THE MATHEMATICS OF ELEMENTARY CHEMISTRY.

BY PRINCIPAL J. MCINTOSH.

Fowler Union High School, California.

The discussion of this subject naturally divides itself into three parts.

I. Mathematics. 1st, from an ideal standpoint. 2d, as it is. 3d, as chemistry teachers want it.

II. The work done in Mathematical Chemistry.

III. The results obtained.

Some noted educator has given us the following: "Whatever improves the mental powers, strengthens the judgment, and sharpens the faculties to keener discernment; in fact, whatever trains the energies and capacities, directing them to their true ends, tends to culture in its highest and best sense." Many maintain that mathematics, in its real sense, holds the broadest place in this field, particularly as it strengthens the judgment and sharpens the faculties to keener discernments. Kepler exclaimed, that "the laws of nature are but the mathematical thoughts of God." Maxwell said: "All knowledge is founded on the comparison of one quality with another. Knowledge that is not exact has but little value and frequently is a detriment to its possessor."

This is very different, however, from the mathematics as we know it in the public schools today. The grade teacher complains because the pupils come to her ill-prepared in their arithmetic, likewise the high school teachers and university instructors. It is probably no exaggeration to say that thirty-five per cent of the pupils fail in arithmetic and a similar ratio in algebra and geometry. From this condition it seems that our schools need men and women who know the underlying principles of mathematics and parents who insist that their children shall think on these things and not upon the next social event of the season.

Most pupils find the solving of new problems very difficult and many find it impossible. The best pupils do the work and the poor ones memorize it. This fact is most noticeable in classes in geometry. In the algebra class, the pupils spend entirely too much time looking for the answer. Our leading educators tell us that we learn from the concrete to the abstract, yet, we teach the abstract mathematics first, then later in their

work in physics and chemistry get the concrete. The pupils see little relation between the two and this is a very difficult matter to teach. All teachers, no doubt, have had the experience with students who could not solve for an unknown when it was T, V, or L, but as soon as X was placed for this unknown, they could solve readily.

The old technical grammar was very unpopular. The boys would not study it; now correlation has made English an interesting study. Even so, the English teachers tell us that technical grammar is an absolute necessity to an understanding of the language. Similarly, mathematics is a great aid to the study of science. "It is absolutely necessary to anything more than a superficial knowledge of the subject." The student must learn that the method of solution of a problem is found in the problem itself, when once read and interpreted properly. "Mathematics had its origin in trying to solve practical problems," and it still used by the engineers who are solving the great problems that are benefiting the human race. The chemist is none the less practical than the engineer.

These facts being true, we ask the teachers of mathematics, First, to drill their students upon the correct manipulation of equations, using different letters for the unknowns; Second, to teach ratio, direct and inverse, proportion, percentage and graphs. Nearly all the problems in mathematical chemistry are in the form of equations, and these equations involve either the direct or inverse ratio. The student must know percentage to calculate the percentage, composition of compounds, and graphs for the drawing of curves of solubility, etc.

So much for the value of elementary mathematics and the need of the preparation of the student for the mathematical chemistry. Why? Freer states: "There are two laws that are fundamental throughout chemistry, the qualitative and quantitative relations. One is as important as the other, and should correlate each other." He further states that "An elementary course in chemistry is not to produce a chemist, but to give the beginner some fundamental principles of the science." The California Universities are quite in line with this idea. Stanford favors a thorough knowledge of elementary chemistry, as a preparatory course, while the University of California desires some qualitative analysis in the elementary course, yet, both universities require the solution of many problems to fix the principles.

The student doing university work states that the solution of problems is of invaluable help to him as a preparation for the advanced work.

One of the benefits derived from the meetings of this Association is that its members come together for mutual help and instruction, but the greatest benefit comes about by the writers of the different papers presenting their views upon some particular subject that they have worked out in their own experience, giving the difficulties met, their attempts at mastering them, and the results obtained. With this end in view we come to the second point. The work done in mathematical chemistry.

Knowing that there are from twenty-five to fifty per cent of the class that have forgotten the above points that the mathematics teacher is requested to fix, in the first lessons, we review these terms and explain the new ones that will be used. The pupils must know, in addition to the mathematical terms, the words meter, centimeter, millimeter, gram, cubic centimeter, the relation of one gram to one cubic centimeter, a barometer, how it is used, how to read it, the terms pressure, standard pressure, atmospheric pressure, an atmosphere, volume, thermometer, the two kinds, Centigrade and Fahrenheit, and how to change from one scale to the other. The class is now ready to form experiments one and two of Richardson's Chemistry understandingly. In experiment one, the pupils easily read Boyle's Tube Apparatus and see that as the pressure increases, the volume of the enclosed gas decreases. They then state the law from which they deduce a general expression for the volume V , at pressure P , when the volume v , and pressure p , are known. Their solving of a few problems fixes this law. In experiment two, Charles' Law is developed. They see that the increase in volume per cubic centimeter per one degree centigrade is a constant; that taking the volume at the lowest temperature this constant, in the form of a common fraction, is approximately $\frac{1}{273}$ of the original volume or the increase in volume due to the increase of one degree is $\frac{1}{273}$ of the volume. Hence it follows that the volume at $1^{\circ}\text{C} =$ volume at $0^{\circ}\text{C}.$ $+$ $\frac{1}{273}$ volume at $0^{\circ}\text{C}.$; volume at $t^{\circ}\text{C} =$ volume $0^{\circ}\text{C}.$ $+$ $\frac{t}{273}$ volume at $0^{\circ}\text{C}.$, letting $V =$ volume at $0^{\circ}\text{C}.$; v the volume at $t^{\circ}\text{C}.$ the class derived the formula $V = v \frac{273}{273+t}$ which they interpret as an expression for the volume of gas under

standard temperature. This argument is carried farther showing that the volume at $-1^{\circ}\text{C}.$ $= \frac{272}{273}$ of the volume at $0^{\circ}\text{C}.$ and at $-273^{\circ}\text{C}.$ $= \frac{0}{273}$ of the volume at $0^{\circ}\text{C}.$, so if the law held true for low temperature at $-273^{\circ}\text{C}.$ the gas would occupy no volume, and for sake of convenience the point $-273^{\circ}\text{C}.$ is called the absolute zero. They discover now a new statement for Charles' Law.

Boyle's and Charles' Laws are now combined into one general algebraic formula: $V = \frac{v\phi T}{P\phi}$ where the major letters represent the things that are in the question and the minor letters the things that are given in the problems. Two or three days are given to the solution of problems to fix this formula.

The student, when performing the experiments, determining the percentage of oxygen in potassium chlorate, the equivalent weight of zinc or magnesium, the ratio by weight in which hydrogen and oxygen combined to form water, sees the need of mathematics and mathematical accuracy to get results. He sees that he must weigh accurately and adjust carefully. He sees that any apparatus may be set wrong and read wrong. When he sees that he must get down to bedrock he gets there. It is then that we begin to get results and this kind of work has its effect in close and logical thinking.

After the above experiment such problems as are found in Newell's Experimental Chemistry and those like the following are given: Find from the following data: First, the percentage of oxygen in potassium chlorate. Second, the weight of a liter of oxygen at standard. Third, a number of liters of oxygen at $27^{\circ}\text{C}.$ 74 cm. pressure that may be obtained from ten grams of potassium chlorate, knowing weight of the test tube, weight of the tube and potassium chlorate, weight after heating, volume of water displaced, temperature, and the reading of the barometer. At this point such terms as chemical reactions, chemical equations, molecule, atom, molecular weight, atomic weight, laws of definite and multiple proportions are explained briefly, just enough for the student to understand what has been taking place in the experiments. From this time on all problems are worked directly from the reaction.

So the work proceeds, performing experiments, discussing the subject matter in the text and solving the problems given at the end of each chapter, through a period of five or six months,

when one month is given over to the discussion of chemical theories and explanation of the phenomena that they have observed. The ground covered in this discussion was well presented last year by a paper* from Mr. Baker of Lowell High School of San Francisco.

A short review is now taken of the problems on reaction and explained from the atomic theory. To Boyle's and Charles' Laws is added the aqueous tension correction. The class is now ready for such problems as the following: The formation of carbon dioxide from Calcium Carbonate and hydrochloric acid is shown from the reaction of $2\text{HCl} + \text{CaCO}_3 = \text{CO}_2 + \text{CaCl}_2 + \text{H}_2\text{O}$. What weight and what volume of carbon dioxide at 27°C . 74 cm. pressure is formed from twenty-five grams of calcium carbonate? How much hydrochloric acid is necessary? How much calcium chloride is formed? Specific gravity of carbon dioxide is twenty-two, aqueous tension at 27°C . is 26.51 mm., combining weight of $\text{H}=1$; $\text{Cl}=35.5$; $\text{Ca}=40$; $\text{C}=12$. $\text{O}=16$. The students must remember the weight of one liter of hydrogen at standard conditions.

Next show that from Avogadro's Law follows the statements that the same ratio exists between the specific gravities of gases as exists between their molecular weights; that the molecular weight of a gas is equal to twice its specific gravity when referred to hydrogen, and 28.88 times its specific gravity when referred to air. Knowing the specific gravity of a gas, its percentage composition, the class readily solves for the molecular weight and chemical formula of a compound, such as the following problem. A compound which analysis shows consists of carbon and oxygen, 27.27 per cent of the former and 72.73 per cent of the latter. The weight of one liter of the gas is 1.97 grams. Find molecular weight and chemical formula.

The Law of Dulong and Pettit is mentioned incidentally in connection with the methods of location of the discovered elements in the Periodic Table. The student sees that the law of Dulong and Pettit only verifies the results for the atomic weights as determined in other ways. But the Periodic Law they recognize as being the most wonderful of all. They read with interest the comparison of the predicted properties and the discovered properties of the new elements and follow carefully the arguments upon the location of Indium in this table. Since the specific heat of

*SCHOOL SCIENCE AND MATHEMATICS, Vol. VI, No. 4, Page 273, April, 1906.

Indium was correctly determined they see that this element has a place in the table.

Problems on specific heat, electrolysis, and those involving Sanford's formula for the combination of Boyle's and Charles' Laws and the Kinetic Gas Theory are left to the class in physics. This completes the work that is done on combination by weight, and next follows combination by volume. The pupils have learned that two volumes of hydrogen and one volume of oxygen have combined to form two volumes of water vapor, that one volume of H and one volume of Cl combined to form two volumes of HCl, so can understand Gay Lussac's Law of simple volume ratio and the numerical proportion. "The number of atoms* contained in a given volume of a gaseous substance bears a simple ratio to the number of atoms contained in the same volume of any other gas." This, with Avogadro's Law, will enable the pupil to understand the reasoning given for the number of atoms in a molecule of H and Cl. All molecular volumes are equal. The half molecular volume of any gas is the volume which is equivalent to the volume of an H atom. If the teacher uses the molecular relation the numbers in the ratio are the coefficient of a compound and one-half the coefficient of an elementary gas, while in the atomic relation the numbers in the ratio are twice the coefficient of the compound and the coefficient of the elementary gas, thus in $2\text{CO} + \text{O}_2 = 2\text{CO}_2$ the molecular ratio is 2:1 and atomic relation 4:2, then follows a list of problems such as: Three liters of a mixture in equal volumes of CH_4 , C_2H_2 and CO are burned the products being CO_2 and H_2O . How much O is required and how much CO formed?

Summing up, a course in Elementary Mathematical Chemistry should consist of problems to fix Boyle's and Charles' Laws, Gay Lussac's Gas Volume Law; on reactions, showing combinations by weight, percentage composition, molecular weights, atomic weights, determinations of chemical formulae, drawing of curves of solubility, etc., and study of the Periodic Table. The best lists of problems that I have found are in Newell's Experimental Chemistry and Bradbury's Manual of Chemistry.

The results bear a simple ratio to the student's preparation in algebra. The percentage of those who do satisfactory work of this character is but little less than the percentage of those who do satisfactory work in the other part of the chemistry.†

*"Atoms" as used in this quotation, would be designed "molecules" by chemists of to-day.—Ed.

†Figures taken from classes in Stockton High School.