THE INTERNATIONAL JOURNAL OF HUMANITIES & SOCIAL STUDIES

Chemistry Teacher Trainees' Perceptions of Chemical Equilibrium

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Abstract
This study investigated Ghanaian chemistry teacher trainees' understanding about chemical equilibrium. A total of 104 second year undergraduate teacher trainees participated in the study. A test consisting of ten, 2-tiered multiple choice questions were used to collect data on the trainees' conceptions about chemical equilibrium. The results from the study indicated that about 46% of the trainees had no conception about chemical equilibrium, while 32% had alternative conceptions, some of which had been identified in other studies in some parts of the world. About 50% of the trainees in this study, in addition, could not comprehend thoroughly on an abstract level. Neither could they appreciate the factors that influenced rates of chemical reactions, equilibrium shifts, nor their implications. In all, only about 23% of the participants understood the concept of chemical equilibrium. Eleven alternative concepts were identified. The use of interactive intervention was suggested for remediation.

Keywords*: alternative concept, chemical equilibrium, interpretive, remediation, teacher trainees, 2-tiered test*

1. Introduction

Students' conceptual understandings have been studied by educational researchers such as Demircioglu, Ozem and Ayas (2004) in Turkey, Locaylocay (2006) in the Philippines, Haider and Al Naqabi (2008) in the United Arab Emirates, Gooding and Metz (2011) in the United States of America, and Treagust (2006) in Australia. They assert in their various reports that students develop other conceptions than scientific ones because of their inability to relate new ideas successfully to familiar ones. Sometimes, the new situation is familiar but differs in other ways, yet, they cannot find the distinguishing characteristics effectively and so varying conceptions become superimposed on each other. The authors yet identified other types of alternative concepts as those that learners encounter when meanings in science are explained differently from the everyday familiar meaning of those same words, such as 'work' and 'force' that they know about in their everyday lives. They further affirm that students have difficulties in interpreting microscopic and symbolic representations of chemical reactions than of macroscopic ones, especially in chemical equilibrium.In such representations, the former levels are invisible and abstract, while the macroscopic level is easily observable with one's natural senses (Demircioglu, Demircioglu, & Yadigaroglu, 2013). For example, students may be more comfortable working with coloured solutions such as those of potassium permanganate or iodine where colours visibly change at end points or those that indicate colours with 'change' in reaction, than to conceptualise what would be truly happening within the particles of the reacting samples at the particulate level and represent it symbolically.

Demircioglu, Ozen and Ayas (2004), intimate that besides students' inability to work among the different levels of representation of chemical species and their reactions, they come to class with their own ideas about phenomena around them, some of which could interfere with scientific truth, and thus complicate their ability to comprehend required concepts effectively. Some of these naïve conceptions or ideas, also called alternative conceptions, could stem from myths that children hear from adults as they grow up, their own unscientific deductions from inaccurate observations and inferences, truly non-scientific facts that they imbibe as they interact with nature, adults and peers as well as teacher- or school-made misconceptions which come as a result of improper teaching methods.

Similar observations about naïve conceptions among Ghanaian students were identified in interpretive studies conducted by Hanson (2015), to assess their understanding of qualitative analysis and stoichiometry by Hanson and Oppong (2015). According to Duit (2009), alternative conceptions interfere with learning and so must be identified and corrected. The researchers in these Ghanaian studies, cited above, observed with concern that some of their learners, who were at the tertiary stage of their formal education, performed cognitively as though they were at the concrete operational stage instead of the formal stage whenever they encountered abstract problems. These students demonstrated comprehension only when they engaged in some kind of interactive activities other than listening and writing or engaged with seemingly real objects. Ideally, students above 15 years are expected to be capable of reasoning analytically, logically, and abstractly. Many chemistry concepts, such as phase equilibria, solution equilibria, periodicity, hybridisation, stoichiometry and energy changes are abstract in nature. Hence, it is expected that tertiary level students who are about 16 years of age and above, should be able to deal with these abstractions and switch among the macro, micro, sub-micro and symbolic levels of matter with ease. That is, students at this stage of cognitive development are expected to understand and translate the particulate nature of matter in diverse dimensions. Yet, many young adult learners find these mental processes difficult and confusing to deal with (Taber & Tan, 2011).

In order to alleviate some of these problems, especially for adult students who are unable to operate at the micro (particulate) and representational levels abstractly, concrete interactive laboratory or classroom activities would be required to enhance their understanding and concept formation through personal experience. Beerenwinkel, Parchman and Grasel (2011) used conceptual change texts to teach the particulate model of matter. They recommended a more practical approach such as laboratory activities to further enhance conception of matter in different representational forms. However, the cost of standard (conventional) equipment prevents many teachers from engaging in hands- and minds-on activities with their students. They, at best therefore, resort to inadequate teaching methods for chemistry, such as demonstration of some simple harmless activities which students could have had personal experiences of and the traditional lecture method (Abdullah, Mohamed, & Ismail, 2008). A few innovative methods have been attempted at by some researchers in recent times to solve the problem of non-performance of laboratory activities. Mafumiko, Voogt and van den Akker (2013), used micro science equipment to enhance Tanzanian secondary school students' understanding on the concept of precipitation successfully. The micro science equipment is a box of miniature plastic ware such as comboplates (wells), propettes and syringes, which serve the same purpose as the macro glassware found in standard laboratories. This micro equipment requires the use of small quantities of chemicals in the range of about 0.01-1 mL of solution and less than a gram of solid substances. They recommended it for use in other less endowed African and developing countries due to their positive outcomes with its use. Other supposedly difficult topics such as chemical stoichiometry (Haider & Al Naqabi, 2008) and phase equilibria (Locaylocay, 2006) were not trialled through the micro chemistry approach suggested by Mafumiko, Voogt and van den Akker (2013). The concepts of acids and bases, as well as acid strength, have been taught through conceptual change text interspersed with computer assisted instruction by Aslan and Demircioglu (2014) in Turkey. Hitherto, Demircioglu, Ayas and Demircioglu (2005), had taught the same concept successfully through conceptual change text without the assistance of videos in the same region. None of aforementioned researchers employed the use of laboratory activities to enhance conception.

Since students have problems representing chemical activities at the particulate level, they are likely to have difficulties in understanding the concept of chemical equilibria. Chemical equilibra is considered as one of the difficult concepts to teach. Students cannot literally see equilibrium shifts or relate equilibrium position to changes in concentrations of reactants and products. Yet, equilibria are a very important topic and must be conceptually understood so as to easily understand the Le Chatelier's principle and other processes involved in the formation of complexes, reaction rates, solubility product, acid-base and redox equilibria. The Le Chatelier's principle, for example, which appears easy to understand, is difficult to interpret in practical circumstances when students are presented with situational problems (Demircioglu, Demircioglu, & Yadigaroglu, 2013). This is quite paradoxical. Chemical equilibrium, particularly, is a condition in which two opposing chemical reactions occur simultaneously at the same rate. This phenomenon occurs naturally. It occurs in our bodies, the air around us and the environment in which we live. The components of air have to be in dynamic equilibrium in order to sustain life on earth as it ensures the ever cyclic processes of natural cycles. The pH of human blood is also maintained through the process of dynamic equilibrium. Knowledge of chemical equilibrium is required in many science topics, as indicated earlier, in order to understand many natural processes. It is also an important part of school science and university chemistry curricula.

During chemical reactions, students are required to think in abstract terms about what would truly be happening within the molecules or particles of the reactants and products being formed dynamically, and sometimes make graphical representations of them. Inability to make useful interconnections among the representational levels of nature, and wrong use of scientific language to explain these phenomena by students and sometimes teachers, leads to the formation of alternative conceptions which could be persistent (Yildirim, Kurt, & Ayas, 2011). Teachers have also been found to have their own alternative conceptions which could result in a vicious cycle of misconceptions (Gooding & Metz, 2011) as they teach them to unsuspecting students.

Based upon Bilgin, Uzuntiryaki and Geban (2003) and Yildirim, Kurt and Ayas' (2011) success in using worksheets to positively to affect Turkish students' achievement in chemical equilibrium, this study proposed to adopt the use of micro science equipment (MSE), to enhance Ghanaian teacher trainees' understanding of chemical equilibrium if alternative concepts were identified through a tiered diagnostic pre-assessment. Tan, Goh, Chia and Treagust (2002) used such a 2-tiered test to assess students' understanding of inorganic qualitative analysis. Tsai and Chou (2002) also used a 2-tiered diagnostic tool to unearth students' conceptual understanding of selected chemistry topics, including chemical equilibrium. Both researchers found that the use of a 2-tiered test unearthed more alternative conceptions than single tiered multiple choice tests where students were not required to assign reasons to choice of answers that they made. In a 2-tiered test, o respondent makes a choice among a list of given answers in an item and then goes on to a follow up item, to assign a reason why they made that first choice. In this way, answers are not merely chosen, but reasons for choices made are further substantiated. This reasoning or second (tiered) part of an item gives an assessor an idea of how well a student conceptually understands the chosen answer for a given problem as the application of logic, discriminatory, and critical thinking skills are required.

2. Purpose and Design

The main aim of this study was to identify and analyse alternative conceptions (if any) that Ghanaian undergraduate teacher trainees in their second year of study could have about chemical equilibrium through a 2-tiered test, and attempt remediation in a follow up study. A review of literature showed that students' misconceptions in most chemistry topics, especially chemical equilibrium have been carried out in the Middle East, Europe and around the Western world. However, little literature on students' conceptions was found for such studies in Africa (Kombo, 2006; Mafumiko, 2008). No literature on students' conceptions about chemical equilibrium was found at the time of this study. It is hoped that findings from this study would add to the knowledge base on research into conceptual studies for the African sub-region and the entire world. The outcome of the analysis of gathered data was based on the Researcher's own interpretations of the trainees' reasoning abilities. The questions which guided the study were:

1. How effective would a 2-tiered diagnostic test be in unearthing Ghanaian undergraduate teacher trainees' conceptions about chemical equilibrium?
2. What conceptions about chemical equilibrium would Ghanaian chemistry undergraduates come up with on a two-tiered diagnostic test?

3. Methodology

A ten-item 2-tiered diagnostic test on chemical equilibrium, dubbed the Chemical Equilibrium Diagnostic Test (CEDT) was culled from 15 designed items which had been validated and found reliable. The items were analysed by senior members in the Department of Chemistry Education and trialled on an equivalent strand of subjects to assess its reliability. Some of the items were found to be conceptual duplications of each other (like items 3 and 15 in Appendix A), while a couple had slightly difficult language (item 13 in Appendix A) and so the best 10 items were selected for the diagnostic test. The CEDT test, which had a KR-21 value of 0.72, was administered to 104 trainees who participated in this study, after permission had been sought from the Head of Chemistry Education Department, and the trainees' own written consents obtained. The first tier of each item had four choices that related to a problem statement, while the second tier presented four possible reasons which could be used to explain a choice made in the first tier. Only one of the reasons in the second tier could scientifically and logically explain the only correct option in the first tier. The reasoning tier in this current study allowed for the determination of trainees' in-depth understanding of basic principles in the topic, *chemical equilibrium* and their application. The participants were given 20 minutes to answer the 10 CEDT items, which are presented as Appendix A. The CEDT items covered the effects of catalyst, temperature and concentration on equilibrium. It was designed to assess the trainees' understanding of the effect of external stress on equilibrium position. The meaning of the terms 'equilibrium constant', 'amount of substance' and 'concentration' were also assessed. The distribution of test of concepts is presented in Table 1.

Concept	**Item number**
Equilibrium constant	1, 2, 4, 5, 12, 15
Equilibrium position	1, 2, 14
Change of stress on an equilibrium system (temperature, catalyst, pressure, concentration)	1, 2, 3, 10, 11, 12
Factors that influence reaction rates	3, 6
Terms: dynamic, amount of substance, and concentration	7, 8, 9, 10, 13

Table 1: Conceptual areas assessed in the CEDT

4. Data analysis

The trainees' responses were awarded points (of 0, 1, 2, and 3) depending on how they fared on the CEDT. A similar mode of scoring was employed in an identical study carried out in Turkey to diagnose chemistry students' understanding of chemical equilibrium (Demircioglu, Demircioglu, & Yadigaroglu, 2013). If both parts of an item were correct, 3 points were awarded and designated as correct choice (CC). If a correct option in the first tier was supported by a wrong reason, then 2 points were awarded and designated as partial choice (PC). However, if a first tier choice was wrong but a correct reason was chosen, then one point was awarded and termed erroneous choice (EC). No point was awarded for a wrong option in the first tier which was supported with a wrong reason from the second tier. If wrong options were selected in both the first and second tiers, it was designated as wrong choice (WC). Thus, the maximum score for the CEDT was 30 points or 100%. Results from the CEDT were analysed for easy interpretation by using simple descriptive means from a range of SPSS tools. A summary of the trainees' performance on the CEDT is presented in Table 2 per items.

Item	**Gross score**	**Correct choices (CC)**	**Partial choices (PC)**	**Erroneous choice (EC)**	**Wrong choice (WC)**
1	67	27	33	7	33
2	37	3	27	7	63
3	50	7	30	13	50
4	61	27	17	7	49
5	50	23	20	7	50
6	40	20	17	3	60
7	60	27	23	10	40
8	*74*	*37*	*30*	*7*	*26*
9	40	17	13	10	60
10	*70*	*40*	*20*	*10*	*30*

Table 2: Trainees' performance on the CEDT items in percentages

The results from Table 2 show that many of the trainees exhibited alternative conceptions about chemical equilibrium. There were more partial (PC), erroneous (EC) and wrong (WC) choices than correct choices (CC) for all the 10 items. When the partial, erroneous and wrong choices were considered as diagnostically defective, it became evident that about 80 (77.2%) trainees had naïve conceptual understanding in almost all of the items, apart from items 8 and 10 (shown in italics). About 24 (23.0%) trainees had partial conceptions, 9 (8.65%) had erroneous conceptions, while 48 (46.1%) made entirely wrong choices. In items 8 and 10, majority of the trainees, 38 and 42 respectively, made correct choices which were supported with correct reasons. It was expected that they would perform well in item 9 because it was based on item 8 which they had answered correctly but performed poorly. Their performance in items 1, 4 and 7 were fairly good, as 27 trainees out of 104, ascribed correct reasons for the choices they made in their first tiers. Trainees' worst performance (least correct responses) were in items 2 and 3, where only three and seven trainees respectively chose correct answers with correct reasons. In all, the correct choices with accompanying reasons turned out to be an average low of 24 (22.8%) trainees, out of 104. The major alternative concepts which were identified are presented as frequencies and percentages in Table 3.

Alternative concept	Frequency	Percentage
1.Powers to which concentrations are raised are sometimes determined by the subscripts in the balanced equation (4,5)	64	61.5
2.Concentrations of solids appear in equilibrium expression (5)	23	22.0
3.Keq increases when a catalyst is added to a reaction mixture (2)	19	18.3
4.Equilibrium shifts in the direction of an added reactant (1,2, 6, 10)	26	25.0
5.Concentration (undefined) affects equilibrium position to the right by hastening the reaction (1, 3, 6, 10)	17	16.4
6.Increase in temperature results in a shift to the right because the kinetic energy of the reacting molecules increase (1, 6,11)	26	25.0
7.At equilibrium the concentration of reactants and products are equal (1, 7, 10)	35	33.7
8.When a system reaches equilibrium no further changes occur (1, 3, 7)	58	55.8
9.A catalyst increases the equilibrium concentration of reactants of a system in equilibrium (1, 2)	44	42.3
10.A forward reaction must first begin and complete before the backward reaction begins (7, 10)	18	17.3
11. Concentration is the same as amount of substance (8, 9)	27	26.0
Average alternative conceptions	33	29.7

Table 3: Percentages of trainees' alternative conceptions with respect to CEDT items

Table 3 shows a distribution of trainees' alternative conceptions.

5. Discussion

The results from Tables 2 and 3 shows that Ghanaian undergraduate teacher trainees have some understanding (23%) about equilibrium shifts especially when it concerns extraction processes (item 10). Perhaps, the trainees were familiar with the process of extraction of arsenic and so could presume the outcome of its production from the ore if some arsenic was removed from the reaction mixture. They were able to reason logically that there would be no equilibrium shift. They could also have based their understanding of the problem to what they perceive in simple one-way chemical reactions, where regardless the quantities of reactants, mole ratio and the kind of product formed would remain the same. However, many alternative conceptions about chemical equilibrium, some of which stem from vernacular misconceptions were also identified.

The use of 2-tiered tests, which were found to unearth students' alternative conceptions by Tsai and Chou (2002) and Tan, Goh, Chia and Treagust (2002), proved very useful also in this study, to unearth alternative conceptions that trainees held about chemical equilibrium. Trainees made choices in a first tier for which their reasoning options in the second tier were incorrect. It was clear to discern from such incompatible answers that trainees did not fully understand options that they made in their first tiers, or merely guessed answers. This tiered test was a better method of assessment, than having students choose answers only in multiple choice items without following up with explanations for them. On the average, only about 24 (23%) of the trainees had correct conceptions about chemical equilibrium; and were able to get their first tiers and some reasoning answers (second tiers) correct for the items tested. Less than half the study sample showed appreciable understanding in any one particular concept. The best performance was observed for item 10, where 42 of the trainees (40%) made full logical choices. In some cases, (as in item 2), only three trainees showed a sound understanding of a desired concept. Some major alternative conceptions were identified in items 2, 3, 6, and 9. These items sought to find out how trainees expressed equilibrium equations mathematically and their implications as well as what it meant to say that a system was in dynamic equilibrium. Here, they had to explain what was actually occurring within the system, with observations such as, 'a reaction was ongoing, with the rates of forward reaction and backward reactions being equal'. They demonstrated virtually no understanding of the situation, as indicated by the answers that they chose. They were expected to know that the species in the reaction were constantly moving. As many as 58 (55.8%) trainees did not know or demonstrate this in the choices they made. Some of the trainees thought that equilibrium was attained when a product was formed or that the forward reaction had 'end' in order for the backward reaction to proceed. The idea of continuity or in simple terms simultaneity was lost on 18 (17%) of the trainees. Interestingly, they thought of 'dynamic equilibrium' in terms of equal concentrations (33.7%). This erroneous idea must have stemmed from a misunderstanding of reversible reactions in their study of acid-base interactions. About 64 (61.5%), adduced that powers to which concentrations were raised could stem from the superscripts in the balanced equations. Equilibrium expressions were wrongly written. Solids were also accounted for in equations instead of species in the gaseous or solution phases by 23 (22%) of trainees. With regard to the influence of external stress (catalyst, temperature, pressure and concentration) on a system in equilibrium, the effect of catalysts and concentration on equilibrium positions were the hardest for 44 trainees to understand. They had to first of all understand that the position of equilibrium specified in a qualitative way, the extent to which a chemical reaction at equilibrium, has proceeded toward completion. For example, if at equilibrium, product concentrations were small relative to reactant concentrations, the equilibrium position would lie to the left. Interpretation of these seemingly simple events appeared to be very abstract and difficult for the Ghanaian trainees to visualise and interpret in the abstract. For each concept, about 48 (46.1%) trainees made obvious wrong or non-scientific choices.

According to Lemke (2007) and Hanson and Oppong (2015), if about 10% of a population in an educational setting showed poor understanding or misconceptions about a desired concept, then it was serious enough to require remediation, as majority of the learners lacked the necessary pre-requisites for further comprehension of the concept. From analysis of the data for this study, it was clear that more than 10% of the population (three times the limiting threshold for conceptual scaffolding) had alternative conceptions about chemical equilibrium. These trainees lacked conceptual understanding of the behaviour of species in a system at equilibrium, especially when a stress factor was introduced. Of more concern was the fact that, the participants in the study were teacher trainees who were soon to go out to impart knowledge to other learners. It was therefore important that their conceptions were identified and the alternative ones corrected so as to avoid the recurrence of a vicious cycle of transfer of misconceptions.

According to Le Chatelier's principle, if a change of condition is applied to a system in equilibrium, the equilibrium position will shift in a direction that best reduces the stress. However, in the case of catalysts, since the reaction moves in both ways, it lowers the activation energy both ways for equilibrium changes in 'an equal' manner, thus equilibrium position will not change or be affected. Yet, 44 mistakes were recorded. The obtained data on the effect of stress on equilibrium position and the effect of catalysts on equilibrium activities were consistent with findings from Locaylocay's (2006) studies of students in the Philippines. The trainees in this current study, however, understood the influence of temperature changes on endothermic and exothermic systems with greater ease than observed among learners in Locaylocay's (2006), Bilgin et al.'s (2003) and other studies. Perhaps, this could have been due to the fact that enthalpy values were supplied as guides for the trainees to know whether reactions were occurring in endothermic or exothermic environments (that is, giving off heat or requiring heat for a reaction to proceed favourably). They intimated, through their choice of answers, that they had difficulty in understanding that changes in pressure (item 6) did not significantly affect the concentrations of solids and liquids as they do gases. This problem challenged their understanding about the particulate nature of matter as they were required to understand on a microscopic scale, how pressure could affect given species, based on their unique intermolecular bonding and spatial particulate arrangement.

In titrimetry and periodicity, students learn that increasing or decreasing concentrations of reacting species has no effect on mole ratio. Their inability to fully understand the underlying concepts leads to confusion when they study the processes which occur in reaction rates and chemical equilibrium. In the current study, trainees assumed that equilibrium position would not change when a reactant or product was altered. They might have equated or paralleled their knowledge about mole ratios to equilibrium position. They failed to realise that if an additional amount of a reactant or product was added to a system, the stress would be relieved so that equilibrium shifts in the direction that uses up some of the added reactant or product (item 3), unlike in ordinary acid-base stoichiometric reactions.

Another major misunderstanding which was observed among the trainees was their inability to distinguish between the concepts of 'amount of substance' and 'concentration' (item 9). They appeared to think of concentration, which is the quantity of a solid to volume of water added, as if it were the quantity of solid in solution (which is not affected by volume of water added). Thus, when an external factor such as concentration was affected, they rationalised it as amount of substance. Besides, the knowledge of one-way reactions which they learn first, especially when learning to write and balance chemical equations posed a problem in their interpretation of equilibrium reactions. More often, when an external factor was applied, the trainees assessed the situation mostly in the forward reaction. Only a few applied their conception of 'equilibrium' and looked for a 'route' that would alleviate the system of the imposed stress. Majority of the trainees only looked in the forward or 'one-way' directional reaction and made an unscientific deduction. An equally possible backward reaction, for them, was non-existent in reality. Reactions moved forward only. Interestingly, the trainees could state the Le Chatelier's principle, but not apply it. At best, they explained that, after a forward reaction went to completion, the reverse process or reaction began. These interpretations called for remediation as these study subjects were teacher trainees who were to go out to teach young high school students. The remediation was worked at for the subjects in a follow up project.

6. Conclusion

The 2-tiered test was found to be very useful in unearthing the trainees' alternative conceptions about chemical equilibrium in this study, in order for remediation methods to be developed. As many as 11 major alternative conceptions about chemical equilibrium were identified through the tiered test. The results from the study indicated that, only about 24 (23.1%) out of 104 Ghanaian teacher trainees had correct conceptions about chemical equilibrium. About 33 (31.7%) had mixed ideas about the basic concepts; while about 48 (46.2%) had virtually complete erroneous conceptions. This calls for remediation. This remediation is important for the trainees so that they become equipped with the scientific conceptions necessary for them to devise better ways of imparting them to their prospective students in future. This would in turn reduce the incidence of teacher-made or classroom-induced misconceptions and eventually break the vicious cycle of transfer of misconceptions which emanate from teachers and poor teaching methods.

7. Recommendation

It is recommended that interactive engagement approaches such as conceptual change texts, practical laboratory activities, mind maps, concept maps and worksheets (Yildirim, Kurt, & Ayas, 2011) should be employed as intervention strategies to help learners who have alternative conceptions to correct their erroneous ideas and builder sounder concepts through personal experiences and observations.

8. Acknowledgement

The Researcher appreciates the second year teacher trainees of the 2011/12 academic year who contributed to the success of this article.

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Appendix A

Chemical equilibrium diagnostic test (CEDT)

The chemical reactions (A and B) below will be used to answer questions in this test

A. $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ in the manufacture of tetraoxosulphate (VI) acid, using V_2O_5 as catalyst
B. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$; $\Delta H = -92.4$ KJ mol-1

1. For reaction **A**, what happens to the equilibrium position when temperature is raised?
    a. Position shifts b. remains samec. moves to the right d. *moves to the left

Reason: I make this choice because …………………………………….
    a. Equilibrium will shift to the right because reactions move forward
    b. Equilibrium will remain the same because no reactants have been added
    c. Temperature increases yield and so it shifts to the right as the reaction is exothermic
    d. *Temperature increase means yield reduces and so equilibrium position shifts to the left in the endothermic direction

2. What effect would the catalyst have on the position of equilibrium in this reaction?
    a. *No effectb. adverse effectc. positive effectd. entropic effect

Reason: I make this choice because ………………………………………………..
a. Effect is positive as an alternative route would be provided for more collision
b. The effect could be catastrophic as the catalyst could create some chaos and not allow the reaction to follow its normal pathway
c. *It affects both the forward and backwards reacts equally as it lowers the activation pathways for both and only allows equilibrium to be attained more quickly
d. More collisions occur when the catalyst is introduced, thereby increasing entropy

3. What would be the effect of increasing the concentration of oxygen in the system at constant temperature?
    a. Product would be the samec. there would be a change in the yield
    b. *The yield would increased. the yield would decrease and increase

Reason: I make this choice because ……………………………………………….
a. *Increase in the oxygen concentration would raise the denominator so the numerator does too, since Kc constant or to keep Kc constant
b. Increasing the concentration of oxygen does not affect mole ratios
c. Increasing oxygen will imply a big denominator and so Kc will be very small
d. Concentration of SO_2 will have to go up or else SO_3 produced will be less

4. Choose an expression for reaction A
    a. $K_2 = [SO_3]^2/[SO_2]^2[O_2]$c. $K_2 = P[SO_3]/[SO_2][O_2]$
    b. $K = [SO_2]^2[O_2]/[SO_3]^2$d. $K = 2(SO_3)/2(SO_2)(O_2)$

Reason: I make this choice because …………………………………………...
a. All species have to be represented
b. *P* has been used in front of the squares as there are no units
c. The product is presented as a numerator first and then the reactants as denominator
d. The powers to which concentrations are raised are always determined by coefficients

5. The equilibrium constant expression for the reaction: $NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$ $\Delta H = -102.4$ would be:
    a. $Keq = [NH_3]\ [HCl]/[NH_4Cl]$c. $[NH_4Cl]/[NH_3]\ [HCl]$
    b. *$Keq = [NH_3]\ [HCl]$ d. None of the displayed answers

Reason: I make this choice because ……………………………………….
    a. *Only concentrations of gases and substances in solution are written in an equilibrium expression
    b. All reacting species have to be represented in the equilibrium expression
    c. Only the products have to be represented in an equilibrium expression
    d. Reaction occurs in the boundary space between reactants

6. Considering equation B above, which of the following procedures is not likely to increase the rate of production of ammonia gas?
    a. Increasing the pressure of the system at constant temperature
    b. *Increasing the temperature of the system at constant volume
    c. Increasing the volume of the system at constant temperature
    d. Increasing the concentration of the reactants at constant temperature

Reason: I make this choice because ……………………………………
a. *on increasing temperature more reactants are formed
b. more products are formed when temperature is increased
c. inadequate information is given
d. temperature changes will have no effect on the production of $NH_3(g)$

7. Explain the term ‘dynamic equilibrium’ with respect to reaction B
a. It means a point in time when equality has been attained at both sides of the equation
b. *It means the rate of forward reaction is equal to that of the backward reaction; constantly moving
c. At the stated temperature the equation will be as appears in equation B
d. It is that point in time when stability has been achieved and no further reaction occurs

Reason: I make this choice because ………………………………………….
a. once equilibrium has been attained it means that amounts of substances are the same at both ends
b. forward and backward reaction will cease at both ends
c. * The forward and backward reactions have to keep going so that there will be no ‘build up’ at any one end
d. Stability has been attained and no further reaction occurs to upset it

Use the preamble below to answer questions **8** and **9**

In a laboratory activity, a student filled three beakers, A, B, and C, with 40ml, 40ml and 160ml of water respectively. She then added 10, 30 and 40 grams of $Cu(NO_3)_2.3H_2O$ in the same order.

8. Using colour intensity, which beaker would have the greater concentration of Cu^{2+} (aq) ions?

a. Beaker A b. *Beaker Bc. Beaker Cd. the information given is inadequate

Reason: I make this choice because ……………………………………………
a. Beaker A would have the same intensity as all the others
b. It will be difficult to decide as information supplied is scanty
c. Beaker C would have the most solute and so it would have the highest colour intensity, implying greater concentration
d. *Beaker B has 3 out of 4 parts being solute and so would have the greatest colour intensity

9. Which beaker would have the greater amount of Cu^{2+}(aq) ions?

a. Beaker Ab. *Beaker B c. Beaker Cd. the information is inadequate

Reason: I make this choice because ……………………………………………
e. Beaker A would have the same intensity as all the others
f. It will be difficult to decide as information supplied is scanty
g. Beaker C would have the most solute and so it would have the highest colour intensity, implying greater concentration
h. *Beaker B has 3 out of 4 parts being solute and so would have the greatest colour intensity

10. Arsenic can be extracted from its ore by the reacting it with oxygen to form As_4O_6, which is then reduced using carbon, in the reaction: $As_4O_6 (s) + 6C \rightleftharpoons As_4(g) + 6CO(g)$. How will removal of some $As_4O_6(s)$ from the mixture affect equilibrium shift?

a. shift to the reactant side b. * no shiftc. shift to the leftd. not predictable

Reason: I make this choice because ………………………………………
a. reduction of the amount of As_4O_6 establishes a new equilibrium
b. * As_4O_6 is a solid and so does not affect equilibrium
c. As_4 and Co will react to give back more As_4O_6
d. the amount of As_4O_6 removed is not determinable

11. Consider the reaction: $N_2 + 3 H_2 (g) \rightleftharpoons 2NH_3(g)$ ΔH – 92.4 kj/mole

If temperature is increased, the equilibrium will …………………………
a. shift to the rightb. *shift to the left c. remains unchanged d. be unpredictable

Reason: I make this choice because ……………………………………………
a. temperature changes have no effect on equilibrium systems
b. inadequate information is given
c. * on increasing temperature more reactants are formed
d. more products ate formed when temperature is increased

12. Predict the shift in equilibrium position when volume is reduced in the preparation of liquid phosphorus: $P_4 (s) + 6Cl_2 (g) \rightleftharpoons 4PCl_3 (l)$
a. *shift to the rightb. shift to the leftc. no shiftd. unpredictable

Reason: I make this choice because ……………………………………………
a. * The volume is deceased so equilibrium position shifts to the right

b. inadequate information is given
c. reduction in volume has no effect on reacting species and subsequently equilibrium position
d. the PCl_3 will have to dissociate to give back the reactants for the reaction to begin again

13. Assume that we have a reaction of H_2 and Br_2 as $H_2 + Br_2 \rightleftharpoons 2HBr$ at 650 K, with concentrations $[H_2] = 0.1$ M and $[Br_2] = 0.2$ M. The numerical value of equilibrium constant is 48.0 at equilibrium. If the initial concentrations are 0.3 M H_2 and 0.3 M Br_2, what would be the numerical value of Keq of this system at equilibrium?

a. increase b. * remain the same c. decrease

Reason: I make this choice because ……………………………………………

a. increase in concentration of reactants increase concentration of the products
b. the numerical value of Keq changes with amounts of reactants
c. * the numerical value of Keq does not depend on the initial concentrations of the reactants
d. change in Keq is commensurate with change in products formed

14. The difference between equilibrium constant and equilibrium position is ……

a. non-existent as they measure the same parameters
b. a number that tells the concentrations of reactants and products
c. a set of concentrations that satisfies the equilibrium constant expression
d. * The equilibrium constant is a number while the equilibrium position is a set of concentrations that is related to the equilibrium constant expression

Reason: I make this choice because ………………………………………………….

a. equilibrium position and equilibrium constant all measure reactants and products in a reaction
b. only one equilibrium position satisfies a particular equilibrium constant expression
c. * relative amounts of reactants and products in equilibrium with each other is expressed as the equilibrium constant while the position is a set of concentrations that satisfies the Keq expression.
d. not more than one equilibrium position can satisfy the same equilibrium constant expression

15. Consider the reaction: $2SO_2(g) + O_2(g) \rightleftharpoons SO_3(g)$ + Heat

The concentration of O_2 (g) at equilibrium will increase if volume is kept constant and …

a. SO_2(g) is added to the system
b. SO_3(g) is added to the system
c. The temperature of the system is lowered
d. An inert gas such as neon is added to the system

Reason: I make this choice because ……………………………………………………

a. Keeping volume constant for gases does not affect concentrations of substances
b. Increasing SO_3(g) will make equilibrium shift to the left to produce O_2(g)
c. Lowering temperature will break down SO_3(g) to produce more O_2(g)
d. the adding of an inert gas will not affect volume and so more O_2(g) is produced

- The stared (*) options indicate correct answers