FOSTERING BASIC PROBLEM-SOLVING SKILLS IN CHEMISTRY

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ABSTRACT

A triangle divided in three parts was used to relate three variables, or two variables and a constant. Students learned to manipulate a given equation so that one of the variables is a product of the other two variables. Problems relating density, mass, and volume; speed of light, frequency and wavelength; gram, mole, and molar mass, molarity, moles and liters; and number of particles, Avogadro's number, and mole were attempted using triangles. In addition, a special triangle was constructed to relate the variables and a constant of the ideal gas law equation, and was used to solve ideal gas law problems. This visual representation of the problem helped students to understand the factors that need to be considered and the operations that needed to be performed in the problem-solving process. Over the course of two years, the method was used in four different introductory chemistry classes that had a total of 87 students. More than 80% of the students who use triangles were able to arrive at the correct answers. A big percentage of students also liked using triangles to solve simple problems. *[AJCE, 2(2), February 2012]*

INTRODUCTION

Learning chemistry is a challenge for many beginning college students. For one thing, it involves learning the vocabulary, underlying facts, and associated concepts of the field, which requires more than mere memorization. In addition, a good knowledge of algebra is needed to manipulate and solve some simple problems. Often, students who take introductory chemistry courses find it difficult to apply the math they already know from high school, or worse, the basic math skills are lacking altogether. It is not uncommon to find students who will pull out a calculator when asked to multiply 1.1 by 5 or to divide 2.4 by 2. Students also try to memorize how a particular problem has been solved, instead of concentrating on working several related problems at the end of each chapter until they master a required problem-solving skill.

To compound this problem, many freshmen have poor time management skills. They can be slow to realize that the amount of work required in college in order to become successful is exponentially higher than that in high school and that time spent learning outside of class is as important as that spent in the classroom. Another issue impacting time management is the lure of social networking tools. Learning (in and out of the classroom) competes with texting, tweeting, and connecting with friends in social networking sites. All of this interference with learning can result in students who lack focus, skip class, or never realize that they missed class at all. When several of these issues are going on at the same time, those students quickly get overwhelmed by the required work of the course. They end up wanting the instructor to slow down and to be "gentle" when grading their work.

When we consider then that students may come to our introductory chemistry classes with low math skills, inadequate problem solving skills, unrealistic expectations about effort, and poor study habits, it is no wonder that instructors are confronted with huge obstacles in helping students to succeed in freshmen chemistry classes. Oftentimes, students who fail their initial chemistry, which for this report will be termed “CHEM 101”, never come back to retake the course. The challenge then is to make them successful, because if they don’t pass the first time, they will abandon the subject. CHEM 101 is taken by the majority of students in sciences, health related courses and in engineering, but for some, CHEM 101 will be the only chemistry they take in their entire lives, so it is very important that they at least learn a few basic skills in this course.

Because of a growing awareness of (and concern about) these challenges, a strategy that I have found effective in freshmen chemistry classes is “Communication Notes.” The main objective of Communication Notes is to remind and to reinforce what has been covered in class; and four e-mails messages a week are sent out to all CHEM101 students. A few facts, and drills similar to problems provided as examples in this paper, are repeated several times with the hope that they will become second nature for students when encountered during the course of study. A big advantage of this approach is that no significant amount of class time is used up. Minor questions and issues, if any, are usually discussed during the first two minutes of each following lecture.

The use of a triangle first learned in high school, is emphasized in solving problems involving three variables, since the majority of the problems in introductory chemistry, with the exception of the ideal gas laws, can be solved by manipulating equations that contain three variables. The visual representation of the problem helps math-challenged students to understand the factors that need to be considered and the operations that need to be performed in the problem-solving process.

The difficulty of teaching beginning chemistry students unit analysis problems (1) and stoichiometry (2) has been previously addressed. Blending English and math and not mere equations has also been suggested as a useful tool for student learning (3). Dimensional analysis is commonly used to help students arrive at a required answer by tracking units, and has its advantages and disadvantages.

In this paper the use of a triangle to solve three variable problems is presented as a useful technique for beginning chemistry students. Problems similar to those presented in this paper are sent out to students by email during the time when each topic is being covered in class.

THE TRIANGLE METHOD IN CHEMISTRY

One of the first equations students encounter is one relating density, mass and volume. Students are told that density is mass per unit volume, and in mathematical terms,

Density = mass/volume

The following questions test the handling of the expression. What happens when the density and the volume are given and one is asked to find the mass; or, the density and mass are given, and the finding the volume is the task? Using simple algebra, mass can be expressed as density x volume, and volume as mass divided by density. At that point students think that they are faced with learning three different equations.

It is important to emphasize that they do not have three different equations; that it is only one equation, and that, that equation can be used to find an unknown when two variables are given. The following triangles, one using variables and the other, the corresponding units, can be used for solving problems involving density, mass, and volume.

Density = Mass/Volume = grams/mL or grams/cm^3. 1 ml=1cm^3; 1/cm^3 = cm^{-3}.

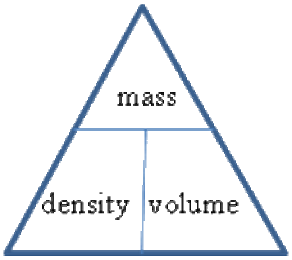


Figure 1

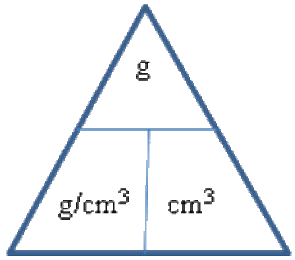


Figure 2

The horizontal lines in the figures represent division, and the vertical lines represent multiplication. Thus, mass = density x volume (g = grams/cm^3 x cm^3); volume = mass/density (cm^3 = grams/grams.cm^{-3}); and density = mass/volume (g /cm^3). Looking closely at the units in the triangle, we realize that multiplying the two units below the horizontal line yields the unit above that line. Another way of writing g/cm^3 is g.cm^{-3}.

a) g.cm^{-3} x cm^3 = g

b) g/gcm^{-3} = cm^3

We can also think about units as if as they were numbers. Let us visualize this using the triangle below.

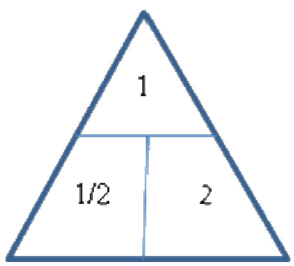


Figure 3

Using the numbers in the triangle,
Two numbers, ½ and 2 can be multiplied to yield 1. Also note that 1 ÷ ½ = 2.
In summary, to get 1, multiply ½ by 2; to get ½ divide 1 by 2; and to get 2 divide 1 by ½.

Examples

1. The density of mercury (Hg), the only metal that is a liquid at room temperature, is 13.6 g/mL. Calculate the mass of 16.50 mL of the liquid.

Mass (g) = density ($g.cm^{-3}$) x volume (cm^3). Note that 1 mL = 1 cm^3.

Mass = 13.6 $g.cm^{-3}$ x 16.50 cm^3 = 2.24 x 10^2 g.

2. Bromine is a reddish-brown liquid. Calculate its density if 283 g the substance occupy 94 mL.

Density = g÷cm^3. Remember that 1 mL = 1 cm^3

Therefore density = 283 g÷ 94 cm^3 = 3.0 g/cm^3.

3. The density of water is 1 g/cm3. What is the volume 5 g of water?

   Volume = g/$g.cm^{-3}$

   Volume = 5 g/1 $g.cm^{-3}$ = 5 cm^3, or 5 mL, since 1 mL =1 cm^3.

Problems involving Avogadro's number

In the SI system the mole (mol) is the amount of a substance that contains as many elementary entities (atoms, molecules, or other particles) as there are atoms in exactly 12 g or 0.012 kg) of the carbomn-12 isotope. The actual number of atoms in 12 g of carbon-12 is determined experimentally. This number is called Avogadro's number (N_A), in honor of the Italian scientist Amedo Avogardo. The currently accepted value is N_A = 6.0221415 x 10^{23}. Generally, we round it to 6.022 x 10^{23}. Thus, just as one dozen of pencils contains 12 pencils, 1 mole of copper atoms contains 6.022 x 10^{23} Cu atoms.

Finding the number of particles (atoms, molecules or ions) in stuff requires us to know Avogadro's number (6.022 x 10^{23}) and the number of moles (amount) of stuff.

1 mole contains 6.022 x 10^{23} particles

2 moles contain 2 x 6.022 x 10^{23} particles

10 moles contain 10 x 6.022 x 10^{23} particles, etc.

We see an important relationship developing here.

Number of particles = Avogadro's number x moles.

Particles = N_A x moles. The following triangle can also be used.

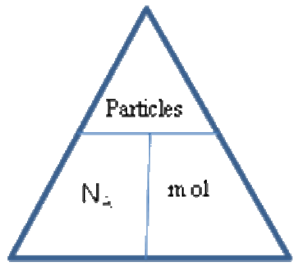


Figure 4

Gram-mole conversions

Grams = moles x molar mass = moles x grams/mole.

Moles = grams ÷ molar mass =grams /grams.mol^{-1}.

Molar masses in grams/mole are what we get from the periodic table of elements, so we focus on using that quantity to move from moles to grams and vice versa.

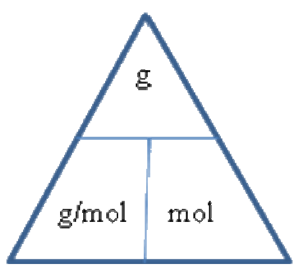


Figure 5

Examples

1. Sulfur (S) is a nonmetallic element that is present in coal. When coal is burned, sulfur is converted to sulfur dioxide and eventually to sulfuric acid that gives rise to the acid rain phenomenon. How many atoms are there in 12.5 g sulfur?

Solution: There is g and mol in Fig. 5, so starting from grams, the number of moles can be found, followed by finding the number of particles by using Fig. 4. Let us use Fig. 5 first to find the number of moles. Figure 4 will be used to find the number of atoms (particles).

Using Fig.5, we need to get the molar mass of sulfur from the periodic table of elements, which is 32.07g/mol. G/mol can be written as $g.mol^{-1}$.

$Mol = g \div g.mol^{-1}$

$Mol = 12.5\ g \div 32.07\ g.mol^{-1} = 400.875\ mol.$

We now move to Fig. 4 to find the number of atoms.

Atoms (particles) = Avogadro's number (Na) x mol

Atoms = $6.022 \times 10^{23} \times 400.875$ mol.

Atoms = 2.41×10^{26}.

2. What is the mass of 4.70×10^{24} atoms of Cr?

Solution: The first thing we need to do is to find the number of moles using Fig. 4. A little inspection indicates that since Avogadro's number is 6.022×10^{23}, the number of moles in the problem will be greater than one. Using the periodic table we know that the atomic mass of Cr is 51.9961 g/mole.

Using Fig. 4, the number of moles = Particles $\div Avogadro's number$

Number of moles = 4.70×10^{24} atoms $\div$ 6.022×10^{23} $atoms.mol^{-1}$ = 7.80 mole.

Next we use Fig. 5 to find grams. Grams = moles x g/mole = 7.80 mole x 51.9961 g/mole = 3163 g.

Molarity, moles, and liters

Molarity (M) = moles/liter (mol/L or mole x L^{-1}). The liter is quite big and in the laboratory, liquid volume measurements are often carried out in milliliters (mL). We must be able to easily convert mL to liters. 1,000 mL = 1 L. To convert from mL to liters divide by 1,000.

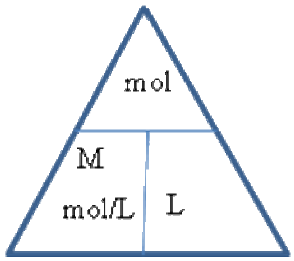


Figure 6

Examples

1. A solution of 36.1 g NaCl is dissolved in sufficient water to give a total volume of 525 mL. The molar mass of NaCl is 58.44 g/mol. How do we get 58.44 g/mol? What is the molarity of the solution?

Solution: Molarity = moles/liter. We need to find the number of moles using Fig. 5.

Moles = 36.1 g /58.44 $gmole^{-1}$ = 0.76 mol NaCl.

We convert ml to L. 525 mL = 0.525 L

Molarity = 0.76 mol/ 0.525 L = 1.28 mole/L or 1.28 M.

2. How many moles are in 250 mL of 0.023 M of NaOH solution?

Solution: We are given volume and molarity (M). From Fig. 6, we see that we can get moles by multiplying moles/L with L. We need to convert 250 mL to liters. 250 mL = 0.250 L, ¼ L.

As a reminder, moles/liter can be written as moles L^{-1}.

Moles = 0.023 moles L^{-1} x 0.250 L = 0.0060 moles. The number of grams of NaOH needed to prepare the solution can be calculated by suing Figure 5. The molar mass of NaOH is 39.997 g/mol. Therefore amount in grams will be 39.997 g/mole x 0.0060 moles = 0.24 g.

Wavelength and frequency

Wavelength (λ), frequency (ν), and the speed of light (c) = 3.00 x 10^8 ms^{-1} in a vacuum. In this particular case we have two variables and a constant, and we can still employ the same triangle method to find either wavelength when frequency is given or we can solve for frequency if we know the wavelength.

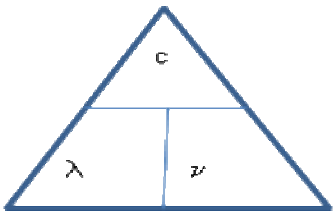


Figure 7

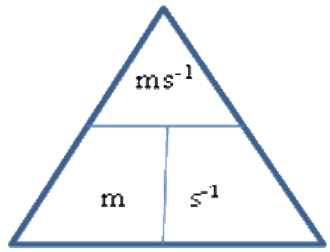


Figure 8

The speed of light c = wavelength x frequency; c =λν. Fig. 7 shows the relationship between variables and Fig. 8 shows the relationship between the corresponding units.

Examples

1. A microwave oven uses radiation with a frequency of 2.5 x 10^9 /s. What is the wavelength of that radiation? Note that 2.5 x 10^9/s can be written as 2.5 x $10^9 s^{-1}$. Also Remember that 1 hertz = 1 s^{-1}.

Solution: Wavelength (m) = ms^{-1} ÷ s^{-1}

Wavelength (m) = 3.00 x 10^8 ms^{-1} ÷ 2.5 x 10^9 s^{-1} = 0.012 m = 12 cm

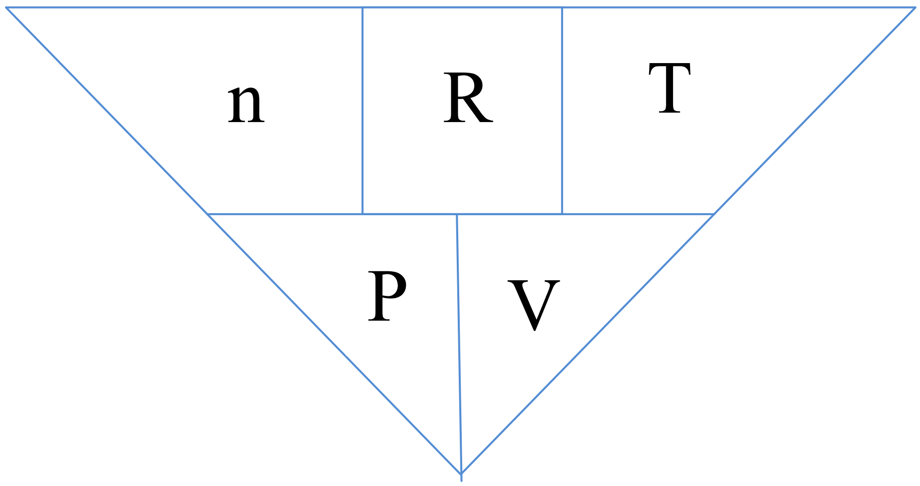
2. Ham radio operators often broadcast on the 6-meter band. What is the frequency of this electromagnetic radiation in MHz? 1 hertz = $1s^{-1}$; 1MHz = 10^6 Hz

Frequency (s^{-1}) = ms^{-1}/m = ~~m~~s^{-1}/~~m~~ = s^{-1} (Hz)

Frequency = 3.00 x 10^8 ms^{-1}/ 6 m = 30.0 x 10 ms^{-1}/6m = 5.00 x 10^7 Hz = 50 MHz.

The ideal gas equation

Even non-major students can use the following modified triangle to solve simple problems involving the ideal gas equation.



Example

Sulfur hexafluoride (SF_6) is an odorless, colorless, very unreactive gas. Calculate the pressure (in atm) exerted by 1.52 moles of the gas in a steel vessel of volume 2.72 L at 65.4°C.

Number of moles = 1.52; R = 0.0821 L.atm/K.mol; T = (65.4+ 273) K = 338.4 K; V = 2.72 L.

Using the triangle, Fig. 9,

$$P = nRT/V = \frac{(1.52\ \text{mol})\ (0.0821\ \text{L.atm/K.mol})\ (65.4 + 273)\ \text{K}}{2.72\ L} = 15.5\ \text{atm}$$

PRELIMINARY FINDINGS

Students' comments about the use of triangles to solve simple problems

When I asked whether the use of triangles to solve problems was useful, the following representative responses were received. The total number of respondents was sixty two students.

- "Yes, I memorized all the triangles for this final and it was very helpful."
- "No, I prefer to just use the formulas."

- "Yes, the triangles were helpful. In high school, I could never remember how to do the mole ratios, but the triangles definitely helped."
- "The triangles were extremely helpful because they are easy to use. You should print out an entire sheet with them on it, and let students use them on the test."
- "Yes very! Gave visual representation to variables, plus, made going from one variable to another very easy."
- "Yes, I liked the idea since it made it so easy to remember how variables were connected in different equations."
- "Yes they were. They gave a simpler way to solve problems."
- "Yes, they simplified the equations and were very easy to remember."
- "Yes, it was easy to see how to get the unknown by looking at what made what in different sections."
- "Yes, it was an easy way to remember how to relate the unknown to the two other things that were given."
- "Yes, the triangles were very helpful in remembering how to convert from grams to moles as well as other equations (Density = mass/volume)."
- "I did not think they were helpful to me, because in math I was taught another way to do algebra. But my friends liked using triangles."
- "Yes, I used the triangles to find density, molarity, and to convert moles to grams."
- "I thought a few of the triangles were helpful, but if you understood the concept the triangles weren't helpful or necessary. I found it easier to learn the concept rather than memorizing the order of things in the triangle."

- "Yes, they helped in remembering whether or not to multiply or divide, but were confusing at first."
- "I thought the triangles were very helpful. I'm a visual learner and I like to see things to ensure that I'm right and not count on my memory."
- "No. I was more confused using a triangle than when I was setting up a problem in a more algebra form. Stoichiometry was a lot easier for me to follow my work and double check it."
- "Yes, I loved it because I did not have to memorize three different equations for frequency, wavelength, and the speed of light. Learning the stupid symbols was hard enough."

CONCLUSION

The triangle method to transform three variable equations, for example, the one that involves density, mass and volume; and those that involve two variables and a constant, for example, speed of light, wavelength and frequency were found to be useful for the majority of students. The weakest students were also able to draw triangles and use them to solve problems related to topics covered above. As long as students were able to rewrite an equation involving three variables in such a way that one variable is a product of the other two variables, which usually required simple cross multiplication, they found it easy to solve problems for an unknown variable when the other two variables were provided.

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