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ELEMENTARY CHEMICAL CALCULATIONS

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Chemistry as a mathematical science teaches an analytical approach to the solution of problems. This, we believe, carries over to other subjects and other situations. In solving chemical problems the student is taught to recognize the items which are given and those which are sought for. He is taught to bring to bear on the problem at hand the relationships among the quantities given and those to be found. One trained in this manner, when confronted with an unknown situation, will perhaps bring logic and organization to bear upon its solution.

Let us be concrete and take a few illustrative problems and see how the student is trained to solve them. Let us take a very simple problem at first and discuss its solution.

How many grams of silver chloride can be obtained from 10.00 g of calcium chloride if the yield is 100 per cent?

There are two methods of approach. One is algebraic, involving ratio and proportion; the other arithmetical. In either case the problem must be analyzed in order that the given and the required be clearly recognized. As a first step in solving many problems, it is best to have the pupil write and balance the equation representing the chemical change. This step teaches the pupil the chemistry involved.

Later the reactions are many and complex in going from given to unknown, and therefore it is logical to teach the student to recognize chemical equivalents.

Solving the problem given above from the algebraic standpoint, one would proceed as follows. In the first step of writing and balancing the equation, any soluble silver salt may be selected, and the nitrate is used here.

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

The second step is to read the problem again and to place under the formula of the known in the balanced equation the amount given, and under the formula of the unknown the symbol y. This symbol is chosen to prevent confusion with the multiplication sign.

The units are always included. In the third step of the solution, the pupil is taught to write the correct multiples of the atomic or molecular weights of the given and required substances over the respective formula for each in the balanced equation. This would give

$$\underset{10.00\ g}{\overset{110.99}{CaCl_2}} + 2\ AgNO_3 \longrightarrow \underset{y\ g}{\overset{2x143.34}{2\ AgCl}} + Ca(NO_3)_2$$

The fourth step is to point out to the pupil that if one molecular weight (110.99 parts by weight) of calcium chloride yields two molecular weights (2x 143.34 parts by weight) of silver chloride, then 10.00 g of $CaCl_2$ will yield y g of silver chloride, or expressed as a proportion

$$\frac{110.99}{2(143.34)} = \frac{10.00\ g}{y\ g}$$

The proportion can be written also

$$\frac{110.99}{10.00\ g} = \frac{2x143.34}{y\ g}$$

In either case

$$y\ g = \frac{10.00x2x143.34\ g}{110.99} = 16.82\ g$$

In the arithmetical procedure the steps are similar to the algebraic one except that a question mark is written under the unknown. The solution is to find the amount of unknown per unit amount of the known, and then the amount of unknown per given amount of the known. This is the procedure followed in solving arithmetical problems in the grades. Thus for the problem given above

$$\underset{10.00\ g}{\overset{110.99}{CaCl_2}} + 2\ AgNO_3 \longrightarrow \underset{?\ g}{\overset{2\times 143.34}{2\ AgCl}} + Ca(NO_3)_2$$

then

$$\frac{2\times 143.34}{110.99} \times 10.00 = 16.82\ g \text{ of } AgCl$$

↑ Grams of AgCl per g of $CaCl_2$ (under $\frac{2\times 143.34}{110.99}$)

↑ Grams of $AgCl_2$ per 10.00 g of $CaCl_2$ (under $\times$ 10.00)

The complete statement of the solution of the problem to a given point is indicated by the arrow. This type of procedure is better suited to the solution of more complex problems. Let us choose such a problem and follow its solution.

A sample of impure ferrous ammonium sulphate weighs 0.5013 g and furnishes 0.0968 g of Fe_2O_3. What is the percentage $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$? (7).

In the solution of this problem it is best to use chemical equivalents. The student at this stage of training should recognize that one molecule or one molecular weight, respectively, of Fe_2O_3 is equivalent to two molecules or two molecular weights, respectively, of ferrous ammonium sulphate. The solution then is as follows:

$$\frac{\overset{(2\times 392.15\ g)}{2\ Fe(NH_4)_2(SO_4)_2\ 6H_2O}}{\underset{(159.70)}{Fe_2O_3}} \times 0.0968 \times \frac{1}{0.5013} \times 100 = 94.8 \text{ Per cent ferrous ammonium suphate in the impure sample}$$

↑ Grams of ferrous ammonium sulphate per g of ferric oxide (under $\frac{2\ Fe(NH_4)_2(SO_4)_2\ 6H_2O}{Fe_2O_3}$)

↑ Grams of ferrous ammonium sulphate per 0.0968 g of ferric oxide. This is the g of ferrous ammonium sulphate in the sample of impure ferrous ammonium sulphate. (under $\times$ 0.0968)

↑ Grams of ferrous ammonium sulphate per g of impure sulphate (under $\frac{1}{0.5013}$)

↑ Grams of ferrous ammonium sulphate per 100 g of impure sulphate; this is parts per 100 parts which is per cent (under $\times$ 100)

Let us solve two other typical problems. A sulfuric acid solution has a density of 1.84 g per milliliter and is 96.0 per cent by weight hydrogen sulphate (H_2SO_4). Calculate the molality, molarity and normality of the solution.

[7] Hamilton and Simpson, *Calculations of Quantitative Chemical Analysis*, second edition, McGraw-Hill Book Co., Inc., 1937, p. 75.

$\frac{96.0}{4.0}$ ×	1000 ×	$\frac{1}{98.02}$	244.8 m
Grams of H_2SO_4 per gram of H_2O	Grams of H_2SO_4 per 1000 g of water	Moles of H_2SO_4 per 1000 g of water. This is the molality	

$\frac{96.0}{100}$ ×	1.84 ×	1000 ×	$\frac{1}{98.02}$	18.02 M
Grams of H_2SO_4 per grams of solution	Grams of H_2SO_4 per 1.84 g of solution, which is the grams of H_2SO_4 per ml of solution	Grams of H_2SO_4 per 1000 ml of solution	Moles of H_2SO_4 per 1000 ml of solution. This is the molarity	

$\frac{96.0}{100}$ ×	1.84 ×	1000 ×	$\frac{1}{49.01}$	36.04 N
Grams of H_2SO_4 grams of solution	Grams of H_2SO_4 per 1.84 g of solution, which is the grams of H_2SO_4 ml of solution	Grams of H_2SO_4 per 1000 ml of solution	Equivalent weights of H_2SO_4 per 1000 ml of solution. This is the normality	

The freezing point of the solvent is lowered to -0.465 C by the addition of 34 g of sugar in 400 g of water. What is the molecular weight of the sugar?

$\frac{34}{400}$ ×	1000 ×	$\frac{1}{0.465}$ ×	1.86	340 Molecular weight
Grams of sugar per g of water	Grams of sugar per 1000 g of water	Grams of sugar per 1000 g of water for a depression 1° C	Grams of sugar per 1000 g of water for the molal freezing point depression of 1.86° C. This is the molecular weight	

More complex problems may require analysis by parts. However, the parts may be fitted together to make a logical solution of the problem.

In more advanced chemical theory, neither the arithmetical nor the algebraic methods of solving problems will suffice. The solutions at these levels will require a knowledge of calculus, differential equations, or higher branches of mathematics.

We believe that the logical methods of reasoning developed in chemical calculations will carry over to other life situations and will stimulate a reasoned approach to the solution of problems in general.