SENIOR SECONDARY STUDENTS' PERFORMANCE IN SELECTD ASPECTS OF QUANTITATIVE CHEMISTRY

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ABSTRACT

The purpose of the study was to investigate students' performance in chemical calculations involving gas equation, mole concept and chemical equations. 100 Senior Secondary (SS) students from 10 schools in Port Harcourt metropolis participated in the study. Twenty-item objective test was the data collecting instrument. Overall findings of the study showed that students performed poorly in chemical calculation. Inability to make out the goals of test items, not being able to recall information from memory, use of wrong units, difficulties in inter-unit conversions, reasoning deficiencies using information from the stem of test items and from their memory were some of the problems of the students. Implications of these findings for chemical education were discussed. *[African Journal of Chemical Education—AJCE 5(1), January 2015]*

INTRODUCTION

In November/December, 2013 West African Secondary School Certificate Examination Chief Examiners' report [1] on chemistry observed, among others, the weaknesses of candidates which included poor expression and presentation of facts, poor mathematical skills and inability of students to use appropriate technical terms in definition and explanation of concepts.

The case of the difficulty students' encounter in learning some aspects of chemistry is not new [2-6]. Mathematical aspects of chemistry, specifically quantitative chemistry, is of concern to secondary chemistry teachers. Quantitative chemistry at the secondary school level involves mainly simple calculations related to ratio, proportion, formula transformation, addition, subtraction, multiplication and division. Studies of Koleosho [7] on calculations involving formulae and equations, Eniayeju [8] on mass and volume relationships in chemical reactions and the stoichiometry, Abijo [9] on calculations on mole concept, Bello [10] on a calculation involving solubility expressed in mole of solute per dm^3 of the solution, to mention a few, reveal the various mathematical problems students have. We also know that mathematics and students are not best of friends in that most students dread mathematics. There are clear indications of students' poor performance in mathematics [11].

For students to tackle quantitative chemistry, their performance in mathematics must appreciate. If students must learn quantitative chemistry, the teacher must carry out the dual role of teaching chemistry as well as teaching mathematics. This is a problem, especially if the teacher is handicapped in mathematics. This problem, notwithstanding we have success stories of chemistry teachers coping with the situation [12-18]. As the teachers are improving in their methods and strategies in assisting the students learn quantitative chemistry, there is that urgent need to continue to assess the performance of the students.

Handy and Johnstone [19] working with white children examined students' performance in chemistry using objective tests. Their study revealed students' performance in "reasoning process concordant with those of the question writer (the teacher), by guessing, by merely rejecting all of the distracters, other devious procedures, and factual recall alone". The use of objective test in assessing students in chemistry is common in Nigeria both in local and national examinations. In fact, Federal Government [20] has long directed practitioners in the educational sector, for all disciplines, including chemistry, that assessment of the students should include among others multiple choice items.

Specifically, through multiple choice items the study investigated students' performance in some aspects of quantitative chemistry, namely, calculations involving gas equation, mole concept, determination of molecular formula and structure of compounds, and chemical equations. The study, apart from the interest in performance, will further reveal students' difficulties in chemical calculations, which might lighten the yoke of the teacher.

METHODOLOGY

One hundred senior secondary students drawn from ten schools in Port Harcourt, metropolis of Rivers State participated in the study. The instrument used in the study was a twenty-item multiple choice objective test. The test items were drawn from chemistry areas of calculations involving a gas equation, the mole concept, determination of molecular formula and structure of compounds, and chemical equations.

Chemistry teachers of the students validated the test items. Apart from few test construction mistakes which were rectified, the items were found to be within reach of students. They were ready to be used to study the performance of the students in chemistry.

The test was administered to the students in their various schools. Chemistry teachers of the students assisted in the administration of the test after the principal of the schools granted the permission. A day was chosen for the test administration considering schools schedules. Students were requested to bring their pencils and erasers only to their various examination halls. When the students were seated, test item papers were given to them. On the spaces provided, students gave their names, schools and proceeded to answer the questions. The students were allowed thirty minutes for the twenty test items. At the end of the given time, the test papers were retrieved from the participating students.

ANALYSIS OF DATA

Item analysis was carried out to find out the distribution of the responses for the various options offered in the test items. The frequency distribution was converted to percentage (in brackets). Reasons given by the students (SS) for the options they ticked were also considered. The analysis is presented for each test item, thus,

Item 1: A certain amount of gas occupies $5.0m^3$ at 2 atm. and 10^oC. Calculate the number of moles present (R = 0.082 atm. dm^3K^{-1} $mole^{-1}$)

(a) 0.400 moles (b) 1.521 moles √(c) 0.431 moles (d) 0.34 moles

SS: (45%) (30%) (20%) (5%)

Item 2: 2.0 moles of an ideal gas are at a temperature of -13^OC and a pressure of 2 atm. What volume in dm^3 will the gas occupy at that temperature?

√(a) 21.32 dm^3 (b) 21.23 atm (c) 20.21 dm^3 (d) $21.24dm^3$

SS: (18%) (23%) (48%) (11%)

Item 3: Under a pressure of $300Nm^{-2}$, a gas has a volume of $250cm^3$. What will it's volume be, if the pressure is changed to 100 mm Hg at the same temperature? (760mm Hg = 101 $325Nm^{-2}$)

	(a) $51.50cm^3$	(b) $56.52cm^3$	√(c) $56.25cm^3$	(d) $50.25cm^3$
SS:	(30%)	(29%)	(11%)	(30%)

Item 4: A certain mass of gas has a volume of $241cm^3$ at 18^OC and 753mm Hg pressure. What would its volume be at STP?

	(a)$203cm^3$	(b)$201cm^3$	(c) $221cm^3$	√(d) $224cm^3$
SS:	(30%)	(14%)	(28%)	(28%)

Item 5: A gas has a volume of $500cm^3$ when a pressure of $1000Nm^{-2}$ is exerted on it. What will be its volume, if the pressure is changed to 150mm Hg at the same temperature (760mm Hg = $101325Nm^{-2}$)

	√(a) $25cm^3$	(b)$20cm^3$	(c)$25dm^3$	(d)$20dm^3$
SS:	(19%)	(12%)	(56%)	(13%)

Item 6: Calculate the number of moles in 1.58g of Solid potassium tetraoxomanaganate (vii)

	√(a) 0.01mole	(b) 0.001mole	(c)1.0mole	(d) 0.10mole
SS:	(12%)	(31%)	(45%)	(12%)

Item 7: Calculate the number of atoms of elements in a sample of 18.63g of lead (Pb = 207)

	√(a) $5.4x10^{22}$ atoms	(b)$0.5x10^{22}$ atoms	(c) $5.0x10^{22}$ atoms	(d) 4.5 $x10^{22}$ atom
SS	(13%)	(36%)	(23%)	(28%)

Item 8: How many moles are there in 20g of $CaCO_3$? (Ca = 40) C = 12, O = 16)

	√(a) 0.2moles	(b) 0.02moles	(c) 0.21moles	(d) 0.3moles
SS:	(14%)	(28%)	(28%)	(30%)

Item 9: If 12g zinc reacts with excess hydrogen chloride acid, calculate the number of moles of hydrogen liberated.

	(a) 0.32moles	√(b) 0.032moles	(c)0.230moles	(d) 1.231moles
SS:	(18%)	(18%)	(37%)	(27%)

Item 10: What is the mass of 3 moles of oxygen molecule? (O =16)

	(a) 69g	(b)79g	(c)86g	√(d)96g
SS:	(26%)	(38%)	(14%)	(22%)

Item 11: A compound has a composition C = 93.2%, H = 7.7%. The compound has a relative molecular mass of 78 and burns with a very soothy smell. What is the compound?

	√(a) benzene	(b) toluene	(c) kerosene	(d) fuel
SS:	(18%)	(24%)	(31%)	(27%)

Item 12: The percentage composition of carbon, hydrogen and oxygen in vitamin C was determined by burning a sample weighing 2.00mg. The masses of carbon (iv) oxide and water formed are 3.00mg and 0.816mg respectively. What is the empirical formula of vitamin C?

	(a) C_6H_6O	√(b) $C_3H_4O_3$	(c) $C_2H_2O_4$	(d) $C_2H_4O_1$
SS:	(5%)	(15%)	(33%)	(47%)

Item 13: Sample of calcium chloride 1.64g is dissolved in water and silver trioxonitrate (v) solution added. A precipitate of AgCl weighing 4.24g was formed. Determine the simple formula of calcium chloride.

	(a) CaClO	(b) Cu_4Cl	(c) CaCl	√(d)$CaCl_2$
SS:	(18%)	(30%)	(46%)	(6%)

Item 14: A compound contains 84% carbon and 16% hydrogen. Find the empirical formula of the compound.

	√(a) CH_2	(b) C_2H_4	(c) CH_4Ca	(d)$C_6H_6K_6$
SS:	(18%)	(42%)	(10%)	(30%)

Item 15: A mineral contains 14.7% calcium and 67.7% tungsten (W), the reminder is oxygen. Find its empirical formula.

	√(a) $CaWO_3$	(b) CaO_3	(c) CaO	(d) CaW
SS:	(18%)	(33%)	(28%)	(21%)

Item 16: What volume of dry carbon (iv) oxide (CO_2) gas measured at STP will be produced from the decomposition of 3.5g calcium trioxocarbonate (iv)? (Ca = 40, C =12, O = 16)

	(a) 1.6dm^3	√(b) 0.78dm^3	(c)1.06dm^3	(d)0.6dm^3
SS:	(10%)	(10%)	(28%)	(52%)

Item 17: Calculate the number of moles of calcium chloride ($CaCl_2$) that can be obtained from 25g of limestone, $CaCO_3$ in the presence of excess hydrogen chloride (HCl) (Ca = 40, C=12, O=16, H = 1, Cl = 35.5)

	√(a) 0.25moles	(b)2.5 moles	(c) 0.52moles	(d) 1.25 moles
SS	(13%)	(28%)	(29%)	(30%)

Item 18: What mass of lead (II) trioxonitrate (v), $Pb(NO_2)_2$ would be required to yield 9g of lead (II) chloride, $PbCl_2$ on the addition of excess sodium chloride solution, NaCl? (Pb = 207, N = 14, O =16, Na = 23, Cl = 35.5)

	(a) 10.71g	(b) 10.1g	√(c) 10.7g	(d) 1.10g
SS	(30%)	(26%)	(5%)	(39%)

Item 19: Determine the mass of carbon (iv) oxide, CO_2 produced on burning 104g of ethyne, C_2H_2 (C = 12, O = 16, H=1)

	(a) 35g	(b) 325g	√(c) 352g	(d) 359g
SS:	(20%)	(23%)	(17%)	(40%)

Item 20: In the industrial preparation of hydrogen trioxonitrate(v) acid, ammonia gas, NH_3 is burned in oxygen, O_2 in the presence of catalyst according to the equation:

$$4NH_3(g) + 5O_2(g) \longrightarrow 4NO_{(g)} + 6H_2O(l)$$

If $260cm^3$ of NH_3 is burnt completely, what volume of NO is produced?

	(a) $160cm^3$	(b) $261cm^3$	(c) $360cm^3$	√(d) $260cm^3$
SS	(36%)	(33%)	(30%)	(2%)

DISCUSSION OF FINDINGS

Discussion of findings was done according to the response patterns of the students to the options provided in the solutions of the test items.

(A) Test –Items on Calculations involving Gas Equations

Test-item 1 required the students to find out the number of moles present in $5.0m^3$ of a gas at 2 atm and 10^OC. About 20% of the students got the correct option (c) while the remaining 80% ticked the various distracting options. This question required the application of the formula

PV =nRT. Option (b) 1.521 moles and (d) 0.341 moles were far from option (c) 0.431 moles. However, 45% of the students considered (a) 0.400 moles.

The students seem to have disregarded a whole substantial amount of 0.031moles of the gas. The students' thinking may have been that since it is a gas, this amount may not matter much in the experiment. This idea of possible reasoning of not considering the gas amount as not being substantial seem to have also been applied in the students' choices of answers in items 2 to 5 where the distractive options are closer to the correct options. For instance, in item 3, the correct option is (c) 56.25cm^3 where 11% of the students ticked compared to (a) 51.50cm^3 (30%), (b) 56.52cm^3 (29%), (d) 50.25cm^3 (30%). The reasoning of the students follows the same pattern as in items 2, 4 and 5.

Apart from the students' choices of wrong options in the test items due to mathematical difficulties associated with chemical calculations, application of the correct units is observed to have been misunderstood by over 12% of the students that attempted the test items. In test item 2, the answers are expressed in dm^3 volume. About 23% of the students ticked answer expressed in atmosphere (atm) representing pressure. Similarly, in test item5, answers are expressed in cm^3 (volume). There was still a total of 60% of the students who reasoned that the answer should be expressed in dm^3 (higher level of volume). This is also part of the calculation problem associated with lack of understanding of uniformity of units in the relevant equation or formula.

(B) Calculations Involving the Mole Concept

There were five test items related to the mole concept. Solutions of these test items are also connected to those of items 1 to 5. However, these ones required inter-conversion from mass to particles or amount and vice versa. Items 6, 8 and 9 required the student to calculate the amount in moles. The difficulties the students experienced in items 1 to 5 re-occurred here – the problem of underestimating fractions of the substances just as it was done with the gases. For example, item 6 required the students to calculate the number of moles in 1.58g of solid potassium tetraoxomanaganate (vii). About 12% of the students chose the correct option (a) 0.01 mole. Option (c) 1.0moles where 45% of the students responded is on the far-side of (a) and the remaining distracters (b) 0.001 mole (31%) and (d) 0.10moles (12%).

The students should have reasoned that 1.0moles is a very large amount equal to the molecular mass of the substance. For experiments done at the micro-level, the students may not require that large amount of 1.0mole; rather small amount is needed, of course within the range of 0.001 and 0.1mole. The same reasoning of the students in the choice of answers in item 6, seem to apply to item 8, requiring the estimate of the amount in moles of 20g of calcium trioxocarbonate (iv). Test-item 7 required the estimation of the number of atoms (particles) in 18.63g of lead. This problem involves the knowledge of applying 207g (atomic mass) of lead containing 6.02×10^{23} atoms (Avogadro's constant). While only 13% of the student ticked 5.4×10^{22} atoms (a), most of the students indicated the distracters (b, c, d). It is thought that the mathematical problem of division and applying the laws of indices would have been responsible for the wrong choices of the options.

On the other hand, in item 10, the problem required conversion from amount in moles to mass. The students should have noted first that what is to be converted is 3moles of oxygen "molecules" not oxygen "atoms". Only 22% of the students considered (d) 96g while the rest of them took the wrong options. Apart from the chemical calculation problem, lack of understanding of the problem statement affected the reasoning patterns of the students.

(C) Calculations Involving Determination of the Molecular Formula and Structures of Compounds

This section concerns items 11 to 15. In these test items, students are presented with some chemical compositions. Students were required to make out the compounds or figure out their empirical formula or molecular formula. Item 11 was not only to find out the molecular formula, C_6H_6 but also to name the compound. About 72% of the students could not name the compound. On close inspection of the rough works done at the back of the test paper by eighteen students showed that they quickly arrived at C_6H_6 but could not name the compound. It is possible that teachers assume that students are conversant with names of organic compounds, and so do not see the need to match the molecular formula with the names of the compounds.

Arriving at the molecular formula of a compound sometimes may require getting at the empirical formula. The initial step is to divide the compositions by atomic masses of the elements followed by further division with the lowest factor and so on. These are all mathematical algorithms that make demands on the memory capacity of the students. Students are failing to cope means that they cannot calculate empirical formula which leads them to find molecular formula. For test items 12, 13, 14 and 15, over 50% of the students could not calculate empirical formula from the given chemical compositions. What the teacher might do is to identify those aspects of chemical calculation that require mathematical algorithms. First, get the student acquainted with the problems before relating them to the chemical calculations. When that is done, one can now consider the reasoning patterns and further pinpoint where there are problems for remediation.

(D) Calculations Involving Chemical Equations

Test items 16 to 20 are connected with calculations involving chemical equations. It means that in these test items, students should be able to write chemical equations and balance them or determine whether they are balanced or not. From the equations, it is possible to obtain the proportion of the reacting entities which can be equated to standard temperature and pressure (STP). Item 16 required the estimation of volume of dry carbon (iv) oxide (CO_2) gas measured at STP from the decomposition of 3.5g of calcium trioxocarbonate (iv).

Only 10% of the students got the correct option, while the rest 90% failed to answer the question. It was observed that students that failed the test could not reason, because they failed to write chemical equations, recall from memory volume of gas occupied at STP. The need to balance equations so as to solve the problem at hand became clearer with item 20. The equation was provided and balanced, but only 2% of the students ticked the correct option. The test required the estimation of the volume of Nitrogen Oxide produced after burning 260cm^3 of ammonia. The reasoning was to consider the 1;1 ratio of ammonia used to produce nitrogen oxide. Answers like 160cm^3, 260cm^3 and 360cm^3 do not fall in line. They appear to be guessed as the students could not utilize the information given in the equation. It means that students could also write chemical equations without knowing how to extract information from them.

Test items 17, 18 and 19 are such problems that rely heavily on the information given in the chemical equation. Less than 17% of the students could provide the correct options to the test items. The teacher will need to teach writing and balancing equations before bringing them into problems like this. Students should understand the reactions so that writing the equations will be meaningful to them. The coefficients of the equations should be made very clear to the students so that they know how they are related to amounts (in moles) and in grams. The coefficients of the molecules or compounds are very useful in chemical calculations involving chemical equations. The coefficients can relate to a number of variables in chemistry depending on the nature of the problem. For example $4NH_3$ (g) could means 4moles or parts by volume or 4 parts by pressure as the case may arise in a problem. Students could not utilize the coefficients in their reasoning and so obtained distracters as answers.

IMPLICATIONS OF FINDINGS FOR CHEMICAL EDUCATION

Chemistry and chemical technology contribute to the quality of life on the planet earth in many areas: health, nutrition, agriculture, transportation, materials and energy production, and industrial development. Mathematical contents and operations in these areas are helping in improving further the quality of life. Concerning the health sector, for example, it has been suggested by Professor Gabriel Oyibo, a Nigerian-born US mathematical physicist, using his God Almighty Grand Unified Theorem (GAGUT), that the solution for the dreaded HIV/AIDS may be found in mathematical manipulations of the virus [21]. It is also suspected that Ebola Virus Disease (EVD) cure could be sorted out in the same way. Research is ongoing. We cannot afford to do away with mathematics in the science disciplines including chemistry.

The findings of the study which clearly indicated the poor performance of the students in chemical calculations need to be treated with the utmost concern. Learning chemicals facts, concepts, principles and theories with chemical calculations is imperative if we must produce sound chemists, technologists, engineers, agriculturists and medical doctors, just to name a few. Teachers' complaints about chemistry students' inability to cope with quantitative chemistry is no longer tenable. Good chemistry teachers are continuously trying out methods and strategies necessary to combat students' difficulties in chemical calculations involving gas equation, mole concept, determination of molecular formula and structure of compounds, and chemical equations, being mindful that these are in the heart of chemistry curriculum.

Students are not doing well in quantitative chemistry involving gas equation, mole concept, determination of molecular formula and structure of compounds and chemical equations. Considering, the relevance of these areas in chemistry and related discipline students should make frantic efforts to learn them. Chemistry teachers should improve on their approaches to teaching quantitative chemistry.

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