analysis is versatile and used by many chemistry teachers and current textbooks, other research contends that students learn "to get the units to cancel" without understanding the logic behind the algorithm. Students learn to become "technicians" rather than "problem-solvers" (Schrader, 1987:518). Krajcik (1987) alleges that memorization of the algorithm "often leads to students becoming confused and learning to dislike science" (p.32). Obtaining the correct answer is not the only goal of a problem solving situation. Just because students may not be mature enough to achieve a thorough

understanding is not grounds to settle for anything less than improving latent problem solving skills.

> It is certainly much easier to utilize the [dimensional analysis] method, and the intellectual skills involved are much more straightforward to illustrate and "explain". But what is terribly wrong, in my opinion, is that the students are not learning anything of value but the method itself. They can literally work hundreds upon hundreds of problems without *ever* having to stop and contemplate the meaning of the quantities with which they are dealing. (Cardulla, 1987:520)

The use of proportions requires students to think critically as they evaluate the information given, recognize relationships and correlations and plan a strategy for solution. Rather than asking "What is the answer and how do I get it?", a strong problem-solver asks "What kind of problem is it?" or "What strategy is helpful for this kind of problem?" (Middlecamp, 1987:516)

The same three problem examples are now solved by the use of proportions:

Example 4. A bag contains 12 marbles. How any marbles in 2.5 bags?

IF 1 bag contains 12 marbles, then 2.5 bags will contain x marbles.

Proportion:

$$\frac{1 \text{ bag}}{12 \text{ marbles}} = \frac{2.5 \text{ bags}}{x}$$

$$x = \frac{(12 \text{ marbles})(2.5 \text{ bags})}{1 \text{ bag}}$$

$$x = 30 \text{ marbles}$$

Example 5. How many inches are there in 2 miles?

IF 5280 feet = 1 mile
THEN x = 2 miles

Proportion a:

$$\frac{5280 \text{ feet}}{1 \text{ mile}} = \frac{x}{2 \text{ miles}}$$

$$x = \frac{(5280 \text{ feet})(2 \text{ miles})}{1 \text{ mile}}$$

$$x = 10{,}560 \text{ feet}$$

IF 1 foot = 12 inches
THEN 10,560 feet = y inches

Proportion b:

$$\frac{12 \text{ inches}}{1 \text{ foot}} = \frac{y}{10{,}560 \text{ feet}}$$

$$y = \frac{(12 \text{ in.})(10{,}560 \text{ feet})}{1 \text{ foot}}$$

$$y = 126{,}720 \text{ inches}$$

Example 6. How many grams are in 10 liters of oxygen gas at STP?

IF 1 mole occupies a volume of 22.4 liters at STP,
THEN how many moles are in 10 liters?

Proportion a:

$$\frac{1 \text{ mole}}{22.4 \text{ liters}} = \frac{x}{10 \text{ liters}}$$

$$x = \frac{(1 \text{ mole})(10 \text{ liters})}{22.4 \text{ liters}}$$

$$x = .45 \text{ mole in 10 liters}$$

IF 1 mole of oxygen has a mass of 32 grams,
THEN how many grams would .45 mole weigh?

Proportion b:

$$\frac{32 \text{ grams}}{1 \text{ mole}} = \frac{y}{.45 \text{ mole}}$$

$$y = \frac{(32 \text{ grams})(.45 \text{ mole})}{1 \text{ mole}}$$

$$y = 14.3 \text{ grams of oxygen gas in 10 L at STP}$$

Krajcik (1987) administered a 15-item test for formal reasoning skills called the Lawson Test to a group of students. The test involved proportional reasoning, variables, probability, and conservation of mass. The same students were given the American Chemical Society Standardized Achievement Test in Chemistry. Krajcik concluded that the ability to apply proportional reasoning patterns was a major factor that differentiated high and low Lawson scores on the ACS exam (p. 32).

The task of this researcher was to investigate the effectiveness of proportional reasoning in the

solution of stoichiometric problems and its effect on the development of critical thinking skills. The target group had experience with the periodic chart and formula writing prior to the unit on stoichiometry. The target group was then divided into two subgroups which were presented identical lecture information, laboratory verification, exercises/problems for practice and tests. The variable was the actual method used in solving the exercises and problems. The Test group was presented solutions by proportional reasoning. The Control group was presented dimensional analysis. Test results were analyzed and conclusions drawn as to the effectiveness of proportional reasoning in the understanding of the concepts and the development of problem solving skills. The attitude of the students toward the topic of stoichiometry was also surveyed.

CHAPTER III

Method

Clearance from the high school administrator was given to proceed with the study. The next task of the researcher was to discuss the feasibility of the practicum topic with the Science Department Chairman. Over a two week period, several informal sessions were arranged to discuss formative ideas, controls and projected difficulties. The use of proportions and dimensional analysis was discussed in light of the experience and backgrounds of the researcher and chairman. The curriculum sequence of topics was altered to assure that the unit of study did not fall awkwardly over an extended vacation when subject continuity would be lost. An initial meeting was scheduled with the Practicum Advisor where further direction was given. This preliminary groundwork and literature search took approximately eight weeks.

A survey (Appendix A) was developed to establish the degree of difficulty teachers perceive students experience with this unit. The survey was mailed to 40 public and private high

schools within the target county. Three weeks were allowed after mailing for the return of the surveys before the results were tabulated. Sixty percent or 24 of the 40 surveys were expected to be returned. The actual return was 67%.

Random distribution of students in four chemistry classes was accomplished by computer scheduling. The four classes were further divided into two subgroups so that there were approximately equal numbers of students in each subgroup to be studied. Periods one and seven, having 29 students, served as the Test group. Periods four and five, having 28 students, made up the Control group. The Test group was taught to solve the stoichiometry problems by proportions while the Control group was taught dimensional analysis.

The Test of Logical Thinking, referred to as the TOLT (Tobin, 1982) (Appendix B) was administered on the first and last days of the unit. This instrument measured five areas of critical thinking believed to be necessary for success in high school chemistry: proportional reasoning, control of variables, probabilistic reasoning, correlational reasoning and

combinatorial reasoning. Students were not told ahead of time that this logical thinking assessment was going to be given. They were informed that the results of this test would not be recorded in the teacher's gradebook, but the information would be used to help them do well in the unit. Subjective observations such as body language and verbalizations during and after the test were logged for future reference.

The curriculum used by the department presented dimensional analysis as the method for solving mole problems. To prevent the possibility of the Test group (proportionalities) reading the text and becoming confused or solving the problems by the alternate method, students were told that they would not need their textbooks for this unit. All subject material was presented in class supplemented by appropriate work sheets, visual aids and laboratory experiences. The teacher's lesson plans guaranteed that all students were given the same material, labs and worksheets uniformly and in the same sequence.

The only variable in the two groups was the actual mathematical method taught for the solution

of the problems. Absenteeism was handled according to pre-established classroom procedures:

a. obtain a complete set of notes from the class period;

b. obtain printed materials from the teacher and complete them;

c. see the teacher personally if there are any questions on the material missed; and

d. hand in any assignments for grading.

There was no way to completely prevent students in the two groups from studying together or comparing notes outside of class. In the event that students inquired about using the alternate method, the teacher took care not to favor one method over the other. However, the students were limited to the use of the method prescribed in their particular class.

The sequence of lesson topics covered was:

1. Administer TOLT as pretest
2. Review of symbols, formulas, atomic mass units and conservation of mass
3. Balancing chemical equations - worksheets; quiz
4. Types of chemical reactions
5. Lab: Types of Chemical Reactions

6. Predicting products of single and double replacement reactions - group work; worksheet; quiz

7. Test: Balancing equations, types of chemical reactions and predicting products

8. Administer stoichiometry unit pretest

9. Definition of stoichiometry

10. Determination of GAM, GFM, GMM with appropriate practice; quiz

11. Definition of a MOLE with numerous analogies and examples

12. Lab: Determining the Gram Atomic Mass of an Element (Wagner, 1989)

13. Worksheet I and II: One-step mole problems; group work and homework

14. Review: mole/mass, mole/volume and mole/number-of-particles problems

15. Quiz: One-step mole problems

16. Introduce two-step mole problems with examples

17. Worksheet III and IV: Two-step problems (mole/mass/volume/number-of-particles problems); group work and homework

18. Quiz: Two-step mole problems

19. Relationship between moles and coefficients of balanced equations

20. Lab: Relating Moles to the Coefficients of Balanced Equations (Wagner, 1989)

21. Worksheet V and VI: Moles and Coefficients; group work and homework

22. Quiz: moles and coefficients

23. Lab: Mole and Mass Relationships (Wagner, 1989)

24. Lab: Mass-Mass Relationships (Wagner, 1989)

25. Quiz: mole relationships and balanced chemical equations

26. Review worksheet on unit material

27. Unit Test: Stoichiometry - posttest

28. Re-administer TOLT

The unit test was graded and returned to the students directly. Results were discussed and questions answered.

The researcher used the Critical Thinking and Self-Reflection Checklist (Appendix C) throughout implementation to insure the infusion of higher order thinking activities. The entire unit presentation with lectures, worksheets, laboratory activities and evaluations took eleven weeks.

CHAPTER IV

Results

Teacher Survey

Twenty-seven of the 40 surveys sent to high school chemistry teachers in the target county were returned. This was a 67% return compared to the expected 60% return. The years of teaching experience ranged from one to 24 years with mean, median and mode each equalling 10.0 years.

Two out of three teachers surveyed used dimensional analysis as their method for teaching stoichiometry. Eight teachers used proportions most often. One teacher used a five-step method incorporating both methodologies.

Whether the teacher used proportions or dimensional analysis did not affect the difficulty students seemed to have with this subject. The teachers ranked the difficulty for students on a scale from one (most difficult) to 10 (least difficult. Those who used proportions ranked the difficulty from two to eight, averaging 4.25. Those who used dimensional analysis ranked the difficulty from one to eight, averaging 4.00.

There was no significant difference in the ranking of difficulty when analyzed according to teacher experience. Teachers with less than 10 years experience, the majority of whom used dimensional analysis, ranked stoichiometry problems 3.8 in difficulty for students. Teachers with 10 years experience, split in their methodology, ranked the unit 4 in difficulty. Teachers with more than 10 years experience, primarily using dimensional analysis, ranked the difficulty 3.9.

Eighty-five percent of the teachers surveyed ranked the stoichiometry unit as being more difficult for students than the majority of other topics covered in introductory chemistry. Twice as many teachers used dimensional analysis than used alternate teaching methods. There was no teacher confirmation, however, that one method reduced the difficulty level of stoichiometry problems for students.

Major Objective One

Several preliminary stoichiometry skills were taught according to the first cluster of objectives (page 10). These included balancing chemical

reactions, classifying types of chemical reactions, predicting the products of single and double replacement reactions, and completing one laboratory activity. Each of the five objectives in this first cluster was reached in the Test group and the Control group. The evaluative tool used for this part of the study measured the above-mentioned skills. The average score for the Test group on this evaluation was 90%. The Control group average was 88%. The printed material used to accomplish this first set of objectives is found in Appendix D.

Major Objective Two

The second cluster of objectives (page 11) focused on stoichiometry problems requiring an understanding of the mole concept and its use in chemical equations. The pretest was administered prior to instruction for this set of objectives. The printed material used to accomplish the second cluster of objectives is found in Appendix E.

The method used to solve the stoichiometry problems varied with the onset of objective 2.2. Initially, the Test group showed a noticeable drop

in their capability to solve one- and two-step stoichiometry problems as evidenced by a lower average score. As it became necessary to apply these skills to balance chemical equations, the test group showed little improvement. Note that by the end of the unit, however, identical class average scores were earned by both groups.

Table I

Objective Two Class Results

Objective	Expected results	Number of students meeting objective		Average score	
		Test	Control	Test	Control
2.1	22 score 80% +	28	27	94%	90%
2.2	22 score 75% +	28	27	88%	88%
2.3	14 with <50% error	13	14	-	-
2.4	21 score 75% +	25	28	88%	95%
2.5	21 score 75% +	22	16	80%	75%
2.6	21 score 75% +	18	15	70%	77%
2.7	all do 2 labs	22 24	22 27	84% 87%	86% 91%
2.8	22 score 75% +	21	20	81%	81%

The activities and quizzes used to achieve objective two assessed the students' ability to use the prescribed algorithm. Based on the average scores earned by the end of the unit, it was clear that the Test group had acquired the skills necessary for the unit test.

To confirm that the comparable scores on the unit test were a result of the performance of the same skills used by the Control group, selected test questions were analyzed. Twenty-one of the 50 unit test questions required some degree of proportional reasoning. These items were questions 17, 21, 23 through 36, 39, 40, 45, 46 and 48. Upon examining these questions in particular, the number of correct responses by the Test group increased from 200 on the pretest to 484 on the posttest. This represented a 50% increase in the number of correct responses given by the Test group. The Control group improved from 172 to 468 correct responses, equivalent to a 57% improvement. The Test group had, in fact, been able to meet the stated objectives with skills equivalent to the Control group.

Major Objective Three

Objective three (page 13) addressed improved critical thinking skills developed in conjunction with the stoichiometry subject matter. The TOLT was administered early in the study and on the last day. The highest score possible was a 10. The statistical mean for 11th graders was published as 4.5.

Table II - Test of Logical Thinking

	Test Group		Control Group	
	pretest	posttest	pretest	posttest
range	0 - 10	1 - 10	1 - 10	2 - 10
mean	6.1	6.4	5.7	7.0
median	6.0	6.5	5.0	7.5
mode	5, 7	7, 10	4	7, 10
# perfect scores	3	6	4	7
	(11% increase)		(11% increase)	
# students improving by at least 1 point	-	14 (54%)*	-	19 (79%)*

*Students who scored 10 on the pre-TOLT were not included in the calculation of these percents.

Major objective two was not achieved in the Test group. A closer look at the TOLT was necessary. The first two items of the TOLT specifically measured proportional reasoning skills. Each item consisted of two parts - the selection of the answer and then the selection of the correct reasoning leading to that answer. Sixty-two percent of the students in the Test group scored both items correctly on the TOLT pretest. Seventy-eight percent scored both of these items correctly on the TOLT posttest. Forty-six percent of the students in the Control group marked both items correctly on the TOLT pretest, while 73% marked them correctly on the posttest. This showed a 16% improvement in the Test group and a 27% improvement in the Control group. The Control group evidently had acquired the skill of proportional reasoning without its instruction in the chemistry unit itself.

Major Objective Four

Major objective four (page 13) addressed the students' attitudes toward their study of stoichiometry. The first affective expressions

came after the TOLT pretest. The Test group and the Control group made essentially identical comments:

"None of the reasons given is how I got the answer."
"I know the answer, but I don't know how I got it."
"This is stupid."
"This is easy."
"Should we guess if we don't know?"
"What if my reason is not here?"

The general consensus was that the test did not have anything to do with their ability to achieve in chemistry. After the students were told that their class average score on the pretest was 5.9 compared to the statistical average of 4.5, they were amazed. The second time they took the assessment, they made a concerted effort to top their previous score. The average score on the TOLT posttest was 6.7.

The "How are you doing?" questionnaire (Appendix F) was given to each student at the end of weeks two through six of instruction in objective two. At the end of week two, some students expressed apprehension about future math requirements, but most of the comments were positive. Two students in both the Test group and

the Control group expressed a need for help. These were aided by the teacher outside of class time.

Each week the number of students who expressed a need for help or concern over their ability to master the material increased to a maximum of nine in the Test group and eight in the Control group by week six. Each student was offered teacher help. The maximum number of students requesting help was equal to the stated objective.

In general, the students recognized the difficulty of the material but were not threatened by it. They seemed to accept the challenge. By the end of the study, several students commented "this wasn't as bad as you told us."

The researcher concluded from this study that teaching stoichiometric relationships through proportional reasoning had no apparent effect on the developing critical thinking skills in the Test group of high school chemistry students studied. There was, however, an apparent improvement in the students' ability to work together toward solutions, to express their thinking process verbally and to listen and evaluate the comments of

others. A most significant observation was the capability of the Test group to enter the subsequent unit on gases with the necessary proportional reasoning skills.

CHAPTER V

Recommendations

It is not wise to make sweeping generalizations based on a small number of students in a single school. This researcher realizes there were extraneous variables which influenced the conclusions. Further study, therefore, is needed. A parallel study using a larger sample size would be the primary recommendation.

One post study observation made by the researcher showed a natural application of proportions in the subsequent chapter on gases by the Test group. The Control group had to be re-instructed in the set-up of the dimensional analysis when applied to gases. A further study would test the feasibility of proportions in subsequent chemistry units.

Results of this study, however, are profitable for any chemistry teachers who are facing the same struggles yearly. Upon approval of this project, an abstract will be sent to the 39 county high schools surveyed, Prentice Hall (publishers of the curriculum used) and the CHEM-ED Division of the American Chemical Society. Copies of the project

will be sent to the two International Associations to which similar parochial schools belong. It will be suggested that the findings be used in a workshop at the scheduled Fall, 1991 conventions throughout the country. An abstract will also be submitted for publication in the Associations' monthly newsletter and Educational Journal which reaches all member schools.

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Appendix A

Survey of Target County Teachers

February, 1991

Dear Colleague,

As a part of a research project, a study is being conducted to determine the most effective method used by teachers of introductory chemistry to solve stoichiometry problems.

Please complete the following survey and return in the enclosed envelope.

Your help is greatly appreciated.

Thank you,

Janice Guthrie

1. By what method do you most often teach mole/mass, mole/volume and mole/number-of-particles problems?

    a. dimensional analysis (factor-label method)
    b. proportions
    c. other ______________________________

2. Please rank on a scale from 1 to 10 the degree of difficulty students experience in solving mole-relationship problems compared to other first-year chemistry concepts.
    1 = most difficult
    10 = least difficult

1 2 3 4 5 6 7 8 9 10

3. How many years have you taught introductory chemistry? _____

Appendix B

Test of Logical Thinking

THE TEST OF LOGICAL THINKING (Tobin and Capie, 1982)

The TEST OF LOGICAL THINKING (TOLT) is a paper and pencil instrument which evaluates logical thinking. The first two items measure proportional reasoning, the third and fourth items measure the control of variables, the fifth and sixth items measure probabilistic reasoning, the seventh and eighth items measure correlational reasoning and the ninth and tenth items measure combinatorial reasoning. Each of the first eight itmes consists of two parts, an answer and a rationale for that answer. Both parts must be correct for the student to score on the item. On items nine and ten the student must have every possible combination to score a point. The range on the test is from 0 - 10.

This test has been used with students from grades 7 to college. The average score for eleventh grade chemistry students is around 4.5 out of 10. The reliability of this test ranges from .80 to .85.

The TOLT has been shown to be a good predictor of chemistry achievement. The proportional reasoning items are the best predictors on the test. Looking at the overall TOLT score, it appears that students scoring below 5 may have difficulty with chemistry, especially the quantitative aspects.

→ KEY
1-C, 2-A, 3-B, 4-A, 5-C, 6-E, 7-A, 8-D, 9-A, 10-D, 11-E, 12-E, 13-A, 14-A, 15-B, 16-D. ITEM 9 - 27 possible combinations, ITEM 10 - 24 possible combinations.

TIME TO ADMINISTER - 40 minutes

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TOLT ANSWER SHEETS I.D. NO.______________

In this test, ten items are presented. You will find items (1) through (8) in the test booklet. You will mark your answers to those items by blackening in the spaces provided below. Items (9) and (10) are attached to this answer sheet.

Item 1

1. (A) (B) (C) (D) (E)
2. (A) (B) (C) (D) (E)

Item 2

3. (A) (B) (C) (D) (E)
4. (A) (B) (C) (D) (E)

Item 3

5. (A) (B) (C) (D) (E)
6. (A) (B) (C) (D) (E)

Item 4

7. (A) (B) (C) (D) (E)
8. (A) (B) (C) (D) (E)

Item 5

9. (A) (B) (C) (D) (E)
10. (A) (B) (C) (D) (E)

Item 6

11. (A) (B) (C) (D) (E)
12. (A) (B) (C) (D) (E)

Item 7

13. (A) (B)
14. (A) (B) (C) (D) (E)

Item 8

15. (A) (B)
16. (A) (B) (C) (D) (E)

Answer Sheet, p. 2 I.D. NO.______________

Instructions for Items (9) and (10)

On Items (9) and (10) you will answer directly in the spaces provided. Item (9) appears below, and Item (10) is on the next page.

The Student Council (Item 9)

Three students from each of grades 10, 11, and 12 were elected to the student council. A three member committee is to be formed with one person from each grade. All possible combinations must be considered before a decision can be made. Two possible combinations are Tom, Jerry and Dan (TJD) and Sally, Anne and Martha (SAM). List all other possible combinations in the spaces provided. More spaces are provided than you will need.

STUDENT COUNCIL

Grade 10	Grade 11	Grade 12
Tom (T)	Jerry (J)	Dan (D)
Sally (S)	Anne (A)	Martha (M)
Bill (B)	Connie (C)	Gwen (G)

TJD SAM ______ ______

______ ______ ______ ______

______ ______ ______ ______

______ ______ ______ ______

______ ______ ______ ______

______ ______ ______ ______

______ ______ ______ ______

______ ______ ______ ______

______ ______ ______ ______

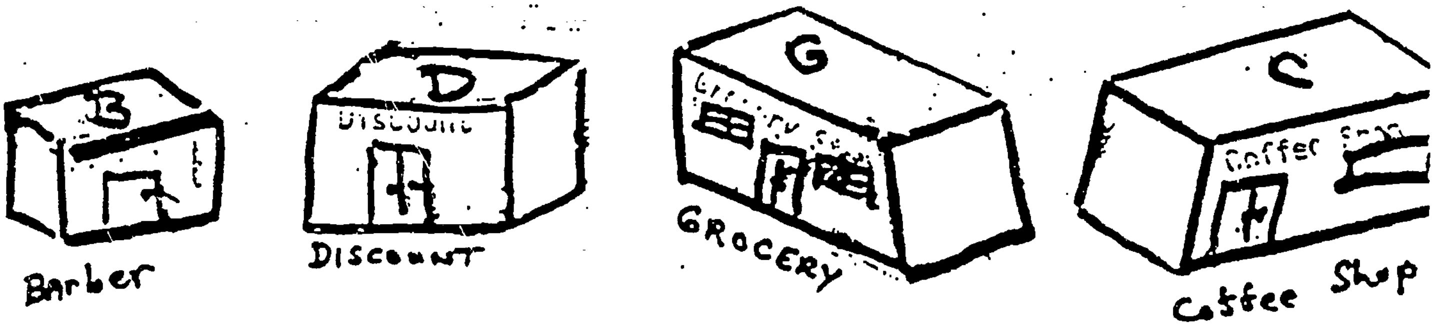
______ ______ ______ ______

The Shopping Center

In a new shopping center, 4 stores are going to be placed on the ground floor. A BARBER SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to locate there.

One possible way the stores could be arranged in the four locations is BDGC. This means the BARBER SHOP first, the DISCOUNT STORE next, then the GROCERY STORE and the COFFEE SHOP last.

LIST ALL THE OTHER POSSIBLE WAYS THAT THE STORES CAN BE LINED UP IN THE FOUR LOCATIONS. <u>You are provided with more spaces than you will need.</u>



BDGC	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____

Orange Juice (Item 1)

1. Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

   A. 7 glasses

   B. 8 glasses

   C. 9 glasses

   D. 10 glasses

   E. other

2. <u>Reason</u>

   A. The number of glasses compared to the number of oranges will always be in ratio 3 to 2.

   B. With more oranges, the difference will be less.

   C. The difference in the numbers will always be two.

   D. With four oranges the difference was 2. With six oranges the difference would be two more.

   E. There is no way of predicting.

3. Given the information in Item 1, how many oranges are needed to make 13 glasses of juice?

    A. 6 1/2 oranges

    B. 8 2/3 oranges

    C. 9 oranges

    D. 11 oranges

    E. other

4. Reason

    A. The number of oranges compared to the number of glasses will always be in the ratio 2 to 3.

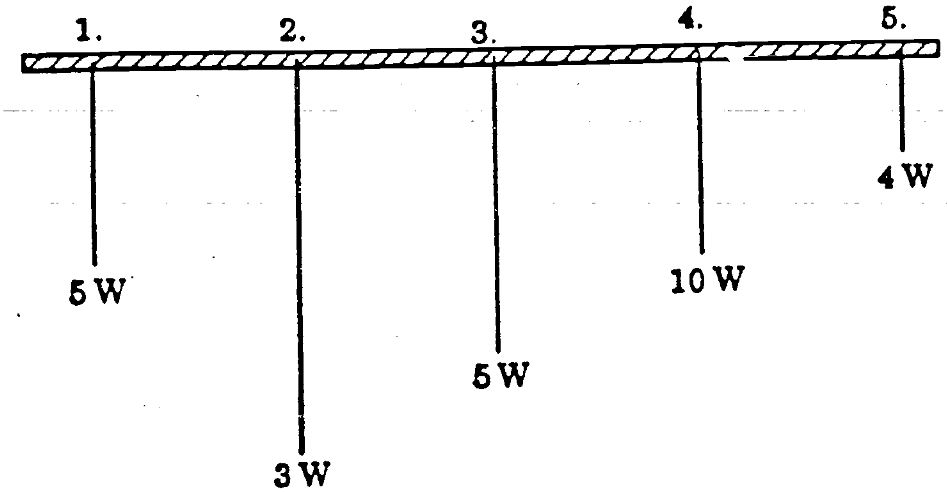
    B. If there are seven more glasses, then five more oranges are needed.

    C. The difference in the numbers will always be two.

    D. The number of oranges will be half the number of glasses.

    E. There is no way of predicting the number of oranges.

The Pendulum's Length (Item 3)



5. Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulums would you use for the experiment?

A. 1 and 4

B. 2 and 4

C. 1 and 3

D. 2 and 5

E. all

6. <u>Reason</u>

A. The longest pendulum should be tested against the shortest pendulum.

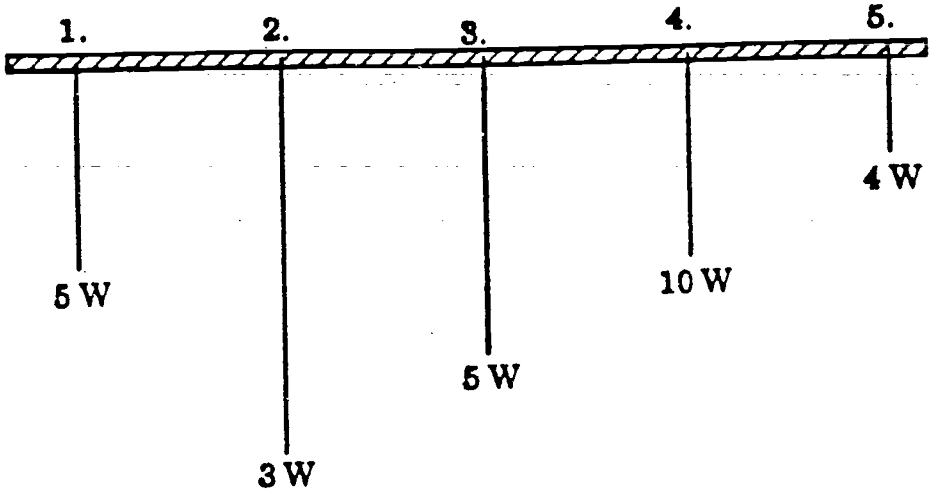
B. All pendulums need to be tested against one another.

C. As the length is increased the number of washers should be decreased.

D. The pendulums should be the same length but the number of washers should be different.

E. The pendulums should be different lengths but the number of washers should be the same.

The Pendulum's Length (Item 4)



7. Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of the time the pendulum takes to swing back and forth.

Which pendulums would you use for the experiment?

A. 1 and 4

B. 2 and 4

C. 1 and 3

D. 2 and 5

E. all

8. Reason

A. The heaviest weight should be compared to the lightest weight.

B. All pendulums need to be tested against one another.

C. As the number of washers is increased the pendulum should be shortened.

D. The number of washers should be different but the pendulums should be the same length.

E. The number of washers should be the same but the pendulums should be different lengths.

9. A gardener bought a package containing 3 squash seeds and 3 bean seeds. If just one seed is selected from the package what are the chances that it is a bean seed?

   A. 1 out of 2

   B. 1 out of 3

   C. 1 out of 4

   D. 1 out of 6

   E. 4 out of 6

10. Reason

   A. Four selections are needed because the three squash seeds could have been chosen in a row.

   B. There are six seeds from which one bean seed must be chosen.

   C. One bean seed needs to be selected from a total of three.

   D. One half of the seeds are bean seeds.

   E. In addition to a bean seed, three squash seeds could be selected from a total of six.

The Flower Seeds (Item 6)

A gardener bought a package of 21 mixed seeds. The package contents listed:

3 short red flowers

4 short yellow flowers

5 short orange flowers

4 tall red flowers

2 tall yellow flowers

3 tall orange flowers

11. If just one seed is planted, what are the chances that the plant that grows will have red flowers?

    A. 1 out of 2

    B. 2 out of 3

    C. 1 out of 7

    D. 1 out of 21

    E. other

12. <u>Reason</u>

    A. One seed has to be chosen from among those that grow red, yellow or orange flowers.

    B. 1/4 of the short and 4/9 of the talls are red.

    C. It does not matter whether a tall or a short is picked. One red seed needs to be picked from a total of seven red seeds.

    D. One red seed must be selected from a total of 21 seeds.

    E. Seven of the twenty one seeds will produce red flowers.

13. The mice shown represent a sample of mice captured from a part of a field. Are fat mice likely to have black tails and thin mice more likely to have white tails?

    A. Yes

    B. No

14. Reason

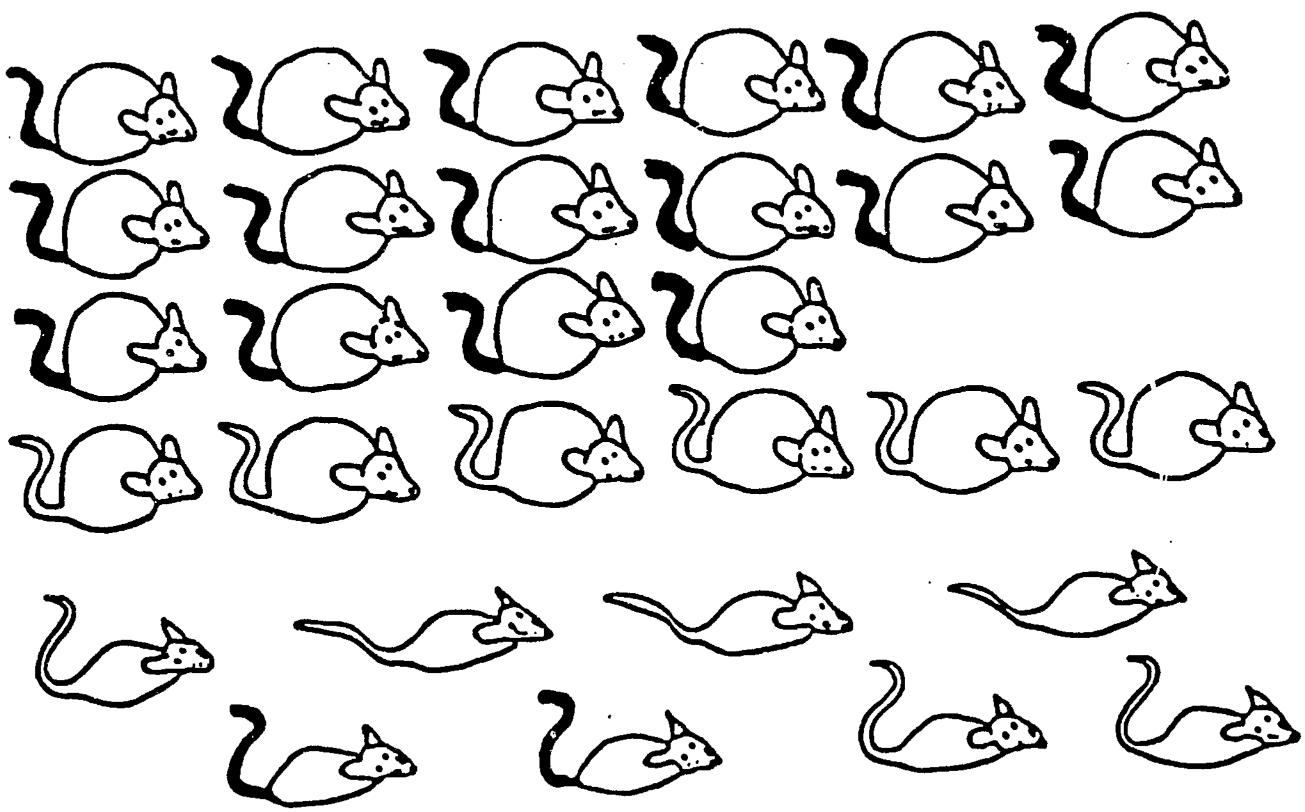
    A. 8/11 of the fat mice have black tails and 3/4 of the thin mice have white tails.

    B. Some of the fat mice have white tails and some of the thin mice have white tails.

    C. 18 mice out of thirty have black tails and 12 have white tails.

    D. Not all of the fat mice have black tails and not all of the thin mice have white tails.

    E. 6/12 of the white tailed mice are fat.



The Fish (Item 8)

15. Are fat fish more likely to have broad stripes than thin fish?

A. Yes

B. No

16. Reason

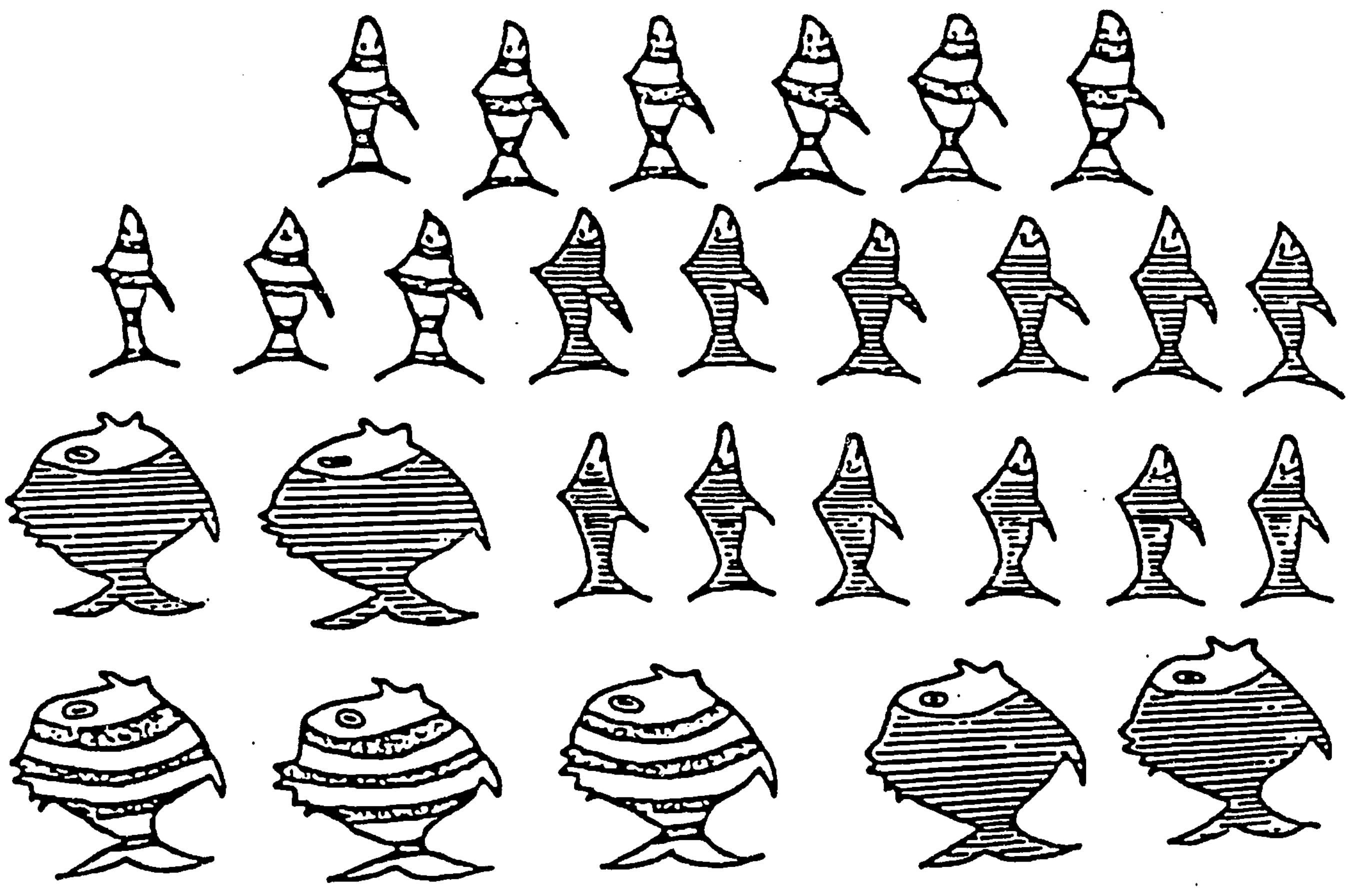
A. Some fat fish have broad stripes and some have narrow stripes.

B. 3/7 of the fat fish have broad stripes.

C. 12/28 are broad striped and 16/28 are narrow striped.

D. 3/7 of the fat fish have broad stripes and 9/21 of the thin fish have broad stripes.

E. Some fish with broad stripes are thin and some are fat.



Appendix C

Critical Thinking and Self-Reflection Checklist

Critical Thinking and Self-Reflection Checklist

The GEM Practicum Internship

John Barell - (Adapted)

Using a scale of 1 to 5, rate your work setting according to the following items:

5=Very Often 4=Often 3=Sometimes 2=Seldom 1=Rarely

CLASSROOM

1.	When students pose unusual or divergent questions, I ask, "What made you think of that?"	5 4 3 2 1
2.	Information in the text is challenged.	5 4 3 2 1
3.	When a decision has to be made between involving the class discussion of an intriguing student idea (topic related) or moving on to "cover" content, I choose the former.	5 4 3 2 1
4.	I encourage participants to seek alternative answers.	5 4 3 2 1
5.	The target group receives positive reinforcement for initiating questions.	5 4 3 2 1
6.	Problems are used as a means for the target group to generate their own questions (or problems), which we then seriously consider.	5 4 3 2 1
7.	Teaching and learning occur without teacher talk.	5 4 3 2 1
8.	Most questions posed during class can be answered with short or one-word answers.	5 4 3 2 1
9.	Students spontaneously engage in critiquing each other's thinking.	5 4 3 2 1
10.	Students are encouraged to relate subject matter to experiences in other subjects or to their personal lives.	5 4 3 2 1

11. I stress how to think, not what to think. 5 (4) 3 2 1

12. Students often set objectives for their own learning. 5 4 3 (2) 1

13. Students spend time working collaboratively to solve subject matter questions. (5) 4 3 2 1

14. One focus in my implementation is trying to help others understand how and why people (mentioned in texts) created ideas, solutions, experiments, rules, principles, and so on. (5) 4 3 2 1

15. Students actively listen to each other. 5 (4) 3 2 1

16. I facilitate collaborative instructional problem solving. (5) 4 3 2 1

APPENDIX D

Objective One Materials

Name ______________
Chemistry Worksheet 1
period _____ date _____

BALANCE EACH OF THE FOLLOWING REACTIONS

1. $Cl_2 + NaI \rightarrow NaCl + I_2$

2. $H_2S + HgCl_2 \rightarrow HCl + HgS$

3. $NH_4OH + Al_2(SO_4)_3 \rightarrow (NH_4)_2SO_4 + Al(OH)_3$

4. $(NH_4)_2S + Ni(NO_3)_2 \rightarrow NH_4NO_3 + NiS$

5. $Na_2CO_3 + CoCl_2 \rightarrow CoCO_3 + NaCl$

6. $H_2S + CuSO_4 \rightarrow CuS + H_2SO_4$

7. $Fe + O_2 \rightarrow Fe_2O_3$

8. $K + H_2O \rightarrow KOH + H_2$

9. $PbO_2 \rightarrow PbO + O_2$

10. $Cu + AgNO_3 \rightarrow Cu(NO_3)_2 + Ag$

11. $Al(NO_3)_3 + H_2SO_4 \rightarrow Al_2(SO_4)_3 + HNO_3$

12. $KClO_3 \rightarrow KCl + O_2$

13. $NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

14. $MgCO_3 \rightarrow MgO + CO_2$

15. $NaOH + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$

Name ____________________
Chemistry Woeksheet 2
period ____ date ______

BALANCE THE FOLLOWING REACTIONS

1. $HgO \rightarrow Hg + O_2$

2. $CO_2 + C \rightarrow CO$

3. $HCl + Al \rightarrow H_2 + AlCl_3$

4. $Zn + AgCl \rightarrow Ag + ZnCl_2$

5. $Cu + AgNO_3 \rightarrow Cu(NO_3)_2 + Ag$

6. $MgCO_3 \rightarrow MgO + CO_2$

7. $Cl_2 + NaI \rightarrow NaCl + I_2$

8. $Al_2(SO_4)_3 + NaHCO_3 \rightarrow Na_2SO_4 + Al(OH)_3 + CO_2$

9. $KClO_3 \rightarrow KCl + O_2$

10. $Al(NO_3)_3 + H_2SO_4 \rightarrow Al_2(SO_4)_3 + HNO_3$

11. $P_4O_{10} + H_2O \rightarrow H_3PO_4$

12. $Al(OH)_3 + H_2SO_4 \rightarrow Al_2(SO_4)_3 + H_2O$

13. $BaCl_2 + H_3PO_4 \rightarrow Ba_3(PO_4)_2 + HCl$

14. $KNO_2 + O_2 \rightarrow KNO_3$

15. $Al + HCl \rightarrow AlCl_3 + H_2$

Name ____________

Balancing Reactions - QUIZ

BALANCE <u>EIGHT</u> OF THE FOLLOWING REACTIONS

1. $Al + HCl \rightarrow AlCl_3 + H_2$

2. $Fe_2O_3 + CO \rightarrow Fe_3O_4 + CO_2$

3. $BaCl_2 + Na_3AsO_4 \rightarrow Ba_3(AsO_4)_2 + NaCl$

4. $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

5. $KMnO_4 + H_2SO_4 + HCl \rightarrow K_2SO_4 + MnSO_4 + H_2O + Cl_2$

6. $Al_2(SO_4)_3 + NaHCO_3 \rightarrow Na_2SO_4 + Al(OH)_3 + CO_2$

7. $Al(NO_3)_3 + H_2SO_4 \rightarrow Al_2(SO_4)_3 + HNO_3$

8. $Fe + O_2 \rightarrow Fe_2O_3$

9. $KClO_3 \rightarrow KCl + O_2$

10. $Ca + H_2O \rightarrow H_2 + Ca(OH)_2$

Name ____________
Chemistry - QUIZ
period _____ date _____

CLASSIFY EACH OF THE FOLLOWING REACTIONS AS
SYNTHESIS
DECOMPOSITION
SINGLE REPLACEMENT
DOUBLE REPLACEMENT

____________ 1. $CO_2 + C \rightarrow 2CO$

____________ 2. $NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$

____________ 3. $S + Cl_2 \rightarrow SCl_2$

____________ 4. $BaCl_2 + 2NaOH \rightarrow 2NaCl + Ba(OH)_2$

____________ 5. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

____________ 6. $CH_4 \rightarrow C + 2H_2$

____________ 7. $Pb(NO_3)_2 + Mg \rightarrow Pb + Mg(NO_3)_2$

____________ 8. $Mg + 2HCl \rightarrow MgCl_2 + H_2$

____________ 9. $H_2SO_4 \rightarrow H_2 + S + 2O_2$

____________ 10. $2O_2 + N_2 \rightarrow N_2O_4$

____________ 11. $3CaBr_2 + 2Na_3P \rightarrow Ca_3P_2 + 6NaBr$

____________ 12. $2KI + Br_2 \rightarrow 2KBr + I_2$

____________ 13. $C_6H_{12}O_6 \rightarrow 6C + 6H_2O$

____________ 14. $2NaF \rightarrow 2Na + F_2$

____________ 15. $Si + O_2 \rightarrow SiO_2$

____________ 16. $2NaI + Pb(NO_3)_2 \rightarrow 2NaNO_3 + PbI_2$

____________ 17. $NaI + Cs \rightarrow CsI + Na$

____________ 18. $H_2 + CO + O_2 \rightarrow H_2CO_3$

____________ 19. $Li_3PO_4 \rightarrow 3Li + P + 2O_2$

____________ 20. $CS_2 + 2F_2 \rightarrow CF_4 + 2S$

TYPES OF CHEMICAL REACTIONS

Name ____________________

Chemistry period _______

There are many kinds of chemical reactions and several ways to classify them. One useful method classifies reactions into four major types:
1. Synthesis
2. Decomposition
3. Single replacement
4. Double replacement

All the types of reactions discussed in this experiment may be represented by balanced chemical equations. You will first observe examples of the four types of reactions. Then you will represent these reactions by balanced chemical equations. The separate parts of this experiment may be done in any order.

PURPOSE:
Observe some chemical reactions and identify reactants and products of those reactions. Classify the reactions and write balanced equations.

MATERIALS:

0.2 M $AgNO_3$
clean copper wire
0.2 M $CuSO_4$
mossy Zinc
Magnesium ribbon
$CuCO_3$
0.2 M $Pb(NO_3)_2$
0.2 M KI

PROCEDURE:

PART I: SINGLE REPLACEMENT

1. Pour 4 cc of silver I nitrate solution into a test tube. Drop into the solution a 3 cm copper wire.

2. Pour 4 cc of copper II sulfate solution into another test tube. Add a small piece of mossy Zinc.

3. Note any change. Set the test tubes aside and observe periodically as you proceed with the experiment.

Observations:

4. Write word equations and balanced formula equations for each of these reactions.

a.

b.

PART II: SYNTHESIS REACTIONS

1. Obtain a strip of magnesium ribbon about 4 cm in length. Note its physical properties.

2. Place a wire mat on the table and light your burner. Hold the magnesium ribbon by one end with crucible tongs. Place the magnesium ribbon in the flame until it ignites, then hold it over the mat until all reaction has stopped.

CAUTION: Do not stare at the flame; it is a very intense light source.

3. Note the physical properties of the product. Compare these with the properties of the magnesium ribbon.

Observations:

4. Write the word equation and the balanced formula equation for this reaction.

PART III: DECOMPOSITION

1. Place 2 heaping microspatulas of Copper II carbonate in a clean, dry test tube. Note the appearance of the sample.

2. Using a test tube holder, heat the $CuCO_3$ strongly for about 3 minutes. Light a wood splint. Extinguish the burner and insert the burning splint into the test tube. If carbon dioxide gas is present, it will put the flame out immediately. Note any change in the appearance of the residue in the test tube.

Observations:

3. Write the word equation and the balanced formula equation for this reaction.

PART IV: DOUBLE REPLACEMENT

1. Pour 2 cc lead nitrate into a small test tube. Pour 2 cc of potassium iodide into a second small test tube. Note the appearance of each solution.

2. Pour the lead nitrate solution into the potassium iodide solution. Record your observations.

Observations:

3. Write the word equation and the balanced formula equation for this reaction.

QUESTIONS:

1. Balance the equations below and identify the type of reaction represented by each equation.

_____a. $Na_2SO_3 + HCl \rightarrow NaCl + H_2O + SO_2$

_____b. $Zn(C_2H_3O_2)_2 + Na_3PO_4 \rightarrow NaC_2H_3O_2 + Zn_3(PO_4)_2$

_____c. $FeS + HCl \rightarrow FeCl_2 + H_2S$

_____d. $HCl + Fe \rightarrow FeCl_3 + H_2$

_____e. $AlCl_3 + NH_4OH \rightarrow Al(OH)_3 + NH_4Cl$

_____f. $H_2 + O_2 \rightarrow H_2O$

_____g. $CuCO_3 \rightarrow CuO + CO_2$

_____h. $Al + HCl \rightarrow AlCl_3 + H_2$

_____i. $CO_2 + C \rightarrow CO$

_____j. $KClO_3 \rightarrow KCl + O_2$

_____k. $P_4O_{10} + H_2O \rightarrow H_3PO_4$

_____l. $MgCO_3 \rightarrow MgO + CO_2$

_____m. $Fe_2O_3 + CO \rightarrow Fe_3O_4 + CO_2$

_____n. $MgO + HBr \rightarrow MgBr_2 + H_2O$

NAME ______________
Chemistry
period _____ date_____

PREDICT THE POSSIBLE PRODUCTS FOR EACH OF THE REACTIONS BELOW AND BALANCE. INDICATE BY WRITING "YES" NEXT TO THE NUMBER OF EACH REACTION WHICH WILL ACTUALLY OCCUR.

1. $Ag + ZnCl_2 \rightarrow$

2. $K + H_2O \rightarrow$

3. $Zn + AgNO_3 \rightarrow$

4. $NaCl + I_2 \rightarrow$

5. $Mg + HCl \rightarrow$

6. $Hg + HCl \rightarrow$

7. $LiOH + Na \rightarrow$

8. $NaI + Br_2 \rightarrow$

9. $Al + H_2SO_4 \rightarrow$

10. $Na + H_2O \rightarrow$

11. $NaCl + KBr \rightarrow$

12. $Pb(NO_3)_2 + ZnCl_2 \rightarrow$

13. $NaOH + H_3PO_4 \rightarrow$

14. $K_2SO_4 + CaCl_2 \rightarrow$

15. $Ca(OH)_2 + H_2SO_4 \rightarrow$

Name ______________
Chemistry - QUIZ
date __________

PREDICT THE PRODUCTS
BALANCE THE REACTION
CIRCLE THE QUESTION NUMBER OF THOSE WHICH WILL OCCUR

1. $CaBr_2 + Na_2CO_3 \rightarrow$

2. $H_2O + Na$

3. $FeBr_2 + AlI_3 \rightarrow$

4. $Cu(NO_3)_2 + Ag \rightarrow$

5. $NaNO_3 + KBr \rightarrow$

6. $NaF + I_2 \rightarrow$

7. $Na_2CO_3 + Ca(OH)_2 \rightarrow$

8. $Ca(OH)_2 + H_2 \rightarrow$

9. $BaCl_2 + K_2SO_4 \rightarrow$

10. $Al + HCl \rightarrow$

Name ____________________
Chemistry Ch 9 Test
Date ________ Period ________

Circle the most correct answer.

1. Which reaction type results in a single product?
    a. synthesis
    b. decomposition
    c. single replacement
    d. double replacement

2. The large numbers used in a balanced chemical formula equation that give the relative number of molecules of a substance taking part in a chemical reaction are called the
    a. subscripts.
    b. superscripts.
    c. coefficients.
    d. exponents.

3. The new substances formed in a chemical reaction are referred to as the
    a. catalysts.
    b. intermediates.
    c. products.
    d. reactants.

4. In a chemical reaction the total mass of the substances before the reaction as compared to the total mass of the substances after the reaction are
    a. equal.
    b. usually greater.
    c. usually smaller.
    d. sometimes greater, sometimes smaller.

5. If a reactant or product in a chemical reaction is followed by (aq) it means that the
    a. substance is in adequate supply.
    b. substance is dissolved in water.
    c. reaction occurs rapidly.
    d. equation for the reaction is already balanced.

6. The word soluble means
    a. solid.
    b. dissolved.
    c. precipitate.
    d. gaseous.

7. In the equation: $2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_2\uparrow + \Delta$
Which substance is the solid?
   a. sodium
   b. water
   c. hydrogen
   d. sodium hydroxide

8. In the reaction referred to in question #7, what is the phase of the hydrogen?
   a. solid
   b. liquid
   c. gas
   d. aqueous

9. If an energy term appears with the reactants, the chemical reaction is
   a. exothermic.
   b. endothermic.
   c. complete.
   d. incomplete.

10. A double replacement reaction will occur if
   a. a precipitate is formed.
   b. water is formed.
   c. a gas is formed.
   d. any of the above.

11. Complete the following word equations AND write and balance the formula equation for each.

SYNTHESIS

a. carbon monoxide + oxygen →

DECOMPOSITION

b. water →

SINGLE REPLACEMENT

c. Aluminum + iron II oxide →

DOUBLE REPLACEMENT

d. Barium chloride + sodium sulfate $\rightarrow$

12. Identify each of the following reactions as Synthesis, Decomposition, Single replacement, or Double replacement.

a. $CO_2 \rightarrow C + O_2$

b. $NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$

c. $S + Cl_2 \rightarrow SCl_2$

d. $BaCl_2 + 2NaOH \rightarrow 2NaCl + Ba(OH)_2$

e. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

f. $CH_4 \rightarrow C + 2H_2$

g. $Pb(NO_3)_2 + Mg \rightarrow Pb + Mg(NO_3)_2$

h. $Mg + 2HCl \rightarrow MgCl_2 + H_2$

i. $H_2SO_4 \rightarrow H_2 + S + 2O_2$

j. $2O_2 + N_2 \rightarrow N_2O_4$

Balance NINE of the following reactions.

13. $KClO_3 \rightarrow KCl + O_2$

14. $Na_2O_2 + H_2O \rightarrow NaOH + O_2$

15. $H_2O_2 \rightarrow H_2O + O_2$

16. $P_4O_{10} + H_2O \rightarrow H_3PO_4$

17. $HI + MnO_2 \rightarrow H_2O + MnI_2 + I_2$

18. $K_2CrO_4 + H_2SO_4 \rightarrow K_2Cr_2O_7 + K_2SO_4 + H_2O$

19. $HCl + KMnO_4 \rightarrow Cl_2 + MnCl_2 + KCl + H_2O$

20. $NH_4OH + Al_2(SO_4)_3 \rightarrow (NH_4)_2SO_4 + Al(OH)_3$

21. $MgO + HBr \rightarrow MgBr_2 + H_2O$

22. $Al_2(SO_4)_3 + NaHCO_3 \rightarrow Na_2SO_4 + Al(OH)_3 + CO_2$

Indicate with a YES or NO whether or not each of the reactions will take place.

_____ 23. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

_____ 24. $LiOH + Na \rightarrow NaOH + Li$

_____ 25. $NaCl + Li \rightarrow LiCl + Na$

_____ 26. $Br_2 + 2NaI \rightarrow 2NaBr + I_2$

_____ 27. $2KI + Br_2 \rightarrow 2KBr + I_2$

_____ 28. $3\,FeBr_2 + 2\,AlI_3 \rightarrow 2\,AlBr_3 + 3\,FeI_2$

_____ 29. $(NH_4)_2CO_3 + CaCl_2 \rightarrow 2\,NH_4Cl + CaCO_3$

_____ 30. $NaI + Pb(NO_3)_2 \rightarrow 2\,NaNO_3 + PbI_2$

APPENDIX E

Objective Two Materials

Name ______________

Chemistry - QUIZ

period _____ date _______

DETERMINE THE GRAM FORMULA MASS OF EACH OF THE FOLLOWING COMPOUNDS. Express your answer to the nearest tenth.

1. Al_2O_3

2. $(NH_4)_2SO_4$

3. $SnCl_2$

4. $Mg(OH)_2$

5. $MgBr_2$

6. $NaClO_3$

7. $Zn_3(PO_4)_2$

8. CO

9. $HC_2H_3O_2$

10. CH_4

Name ______________
Stoichiometry I

Round all numbers to the nearest tenth.

1. What is the mass of one mole of sulfur atoms? ____________

2. What is the mass of 5 moles of calcium atoms?

4. What is the mass of 4.2 moles of carbon atoms?

5. How many moles of carbon atoms would weigh 36.0 grams?

6. Forty-five grams of water is equal to how many moles?

7. How many atoms are present in one mole of Oxygen atoms?

8. How many atoms are present in one mole of Oxygen gas?

9. How many atoms are present in 3.5 moles of NaCl?

10. How many moles of $Ca(OH)_2$ would contain 1.5×10^{23} molecules?

11. What is the volume of 1 mole of hydrogen gas at STP?

12. What is the volume of 2.35 moles of CO_2 at STP?

13. How many moles of Hydrogen gas would occupy a volume of 6.72 liters at STP?

Name ____________

Stoichiometry II

Show your problem set-up. Round to the nearest tenth.

1. What is the mass of 5 moles of sulfur atoms?

2. How many molecules are present in 2.3 moles of oxygen gas?

3. How many moles are in 100 grams of copper atoms?

4. How many moles are present in 101.0 grams of Fe_2O_3?

5. What is the volume at STP of 3.2 moles of ammonia gas, NH_3?

6. How many moles of CO_2 would contain 2.1×10^{23} molecules?

7. How many carbon atoms are present in 2.5 moles of carbon?

8. How many molecules are contained in 0.5 mole of $C_6H_{12}O_6$?

9. At STP, the volume of nitrogen gas is 112.0 liters. How many moles does this represent?

10. What is the mass of 0.75 mole of NaCl?

Name ____________________

Stoichiometry Quiz 1

1. Sketch and label the diagram showing the relationship between one mole and the three other quantities.

2. Calculate the mass of 1 mole of $Al_2(SO_4)_3$.

3. How many moles are represented by 100.0 grams of sodium?

4. What volume will 3.33 moles of oxygen gas occupy at STP?

5. How many moles represent 4.2 x 10^{23} molecules of water?

6. 1.67 moles of hydrogen gas would contain how many molecules?

7. 16.8 liters of water vapor at STP represent how many moles of water vapor?

8. How many grams would 1.85 moles of hydrogen gas weigh?

9. How many moles of NH_4OH would weigh 253.75 grams?

10. How many liters would 3.25 moles of ammonia gas occupy at STP?

Name ____________________
Period ________

DETERMINING THE GRAM ATOMIC MASS OF AN ELEMENT

The atomic mass of an element is the *average* value of the masses of the isotopes in a natural sample of that element. Atomic masses of all the elements are based on the mass of an atom of carbon-12, which has been assigned the value of 12 atomic mass units. An atomic mass unit is defined as 1/12 the mass of a carbon-12 atom.

Chemists do not deal with individual atoms or molecules. Rather, they deal with relatively large numbers of atoms and molecules. To make their calculations easier, chemists often use units of measure that are made up of large numbers of atoms or molecules. One such quantity is called the GRAM ATOMIC MASS, or GRAM-ATOM. A gram-atom is the mass in grams of one mole of atoms. A gram-atom of an element is, therefore, the mass of 6.02×10 atoms of that element. The mass in grams of 1 gram-atom of an element is numerically equal to the atomic mass of that element. For example, 1 gram-atom of carbon-12 has a mass of 12 grams.

There are several methods for determining the atomic mass of an element. In this experiment, the atomic mass of silver will be calculated using a compound, silver oxide, Ag O.

PURPOSE:
From measurements of a binary compound of known composition, determine the gram atomic mass of one of the elements in the compound when the atomic mass of the other is known.

EQUIPMENT:

crucible and cover	microspatula	ring stand
burner	balance	iron ring
clay triangle	safety goggles	crucible tongs
lab apron		

MATERIALS: silver II oxide, Ag_2O

SAFETY: Observe all safety precautions when working with burners and chemicals.

PROCEDURE:
1. Clean a crucible and cover. Place the crucible in the clay triangle as shown. Heat the crucible and cover in the hottest part of the burner flame for about 5 minutes. Be sure to tilt the cover as illustrated. Balance it carefully to avoid breakage. Put out the flame and allow to cool.

2. Measure the mass of the crucible and cover. Record the mass on your data table.

3. Measure out *exactly* 1.75 grams of dry silver II oxide. Add this compound to the crucible. With the cover on the crucible, measure the mass of the crucible and its contents. Record this on the data table.

4. To remove the oxygen gas from the silver II oxide, tilt the cover as before and strongly heat the crucible, cover and contents in the hottest part of the burner flame for 15 minutes. Allow the crucible to cool. Measure and record the mass of the crucible, cover and silver.

5. If time permits, reheat strongly for 5 minutes. After cooling, again measure the mass of the crucible, cover and silver to check for constancy of mass.

6. Complete the calculations to determine the gram atomic mass of silver.

DATA:

A. Mass of crucible + cover __________ grams

B. Mass of crucible + cover + Ag_2O __________ grams

C. Mass of crucible + cover + Ag __________ grams

D. Mass after reheating __________ grams

CALCULATIONS:

1. Find the mass of the silver alone. __________ grams

2. Find the mass of the oxygen lost. __________ grams

3. Find the number of moles of oxygen atoms lost. __________ moles

4. Find the number of moles of silver produced. __________ moles
Remember! You do not know the GAM of silver.

5. Find the gram atomic mass of silver. _________ grams

CONCLUSIONS AND QUESTIONS:

1. Write the balanced chemical equation for the decomposition of Ag O by heating.

2. What is your experimental error in the calculation of the atomic mass of silver?

3. What are the most likely sources of error in this experiment?

4. Define a MOLE. What is the relationship between a mole and a gram-atom?

5. To the nearest whole number, how many moles are in a 120 gram sample of calcium metal? How many atoms is this?

6. What is the gram atomic mass of sodium? What is the mass of 4.5 moles of this element?

7. What is the gram atomic mass of the element oxygen? What is the mass of 1 mole of oxygen GAS? Explain the difference.

Name ____________________
Stoichiometry III

SHOW YOUR PROBLEM SET-UP.

1. Sketch the diagram showing the relationship between 1 mole and mass, volume and number of particles.

2. Find the number of molecules in a sample of oxygen gas which has a mass of 62.0 grams.

3. A sample of carbon dioxide has a mass of 22.0 grams. What volume will the sample occupy at STP?

4. A sample of methane, CH_4, has a volume of 67.2 liters at STP. What is the mass of the sample?

5. Find the number of molecules in a sample of N_2 gas with a mass of 42.0 grams.

6. What is the volume of 14.0 grams of CO at STP?

7. What is the volume of 1.2×10^{24} molecules of NO_2?

8. How many molecules of water vapor are present in 6.7 liters at STP?

9. How many grams would 1.8×10^{24} molecules of N_2 weigh?

10. What is the volume of 1.8×10^{23} molecules of CO_2 at STP?

Name ____________________
Stoichiometry IV

1. What is the weight of 4.0×10^{23} atoms of Copper?

2. How many atoms are in 985.0 grams of Gold?

3. How many grams of O_2 would be needed to produce a volume of 39.2 liters at STP?

4. Find the weight of 134.4 liters of NH_3.

5. What volume would 210.0 grams of Nitrogen gas occupy at STP?

6. A volume of 100.8 liters of water vapor at STP would contain how many molecules of water?

7. What weight of oxygen gas would contain 4.5×10^{24} molecules?

8. 4×10^{23} molecules of ammonia, NH_3, would occupy what volume at STP?

9. At STP, a volume of 163.5 liters of carbon dioxide would contain how many molecules?

10. What is the mass of 2.24 liters of Chlorine gas at STP?

Name ____________________

SHOW YOUR PROBLEM SET-UP FOR FULL CREDIT. Stoichiometry quiz 2

1. How many Gold atoms are present in a 295.0 gram sample of gold?

2. Find the number of molecules in a sample of nitrogen gas with a mass of 42.0 grams.

3. What is the volume at STP of 14.0 grams of CO?

4. What is the volume of 1.2×10^{24} molecules of NO_2 ?

5. How much would 33.6 liters of CH_4, methane gas, weigh at STP?

6. How many molecules are in 112.0 liters of SO_2 at STP?

7. What volume would 91.2 grams of He occupy at STP?

8. How many molecules are present in 98.2 grams of $Ca(OH)_2$?

9. What volume would 4.2×10^{23} molecules of H_2 occupy at STP?

10. What is the mass at STP of 71.7 liters of ammonia, NH_3 ?

Name ____________________

Stiochiometry Worksheet V

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

1. How many moles of $KClO_3$ were required for the reaction?

____

2. How many grams of $KClO_3$ were required for the reaction?

____

3. How many moles of oxygen gas were produced? ____________

4. How many grams of oxygen gas were produced? ____________

5. If 61 grams of $KClO_3$ were used, how many moles of KCl would be produced?

____

6. How many grams represent 1/2 mole of oxygen gas? __________

7. What volume of O_2 would be produced in the original reaction at STP?

____

8. How many atoms are contained in each molecule of $KClO_3$?

____

9. If only 1 mole of $KClO_3$ were used, how many moles of O_2 would be produced?

____

10. If 122.6 grams of $KClO_3$ were used, what volume of O_2 would be produced at STP?

____

Name ____________________
Stoichiometry VI

1. Given: $2\ H_2 + O_2 \rightarrow 2\ H_2O$

__________ a. How many moles of water are produced from each mole of O_2 ?

__________ b. How many moles of O_2 are required to produce 180 grams of water if the reaction is complete?

__________ c. How many grams of O_2 were used in part b.?

__________ d. How many ATOMS are in each MOLECULE of H_2O ?

__________ e. How many grams of H_2O would be produced if we completely reacted 3 moles of hydrogen gas?

__________ f. What volume of H_2 was used in the original reaction at STP?

__________ g. What volume of O_2 was used in the original reaction at STP?

2. Given: $3\ Ag + 4\ HNO_3 \rightarrow 3\ AgNO_3 + NO + 2\ H_2O$

__________ a. How many moles of HNO_3 were used to produce 1 mole of NO?

__________ b. How many grams of HNO_3 were used in the original reaction?

__________ c. How many moles of water were produced?

__________ d. If 161.9 grams of Ag are used, how many moles of $AgNO_3$ will be produced?

__________ e. How many grams of $AgNO_3$ were produced in part d.?

__________ f. How many ATOMS are in each MOLECULE of $AgNO_3$?

__________ g. How many molecules are contained in each mole of $AgNO_3$?

__________ h. How many atoms of silver were used in the original reaction?

__________ i. What volume of NO gas would be produced at STP?

3. Given: $P_4O_{10} + 6 H_2O \rightarrow 4 H_3PO_4$

__________ a. How many moles of P_4O_{10} are required to produce 4 moles of H_3PO_4 ?

__________ b. How many moles of H_2O are required to produce 4 moles of H_3PO_4 ?

__________ c. How many atoms are in one molecule of H_3PO_4 ?

__________ d. How many molecules are in one mole of H_3PO_4 ?

__________ e. How many grams are in one mole of P_4O_{10} ?

__________ f. How many grams are in 6 moles of H_2O ?

__________ g. How many moles of H_3PO_4 would be produced if 71 grams of P_4O_{10} are used?

__________ h. How many moles of P_4O_{10} are represented in part g.?

__________ i. 54.0 grams of water equals ______ mole(s) of water.

__________ j. How many moles of P_4O_{10} would react completely with the amount of water in part i.?

NAME ____________
STOICHIOMETRY QUIZ 3

GIVEN: $2\ Cu(NO_3)_2 \rightarrow 2\ CuO + 4\ NO_2 + O_2$

1. How many moles of $Cu(NO_3)_2$ were required for this reaction?

____

2. How many grams of CuO were produced in this reaction?

____

3. How many moles of NO_2 were produced? ____________

4. How many grams of O_2 were produced? ____________

5. If 187.5 grams of $Cu(NO_3)_2$ were used, how many MOLES of NO_2 would be produced?

____

6. How many grams represent 1/2 mole of oxygen gas? ____________

7. If the reaction is carried out at STP, what volume of O_2 will be produced?

____

8. If only 8.0 grams of O_2 are produced, what volume of NO_2 gas will be produced at STP?

____

9. If 4 moles of $Cu(NO_3)_2$ were used, how many MOLES of O_2 would be produced?

____

10. How many molecules of oxygen gas are in one mole?

____

Name ____________________
Stoichiometry Quiz 4

$2\ NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2\ NH_3 + 2\ H_2O$

__________ 1. How many moles of H_2O are produced from 2 moles of NH_4Cl?

__________ 2. If two moles of $Ca(OH)_2$ were used, how many moles of NH_4Cl would be needed?

__________ 3. If you wanted to produce 7 moles of water, how many moles of NH_4Cl would you need?

__________ 4. What volume of ammonia gas would be produced at STP from 3 moles of NH_4Cl?

__________ 5. What mass of $Ca(OH)_2$ must be used to produce 2.8 liters of NH_3 at STP?

__________ 6. How many molecules of $Ca(OH)_2$ will react with 1 mole of NH_4Cl ?

__________ 7. How many molecules of $Ca(OH)_2$ would be required to produce 67.2 liters of NH_3 at STP ?

__________ 8. How many grams of H_2O would be produced from 18.53 grams of $Ca(OH)_2$?

__________ 9. How many atoms are in one molecule of NH_4Cl ?

__________10. How many molecules of water would be produced from 148.2 grams of $Ca(OH)_2$?

Name ______________________ Date ____________ Class ____________

Relating Moles to Coefficients of a Chemical Equation

Lab 15

Text reference: **Chapter 10, pp. 233–238**

Pre-Lab Discussion

The mole is defined as Avogadro's number (6.02×10^{23}) of particles. These particles may be atoms, molecules, formula units, ions, electrons, etc. The concept of the mole is very important, especially when dealing with quantitative studies of chemical reactions. When calculating quantities of solids or liquids, molar masses are used. The molar mass of a substance is the mass, in grams, of 1 mole of particles of that substance. When calculating quantities of gases, molar volumes are used. The molar volume is the volume occupied by 1 mole of a gas at STP.

Chemical reactions are represented by balanced chemical equations. Proper interpretation of an equation provides a great deal of information about the reaction it represents and about the substances involved in the reaction. For example, the coefficients in a balanced equation indicate the number of moles of each substance. Thus, the ratio of moles of a substance to moles of any other substance in the reaction can be determined at a glance.

In this experiment, iron filings will be added to an aqueous solution of copper(II) sulfate. A single replacement reaction will take place, the products being iron(II) sulfate and copper metal. The balanced equation for this reaction is:

$$Fe(s) + CuSO_4(aq) \rightarrow FeSO_4(aq) + Cu(s).$$

The quantities of iron and copper sulfate used as reactants will be such that the copper sulfate will be in excess. Thus, the iron will be the limiting factor in determining the number of moles (gram-atoms) of products that will be formed. As the equation shows, the number of moles of copper produced should be equal to the number of moles of iron reacted.

This experiment should aid in the understanding of balanced equations and single replacement reactions.

Purpose

Find the ratio of moles of a reactant to moles of a product of a chemical reaction. Relate this ratio to the coefficients of these substances in the balanced equation for the reaction.

Equipment

balance
burner
beaker, 100-mL
beaker, 250-mL
graduated cylinder, 100-mL
ring stand
iron ring
wire gauze
glass stirring rod
safety goggles
lab apron or coat

Materials

copper sulfate crystals ($CuSO_4$)
iron filings (Fe)

Safety

Tie back long hair and secure loose clothing when working with an open flame. Note the caution alert symbol under "Procedure" and follow the precautions indicated. Always wear safety goggles and a lab apron or coat when working in the lab.

Procedure

1. Find the mass of a clean, dry 100-mL beaker. Record this as (a) in your data table.

2. Measure out 8.0 grams of copper sulfate crystals ($CuSO_4$) and add these to the beaker.

3. Measure 50.0 mL of water in a graduated cylinder and add it to the crystals in the beaker.

While one lab partner continues with steps 4 and 5, the other partner should carry out the instructons in step 6.

4. Set up the apparatus as shown in Figure 15-1. Heat the mixture in the beaker to just *below* boiling. DO NOT ALLOW THE LIQUID TO BOIL.

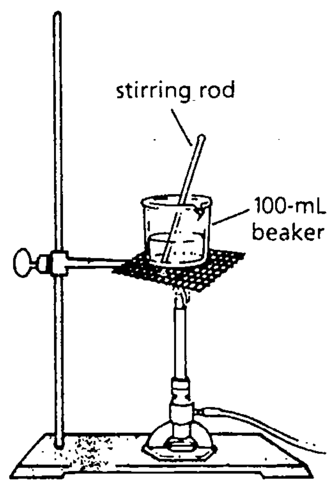


Figure 15-1

5. Continue heating and stir the mixture until the crystals are completely dissolved. Turn off the gas and remove the burner.

6. Using the balance, measure precisely 2.24 grams of iron filings. (Remember: do not place any reagent directly on the balance pan.) Record this mass as (b) in the data table.

7. Add the iron filings, *small amounts at a time*, to the hot copper sulfate solution. Stir continuously. After all the iron has been added and the mixture stirred, allow the beaker to sit for 10 minutes while the reaction proceeds. Record your observations as (d) in the data table.

Name ______________________________

15 Relating Moles to Coefficients of a Chemical Equation (continued)

8. Decant the liquid into a 250-mL beaker as shown in Figure 15-2. Do not disturb the solid at the bottom of the beaker.

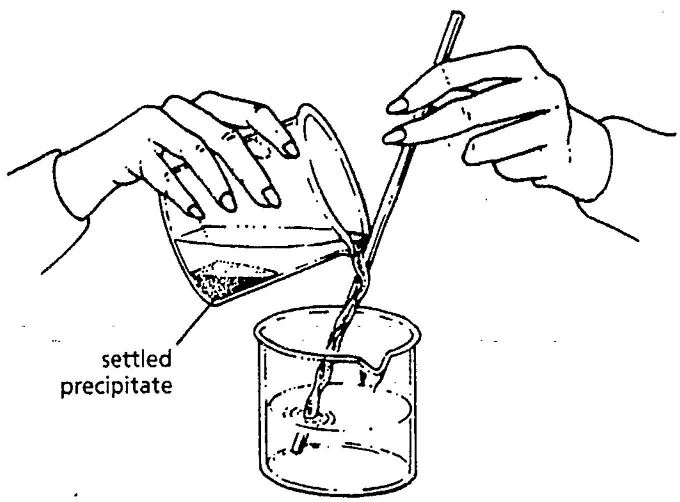


Figure 15-2

9. Add about 10 mL of water to the solid in the 100-mL beaker. Stir vigorously in order to wash off the solid. Let the solid settle and decant the liquid. Repeat the washing.

10. Spread the solid out on the bottom of the beaker and place the beaker in a drawer or oven to dry. Complete step 11 and the rest of this experiment at the beginning of the next lab period.

11. Find the mass of the beaker and the *dry* copper metal. Record this as (c) in the data table.

Observations and Data

a. Mass of empty beaker ________ g

b. Mass of iron filings ________ g

c. Mass of beaker + copper ________ g

d. Visual observations:

Calculations

Use the following information, as needed, to carry out the calculations:

$$\text{no. of gram-atoms} = \frac{\text{mass (g)}}{\text{g-atomic mass}}$$

g-atomic mass of Fe = 56 g Fe/g-atom Fe
g-atomic mass of Cu = 64 g Cu/g-atom Cu

1. Find the mass of the copper produced: c − a ______________ g

2. Find the number of g-atoms of copper produced: ______________

3. Find the number of g-atoms of iron reacted: ______________

4. Find the whole number ratio of g-atoms of iron to g-atoms of copper: ______________

Conclusions and Questions

1. How does the ratio found in calculation 4 compare with the ratio of the coefficients of the same two metals in the balanced equation for the reaction?

____

____

2. How many moles (g-atoms) of copper sulfate are used to produce the solution in this experiment? Why is this amount of copper sulfate said to be "in excess"?

3. Explain why the iron is the limiting factor in this experiment.

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Name ______________________________

15 Relating Moles to Coefficients of a Chemical Equation (continued)

4. A general description of the single replacement reaction in this experiment is: metal + salt in solution → "new" metal + "new" salt solution. Give a balanced equation for another example of this type of single replacement reaction.

____

5. Give general descriptions of two other types of single replacement reactions. Using balanced equations, give a specific example of each type.

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6. Consider the reaction: $Cu(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Cu(NO_3)_2(aq)$. If 3 moles of copper metal reacts, how many moles of silver metal will be produced?

____

____

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____

____

Name ______________________ Date __________ Class __________

Mole and Mass Relationships

Lab 16

Text reference: **Chapter 10, pp. 239–243**

Pre-Lab Discussion

In a balanced chemical equation, all reactants and products must be represented by symbols or formulas. The total number of atoms of each element must be the same on each side of the equation to satisfy the law of conservation of mass.

A calculation of the formula mass of a reactant or product enables a researcher to convert from grams of a particular substance taking part in a reaction to moles of that substance. The mole relationship given by the coefficients of the balanced equation then allows the researcher to calculate how many moles of every other substance will take part in the reaction.

In this experiment, you will investigate the quantitative relationships in the reaction:

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O(g)$$

A known mass of sodium hydrogen carbonate will be reacted with excess hydrochloric acid. Knowing the mass of $NaHCO_3(s)$ that reacts, you can determine from the balanced equation the mass of NaCl that should be produced. You can compare this theoretical value with the actual experimental mass of NaCl produced.

This experiment should aid in the understanding of the mole-mass relationships that exist in a chemical reaction and in the interpretation of a balanced chemical equation.

Purpose

Compare the experimental mass of a product of a chemical reaction with the mass predicted for that product by calculation.

Equipment

balance
burner
evaporating dish
watch glass
microspatula
test tube, 13×100-mm
dropper pipet
ring stand
iron ring
wire gauze
safety goggles
lab apron or coat

Materials

6 *M* hydrochloric acid (HCl)
sodium hydrogen carbonate ($NaHCO_3$)

Safety

Handle the hydrochloric acid with care. Flush any spills with cold water and a dilute solution of sodium bicarbonate and report them to your teacher. Do not lean over the apparatus when heating it in step 6. Note the caution alert symbols under "Procedure" and follow the precautions indicated. Refer to page xi to review those precautions. Always wear safety goggles and a lab apron or coat when working in the lab.

Procedure

1. Flame dry a clean evaporating dish by heating it in the hot part of a burner flame for about 5 minutes. Allow the dish to cool.
2. Find the combined mass of the evaporating dish plus a watch glass. This is mass (a) in your list of data.
3. Leaving the watch glass and evaporating dish on the balance, move the riders to measure an additional 2.50 g. Using a microspatula, add sodium hydrogen carbonate ($NaHCO_3$) to the evaporating dish until the scale balances. Record this mass as (b) in your list of data.
4. Set up the ring stand, ring, and wire gauze as shown in Figure 16-1. Place the watch glass on top of the evaporating dish and place the dish on the wire gauze.

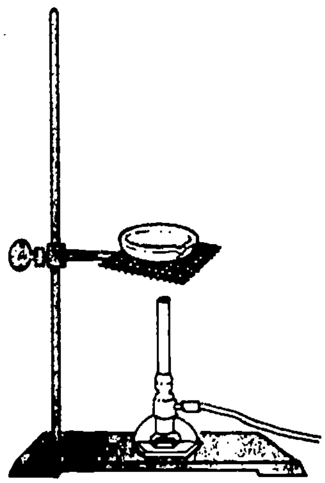

Figure 16-1

5. Obtain about 5 mL of 6 *M* hydrochloric acid (HCl) in a clean, dry test tube. **CAUTION:** *Handle this acid carefully. It can cause painful burns if it touches your skin.* Using a dropper pipet, slowly add HCl to the $NaHCO_3$ in the evaporating dish, a few drops at a time. (See Figure 16-2.) Continue adding acid until the reaction (bubbling) stops. Carefully tilt the evaporating dish back and forth a couple of times to make sure that the acid has contacted all the $NaHCO_3$. After making sure that all bubbling has stopped, remove the watch glass and place it *curved side up* on the lab bench.

Name ______________________________

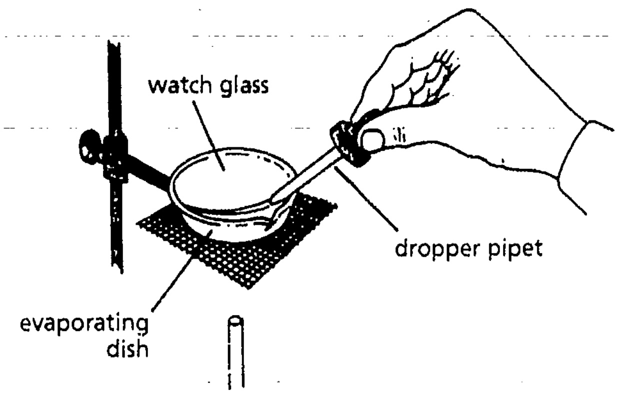

Figure 16-2

6. Holding the burner in your hand, *gently* heat the evaporating dish. Use a low flame and move the burner back and forth to avoid spattering. When almost all the liquid is gone, remove the burner and replace the watch glass on the evaporating dish, leaving a small opening for vapor to escape. Heat gently again until no liquid remains. Allow the dish to cool.

7. Find the combined mass of the watch glass, evaporating dish, and contents (NaCl). Record this mass, (c), in your list of data.

Observations and Data

a. evaporating dish + watch glass __________ g

b. evaporating dish + watch glass + $NaHCO_3$ __________ g

c. evaporating dish + watch glass + NaCl __________ g

Calculations

1. Find the mass of the $NaHCO_3$ reactant, b − a. __________ g

2. Find the mass of the NaCl product, c − a. __________ g

Conclusions and Questions

1. According to the balanced equation for the reaction used in this experiment, what is the ratio of moles of $NaHCO_3$ reacted to moles of NaCl produced?

____

____

2. How many moles of $NaHCO_3$ is reacted in this experiment? How many moles of NaCl is produced? What is the ratio of moles $NaHCO_3$ reacted to moles NaCl produced?

3. Using the balanced equation, calculate the mass of NaCl you would expect to get when 2.50 g of $NaHCO_3$ is reacted with HCl. How does this value compare with the mass attained experimentally?

4. If the masses of all but one of the substances that take part in a chemical reaction are known, explain why it is possible to determine the unknown mass by subtraction.

5. In the chemical reaction $CaCO_3 \rightarrow CaO + CO_2$, if 40.0 g of $CaCO_3$ is decomposed:
a. how many grams of CaO is produced?
b. how many grams of CO_2 is produced?

6. In the reaction $N_2 + 3H_2 \rightarrow 2NH_3$, if 20.0 g of hydrogen reacts:
a. how many grams of ammonia is produced?
b. how many grams of nitrogen reacts?

STOICHIOMETRY

Chemistry Chapters 8 - 9 TEST

Circle the most correct answer on the answer sheet.
DO NOT WRITE ON THIS TEST BOOKLET.

1. The study of the mathematical relationships derived from chemical formulas and equations is called
   a. moles
   b. gram-atoms
   c. stoichiometry
   d. chemathematics

2. The sum of the atomic masses of all the atoms represented in a formula is called the
   a. formula mass in ionic compounds.
   b. molecular mass in molecular substances.
   c. both a and b.
   d. none of the above.

3. One mole of a gaseous substance at STP
   a. contains Avogadro's number of particles.
   b. has a mass equal to its GAM or GMM.
   c. occupies a volume of 22.4 liters.
   d. all of the above.

4. Standard temperature is equal to
   a. 273° K.
   b. 0° C.
   c. both a and b.
   d. none of the above.

5. Which of the following is NOT equivalent to "standard pressure"?
   a. 1 atmosphere
   b. 10 lbs/ sq. in.
   c. 760 mm Hg
   d. 30 in. Hg

6. The volume of any gas at STP is called
   a. Avogadro's number.
   b. a gram-atom.
   c. a mole.
   d. a molar volume.

7. According to Avogadro's hypothesis, equal volumes of all gases at the same temperature and pressure have the same
   a. mass
   b. number of particles.
   c. density.
   d. atomic number.

8. The number of particles in one gram atomic mass of any element is equal to
   a. one dozen.
   b. one hundred.
   c. 2.5 x 10^{20}.
   d. 6.02 x 10^{23}.

9. The symbol " Ca " represents
   a. the name of the element.
   b. one atom of the element.
   c. one mole of the element.
   d. all of the above.

10. The chemical abbreviation for the name of an element is called a(n)
   a. symbol.
   b. formula.
   c. equation.
   d. mole.

11. The standard for relative atomic mass of the elements is
   a. Hydrogen
   b. Carbon
   c. Nitrogen.
   d. Oxygen.

12. Avogadro's number of Helium atoms weighs
   a. 4.00 grams.
   b. 1.0 gram.
   c. (4.0)(6.02 x 10^{23}) grams.
   d. none of the above.

13. White phosphorus has the formula P_4 . This means that in a phosphorus molecule there are
   a. 4 atoms.
   b. 4 molecules.
   c. 4 grams.
   d. 6 x 10^{23} moles.

14. A mole of oxygen gas is compared to a mole of lead. You can be sure that the sample of oxygen and the sample of lead have the same
   a. volume.
   b. mass.
   c. number of particles.
   d. color.

15. Which of the following has a volume closest to 22.4 liters?
    a. indoor sports arena
    b. classroom
    c. coffee cup
    d. computer monitor

16. The coefficients of a balanced equation give information about the reactants and products that can be used to compare
    a. numbers of particles involved.
    b. number of moles involved.
    c. volumes of gases involved.
    d. all of the above.

17. In the reaction: $2\ CO_{(g)} + O_{2(g)} \rightarrow 2\ CO_{2(g)}$
the volume of CO_2 produced at STP when 10.0 L of CO are completely reacted is
    a. 5.0 L
    b. 10.0 L
    c. 20.0 L
    d. 224.0 L

18. To change from moles of a substance given to moles of a substance sought, you use the
    a. coefficients for the substances from the balanced equation.
    b. ratio of molar masses of the 2 substances.
    c. subscripts in the formulas of the 2 substances.
    d. all of the above.

19. In the reaction: $CH_4 + 2O_2 \rightarrow CO_2 + H_2O$
the volume ratio of the reacting gases, methane and oxygen, is
    a. 1 : 2
    b. 2 : 1
    c. 5 : 4
    d. impossible to predict.

20. Which of the following quantities is conserved in a chemical reaction?
    a. moles
    b. molecules
    c. atoms
    d. volume

21. For the reaction $N_2 + 3H_2 \rightarrow 2NH_3$
if 0.5 mole of N_2 and 2.0 mole of H_2 were mixed, the limiting reactant will be the
    a. N_2
    b. H_2
    c. NH_3
    d. all of the above

22. The mass of one mole of $KClO_3$ is
 a. 90.6 grams
 b. 106.6 grams.
 c. 87.1 grams.
 d. 122.6 grams

23. The mass of 2 moles of $Ca(OH)_2$ is
 a. 21.1 grams
 b. 148.2 grams
 c. 114.2 grams
 d. 57.1 grams

24. The mass of 0.5 mole of $Pb_3(AsO_4)_2$ is
 a. 149.1 grams
 b. 389.0 grams
 c. 449.7 grams
 d. 899.4 grams

25. What is the mass of 0.0020 mole of NaOH?
 a. 0.08 gram
 b. 40.0 grams
 c. 8.0 grams
 d. 0.8 gram

26. How many molecules of water are in 0.5 moles of water?
 a. 11.2 molecules
 b. 3×10^{23} molecules
 c. 6×10^{23} molecules
 d. 12×10^{24} molecules

27. How many moles of Calcium would equal 4.2×10^{23} atoms of Calcium?
 a. 1 mole
 b. 0.5 mole
 c. 0.7 mole
 d. 0.05 mole

28. How many atoms are in 0.3 mole of Helium gas?
 a. 6×10^{23} atoms
 b. 1.8×10^{24} atoms
 c. 1.8×10^{23} atoms
 d. 1 atom

29. What is the volume of 0.27 mole of hydrogen gas at STP?
 a. 6.0 L
 b. 1.62 L
 c. 5.5 L
 d. 0.73 L

30. Ammonia gas is measured to have a volume of 83.25 Liters at STP. How many moles of ammonia gas does this represent?
   a. 3.7 moles
   b. 1864.8 moles
   c. 501.2 moles
   d. 13.8 moles

31. How many moles of SO_2 are found in 100.0 L of the compound?
   a. 22.4 moles
   b. 0.224 mole
   c. 4.46 moles
   d. 16.6 moles

32. How many molecules are contained in 18.0 grams of water?
   a. 22.4 molecules
   b. 6.02×10^{23} molecules
   c. 108.4×10^{23} molecules
   d. one

33. How many grams of ammonia gas, NH_3 , are in a 44.8 L sample measured at STP?
   a. 17 grams
   b. 34 grams
   c. 6.02×10^{23} grams
   d. 1.2×10^{25} grams

34. The number of molecules of Nitrogen gas, N_2 , found in 500.0 grams of nitrogen gas is
   a. 1
   b. 5
   c. 18×10^{23}
   d. 1×10^{25}

35. How much would 78.4 liters of hydrogen gas, H_2 , weigh at STP?
   a. 7.0 grams
   b. 3.5 grams
   c. 2.24 grams
   d. 0.602 grams

36. What is the volume of 2×10^{23} molecules of CO gas at STP?
   a. 268.8 L
   b. 67.2 L
   c. 7.5 L
   d. 22.4 L

FOR THE REMAINING QUESTIONS, REFER TO THE BALANCED EQUATION:

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

37. How many moles of Zinc were used to produce one mole of $ZnCl_2$?
    a. none
    b. 1 mole
    c. 2 mole
    d. 3 mole

38. How many grams of $ZnCl_2$ were produced?
    a. 136.4 g
    b. 1 g
    c. 3 g
    d. 6.02×10^{23} g

39. How many moles of $ZnCl_2$ would be produced if 4 moles of HCl were used in the reaction?
    a. 1 mole
    b. 2 moles
    c. 3 moles
    d. 4 moles

40. If 6.54 grams of Zn were used in the reaction, what mass of HCl would be used?
    a. 36.5 g
    b. 7.3 g
    c. 3.65 g
    d. 1 g

41. How many atoms are in one MOLECULE of $ZnCl_2$?
    a. 6×10^{23} atoms
    b. 22.4 atoms
    c. 3 atoms
    d. 1 atom

42. How many molecules are in one mole of $ZnCl_2$?
    a. 6×10^{23} atoms
    b. 22.4 atoms
    c. 3 atoms
    d. 1 atoms

43. How many atoms of Zn would react with 2 molecules of HCl in the original reaction?
    a. 1 atoms
    b. 6 x 10^{23} atoms
    c. 22.4 atoms
    d. 65.4 atoms

44. How many atoms of Zinc are reacting with 2 MOLES of HCl?
    a. 1 atoms
    b. 6 x 10^{23} atoms
    c. 22.4 atoms
    d. 65.4 atoms

45. If 409.2 grams of $ZnCl_2$ were produced, how many moles of HCl would be needed in the reaction?
    a. 409.2 moles
    b. 1 mole
    c. 2 moles
    d. 6 moles

46. What mass of hydrogen would be produced if 3 moles of $ZnCl_2$ were produced?
    a. 2 g
    b. 4 g
    c. 6 g
    d. 8 g

47. What volume of Hydrogen gas was produced in the original equation at STP?
    a. 1 L
    b. 2 L
    c. 22.4 L
    d. 44.8 L

48. What volume of hydrogen gas would be produced from 3 moles of Zinc at STP?
    a. 22.4 L
    b. 33.6 L
    c. 44.8 L
    d. 67.2 L

ESSAY: Answer on a separate sheet of paper.

49. The molar volume for all gases at STP is approximately the same. Provide a rationale for accepting this concept.

50. Why would the concept of the mole be so helpful to chemists?

Appendix F

Weekly Progress Questionnaire

HOW ARE YOU DOING?

Name ______________________________ Week # ________

1. So far, I understand. Yes No Undecided

2. So far, I can handle the material.
Yes No Undecided

3. It's getting harder. Yes No Undecided

4. I can do this ! Yes No Undecided

5. I am satisfied with my progress.
Yes No Undecided

6. Help ! Yes No Undecided