OPAQUENESS TO THE LIGHT OF UNDERSTANDING.

An Investigation into some of the difficulties experienced by a sample of Transkeian Matriculants with the components of the concept of Chemical Equilibrium.

THESIS
Submitted in partial fulfilment of the
requirements for the degree of
MASTER OF EDUCATION (PHYSICAL SCIENCE)
of Rhodes University

by

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JANUARY 1992

ACKNOWLEDGEMENT

At the very outset I would like to thank all those whose co-operation made this study possible: the Transkei Education Department for their permission to conduct this research in Transkeian schools; and the principals, physical science teachers and pupils of the four senior secondary schools involved.

To Mr. S.M. Mema and Mrs. F.T. Limekaya of Butterworth College of Education as well as Prof. E.S. Sawyerr and Prof. S.N. Imenda of University of Transkei for their enormous encouragement.

To the staff of the Department of Education, Rhodes University who gave me tremendous support during the year of M.Ed coursework, the precursor to this research, I owe a debt of gratitude. Their tradition of demanding work of high quality is gratefully acknowledged. Mr. Peter Glover, Mrs. Gill Boltt, Prof. Pat Irwin and Prof. Terry Marsh who lectured during the course-work sessions provided the inspiration for the research.

To Mr. Peter Glover, my supervisor who gave valuable guidance and suggestions and without whose patient and effective direction this half thesis would not have been completed on time I say: 'THANK YOU'.

Last, but not least I thank my wife Marykutty and children Vinod, Vimal and Vijay for their wholehearted moral support and understanding.

ABSTRACT

The purpose of the study was to collect and collate information pertaining to common misconceptions of components of the concept of chemical equilibrium amongst a sample of Transkeian matriculants. 'Equilibrium' is a fundamental concept in physics and chemistry and 'chemical equilibrium' is an important chemistry topic in both the higher grade and standard grade South African matriculation physical science syllabuses. In recent years, South African teachers have identified chemical equilibrium as the most difficult section of the matric physical science syllabus for both teachers and pupils. It has been shown that teachers themselves lack understanding of the basic concepts underlying chemical equilibrium. Constructivist learning theories arise out of research in cognitive psychology. These theories conceive of cognitive development as the assimilation and accommodation of new ideas into extant, dynamic cognitive structures. An inference from the theories is that a study of the preconceptions and/or misconceptions held by pupils before they are exposed to instruction would enable teachers to avoid generating or reinforcing misconceptions. Hence teachers could also take deliberate steps to eradicate those already existing. The sample consisted of 112 Transkeian matriculants from four government senior secondary schools in the Southern Transkei. All were taking physical science. The test consisted of a 40 item multiple choice battery. Each question had three distracters and the options were randomized to avoid patterns and hence guessing. Questions dealing with closely associated concepts were grouped in the paper but no indication of this was given in the paper. The questions are analyzed singly. A brief introduction and outline of the theory on which the group of questions was based is given in each case. The analysis makes use of the frequency of choice of all options, discrimination indices, although they were generally low and item difficulties. The intent in each analysis is to identify the possible misconception(s) underlying wrong answers. Finally conclusions based on the discussion are drawn and recommendations for teaching and further research made.

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INTRODUCTION.

The purpose of the study was to collect and collate information pertaining to common misconceptions of components of the concept of chemical equilibrium amongst a sample of Transkeian matriculants.

The research attempted to establish whether Transkeian matriculants hold misconceptions similar to those revealed amongst high school pupils in Australia (Driscoll, 1970; Hackling and Garnett 1985), the UK (Johnstone et al, 1977), Canada (Wheeler and Kass 1978), Israel (Gussarsky and Gorodetsky 1988, 1990), and other parts of South Africa (Bradley et al, 1990; Brand 1990).

In a pilot study conducted in May, 1990 amongst pupils at two senior secondary schools in the Transkei, the author identified a number of misconceptions about chemical equilibrium (Mammen: 1990). The findings suggested that a more detailed study of such misconceptions would be worthwhile since before the 'right' concepts can be effectively taught, the 'wrong' ones must be exposed (Champagne et al, 1985). Driver and Bell (1986:454) state that from the students' perspective, to learn a concept may require the initial 'unlearning' of misconceptions.

There had been no research in the Transkeian schools to investigate student misconceptions in chemical equilibrium. The author hopes that, besides revealing these, this study will stimulate interest in chemistry education in particular and science education in general in the Transkei.

CHAPTER 1

REVIEW OF LITERATURE

'Equilibrium' is a fundamental concept in physics and chemistry and 'chemical equilibrium' is an important chemistry topic in both the higher grade and standard grade South African matriculation physical science syllabuses. While the higher grade syllabus demands both a qualitative and quantitative treatment of the topic, the standard grade syllabus only approaches it qualitatively.

Not only is the concept of 'equilibrium' fundamental in the physical sciences, it is also (perhaps for that reason) one which pupils find difficult to understand.

> 'Within the domain of chemistry, surveys have revealed that the topic of chemical equilibrium, the mole, oxidation-reduction and reaction stoichiometry give learners most difficulty; of these topics chemical equilibrium was rated as the most difficult for students to comprehend.' (Hackling and Garnett, 1985: 206).

The recognition of chemical equilibrium as a problem area in school chemistry is not recent and as Brand (1990: 36) notes, '... a literature survey...established that reports of difficulty in the teaching and learning of chemical equilibrium went back for half a century.'

More recently South African teachers have identified chemical equilibrium as the most difficult section of the matric physical science syllabus to teach. (Bradley et al, 1989 a: 13). Bradley et al also showed that teachers themselves lack understanding of the basic concepts underlying chemical equilibrium.

Adams (1940), Driscoll (1966), Johnstone et al (1977), Wheeler and Kass (1978), Finlay et al (1982), Camacho and Good (1989) and Gussarsky and Gorodetsky (1990) have all identified chemical equilibrium either as a difficult or **the** most difficult concept in the chemistry section of high school physical science. Green (1982) illustrated vividly that in spite of being an innovative teacher, he found chemical equilibrium a difficult topic to teach.

An understanding of chemical equilibrium demands the assimilation of some of the most important concepts in chemistry. For example, a student can not grasp the concept of chemical equilibrium in any meaningful way without first having understood the concepts of energy changes during chemical reactions, reaction kinetics, concentration, solubility and the mole. An important cognitive demand in mastering chemical equilibrium is that pupils are required to manipulate simultaneously several interacting variables. Camacho and Good (1989: 253) suggest that chemical equilibrium can be seen as a synthesis of most general chemistry concepts and principles.

Gold and Gold (1984, 1985) have identified problems for the teaching and learning of chemical equilibrium arising from the translation and modification of Le Chatelier's Principle by text book authors. Text books themselves serve as sources of misconception. 'Many popular misconceptions about science may be dutiful recitations of 'facts' learned from (science text) books.' (Newsweek, August 6, 1990: 53).

In contrast Bradley et al (1989 c: 637) adopt a less accusing mode and says that although the text book authors may have correct conceptions, their books do not 'teach these completely successfully'. The problem of misconceptions directly transmitted by text books becomes significant when teachers and pupils make extensive use of text books. The author's personal experience in the Transkei indicates that the practice is endemic there. However this is not an isolated practice as Renner et al (1990:

35) state, 'Research has shown that over ninety percent of all science teachers use a text book ninety five percent of the time.' To compound the problem, Bodner (1986: 76) observes that much of what teachers do 'in introductory courses generate misconcepts that are resistant to subsequent instruction.'

Identifying origins of the problems of teaching (physical) concepts has been illuminated by the development of a constructivist view of learning. The central theme of this view is that '... cognitive structure of the learner prior to new instruction determines the ease and fate of the learning process.' (Gussarsky and Gorodetsky 1990:197). However the problem does not lie with the pupil alone and Bodner's (1986: 76) observation is corroborated by Galton et al (1977: 38) when they state, '... some teachers, because they themselves are unfamiliar with certain topics, tend to confuse their pupils and even introduce erroneous ideas.'

Constructivist learning theories arise out of research in cognitive psychology. These theories conceive of cognitive development as the assimilation and accommodation of new ideas (which may, for example, be social, cultural or semantic) into extant, dynamic cognitive structures (Ausubel: 1968; Osborne and Wittrock: 1985; Bodner: 1986; Novak: 1988). Existing frameworks and concepts when taken into the classroom constitute prior, personal or tacit knowledge (Polanyi, 1958) and are often referred to as pre-conceptions (which are not necessarily in conflict with accepted theories), and misconceptions or alternative frameworks (if they are in conflict) (Driver and Bell, 1986). Millar and Driver (1987: 50) notes, 'Learners'... existing ... conceptions and prior knowledge play a part whenever they interact with their environment ...' . According to Driver (1988: 145)

> '... in some cases students' prior ideas are incommensurate with the scientific conception, and attempting to shape their notions into the scientific ideas only

> leads to problems... In the task of designing ... teaching sequences which are better tuned to teachers' understanding it has been necessary to consider the nature of learners' conceptions and how they differ from the learning goals in order to identify appropriate pedagogical strategies.'

'Constructivist' science educators (West and Pines: 1985: 1-3; Novak: 1985: 194; Linn et al: 1989: 171) maintain that pupils generate their own meanings through interaction between school knowledge i.e. learned knowledge (distributed by those in authority: teachers and text book authors) and acquired or naive knowledge (acquired by the pupil from interaction with the environment). There appear to be several distinct possibilities during the process. The pupil may

(a) find no conflict if the school knowledge has no counterpart in acquired knowledge e.g. the zero concept;

(b) find that acquired knowledge can be linked to school knowledge e.g. heating increases the rate of solubility;

(c) integrate the school knowledge with acquired knowledge in a manner not intended by the teacher e.g. the teacher's statement "in a closed system, energy is **conserved**" is understood by the pupil as "... energy is **saved**"; or the teacher says: "energy in any closed system is **constant**" and the pupil understands by this: "all closed systems have energy of the **same** magnitude";

(d) find conflict between the school knowledge and acquired knowledge. When this arises again there are four possible cognitive responses. The pupil may

  (i) reject the school knowledge e.g. refuse to accept the concept of negative solubility when an increase in temperature precipitates cerium sulphate;

  (ii) hold the school knowledge and acquired knowledge independently e.g. heat is accepted as 'energy in transit' for school examination purposes but is privately believed to be substantial: 'the amount of energy possessed by hot objects';

(iii) change acquired knowledge to accommodate school knowledge e.g. '**reversible** reaction' is accepted as meaning a reaction that can proceed in both the 'forward' and 'reverse' directions and not one which favours only the formation of reactants from products;

(iv) substituting acquired knowledge with school knowledge e.g. **closed** does not always mean **shut off** from the environment.

Possibility (b) is what Piaget calls 'assimilation'. The possibilities (c), (d,i) and, in a weaker sense, (d,ii) generate what literature refers to as 'misconceptions'.

There are several other words used as synonyms for 'misconception' in the science education literature. These include 'children's science', 'private knowledge' and 'alternative frameworks'. Gunstone (1988: 81) quotes a study by Gauld (1987) which analysed such words into their basis terms (idea, conception, knowledge etc) and qualifiers (mis-, pre-, private, naive, personal etc). The list consisted of twenty five basic terms and sixteen qualifiers!. It is therefore no surprise that words such as 'misconception' can have many connotations including 'wrong', and 'mistake' which devalue the correctness of the idea as perceived by the pupil (Driver & Easley: 1978; Bodner: 1986; Hewson: 1981; Gunstone: 1988). The pupil's knowledge is not necessarily 'wrong' but rather, as Driver and Easley (1978: 62) suggest '... (does) not have the status of generalised understanding characteristic of conceptual knowledge.'

This author suggests that to maintain clarity, it may be profitable to reduce the usage of the two words 'pre-conception' and 'misconception' in the science education literature : 'pre-conception' to denote the acquired knowledge before instruction and 'misconception' to denote the scientifically inconsistent concepts generated through the interaction of acquired and school knowledge i.e after instruction. But the knowledge which a pupil brings to the science class is probably a mixture of pre-conceptions and misconceptions.

Researchers have used a variety of instruments to identify misconceptions: multiple choice items (Johnstone et al: 1977; Wheeler and Kass: 1978; Hackling and Garnett: 1985, Bradley: 1989 a, 1989 b; Brand: 1990); word associations (Gussarsky and Gorodetsky: 1988, 1990); concept maps (Bodner: 1986); clinical interviews (Ault Jr et al: 1988). Johnstone et al's (1977) test battery incorporated practising teachers' suggestions while Brand (1990) and Wheeler and Kass (1978) developed distracters according to pre-determined categories. Wheeler and Kass (1978) suggest that when a multiple choice test is used, the choice of the correct option by a pupil on a single question that tests a concept does not guarantee that he knows the answer. They show that in order for the researcher to ensure that a pupil has chosen the correct answer through correct thinking, more than one question which deal with the same concept must be given. The findings of their study to expose misconceptions among ninety nine twelfth grade Scottish higher grade chemistry students is given in Table 1.1. (p8)

Long (1987) designed an instrument consisting of nine pairs of multiple choice questions. Each pair tested one particular conceptual error and the questions were randomly distributed in the instrument. His intention was not only to identify misconceptions but also to establish how consistently they presented themselves. Bradley et al (1989 a) using this instrument with matric physical science teachers in the Johannesburg area reported an average score of 70% for the sample. While this score might be acceptable amongst pupils it is alarming when seen in the context of **teacher** misconceptions. The main misconceptions identified in their study related to:

(a) open system vs closed systems;
(b) the length of arrows in the symbol denoting equilibrium;
(c) amount vs concentration;
(d) microscopic vs macroscopic properties;
(e) application of Le Chatelier's principle;
(f) function vs effect of catalysts.

Their conclusion was that misconceptions of chemical concepts relating to chemical equilibrium are prevalent amongst South African physical science teachers.

TABLE 1.1

List of misconceptions

% of pupils	misconception
29%	Mass vs concentration: confusion between the concepts of mass and concentration;
29%	Rate vs extent: confusion between the speed at which a reaction proceeds and how far (extent) it proceeds;
47%	Constancy of K_{eq}: uncertainty as to when K_{eq} is, in fact, constant;
95%	Misuse of Le Chatelier's principle i.e. inappropriate application of Le Chatelier type reasoning;
84%	constant concentration: the inability to appreciate that under certain conditions substances can display a fixed concentration in chemical reactions;
60%	competing equilibria: failure to appreciate and consider simultaneously all the possible factors affecting the equilibrium conditions of a chemical system.

In recent years the body of research on remedying misconceptions has increased rapidly. West and Pines (1985: 6) working with university students and school pupils, claimed that although conceptual change strategies worked well with the former they were not successful with the latter. Abercrombie (1983: 101) suggested two reasons for personal assumptions being resistant to change: firstly one is usually unaware of them and they are taken for granted, and secondly the assumptions consist of a very resilient network of related parts which make it difficult to change one specific part without simultaneously changing the others. Therefore conceptual development, which is an evolutionary process, may be a more profitable strategy in senior secondary schools. Driver and Bell (1986: 454) support this view:

> 'A constructivist view of learning suggest that we may need to consider the content of science curriculum from a more developmental point of view. Such an approach would recognise that students do not necessarily construct a 'complete' understanding of a conceptual area when they are first introduced to it; their thinking may change progressively towards a more sophisticated formal and coherent knowledge structure and that sometimes they **may have to "unlearn" in order to continue to learn.'** (author's bolding)

Concept mapping is a powerful strategy to aid the development of rational approaches to the dismantling of misconceptions. A concept map provides a good basis for a developmental, evolutionary process and follows Toulmin's view rather than the conceptual change/a revolutionary model advocated by Kuhn. West and Pines (1985: 7) suggest that abandoning misconceptions is not always possible 'but (that) when it is, it is a difficult and painful process which requires both a commitment on the part of the learner and special instructional techniques.'

A concept map is an instructional device designed to encourage and reinforce integration and differentiation of concepts. Integration describes the degree to which ideas (knowledge bits) are interrelated and takes account of the number of possible links. Differentiation implies that more specific ideas are subsumed under general ideas hierarchically (West, Fensham and Garrard, 1985: 45-46). Since concepts are man-made to describe observed regularities in events, their interrelationships are significant. Pines (1985: 112-115) claims that there are two fundamental types of conceptual relationship: set-element (or set-subset) and whole-part (or system-element). In Pines' view

'... these basic conceptual relations exist in all disciplined knowledge ... relations underlie all meanings.'

This view supports the need for instructional strategies that develop interrelationships between concepts. West and Pines (1985: 5) suggest that concept maps can be used for 'conceptual development'. Concept maps focus on the assumption and relationships they see between ideas (how pupils structure ideas). The theory of subsumption is based on the assumption that most knowledge is stored hierarchically (Novak: 1985: 192-193). Concept maps help pupils to see and understand the hierarchies.

Gunstone (1988: 76-77) contends that the process of pupils themselves constructing concept maps differs from Osborne and Freyberg's (1985) 'interview about instances', Champagne et al's (1980) 'predict/observe/explain' methodology and Gunstone and White's (1980) 'demonstrate/observe/explain' methodology in that the task involves an approach that must itself be learned. In the concept mapping approach the pupils are either given a number of terms or else they generate the terms from their class notes or the text books. The terms are then arranged making explicit their hierarchical interrelationships. The completed maps indicate how a pupil 'sees' the interrelationship of the terms. The teacher then uses the maps to consolidate pupils' understanding.

Driver and Erickson (1983: 43) and Cook (1985: 37) suggest that concept mapping makes explicit several aspects of the pupil's propositional knowledge where propositions are understood as sets of related concepts. Novak (1978: 3) postulates that acquiring a concept involves appreciating the regularity in some set of events. Staver and Bay's (1989: 344) suggestion that a well defined concept map is characterised by many levels of hierarchy and cross links and contains no isolated concept indicates the magnitude of the cognitive task of the conceptual learning in Novak's terms.

Novak (1988: 83-89) contends that the technique of concept mapping reduces an interview transcript to a graphic representation of pupils' conceptual relationships. Graphic representations, in turn, expose misconceptions and their persistence after instruction and help the teacher to be more effective in overcrowded situations. In this way concept maps could be most useful in Transkeian conditions. Referring to studies by Cardemone (1975), Moreira (1977, 1978, 1979, 1983), Gurley (1982), Chi (1983), Novak, Gowin and Johansen (1983), Feldsine (1983) and Kahle (1984) Novak summarises concept maps.

(a) concept maps are representations of networks;
(b) concept maps have validity as evaluative tools which indicate the extent to which pupils have learned a body of knowledge;
(c) concept maps represent concepts and relationships in a hierarchical manner;
(d) concept maps help teachers to present content in an organised manner;
(e) concept maps reveal that not only are concept labels related to events and objects referred to by their labels but that their whole context in which events or objects are experienced is significant.
(f) concept maps help to facilitate retention as new concepts become linked to higher order concepts and into long term memory.

However despite these positive indications it has been suggested that due to certain limitations concept mapping should not be the only teaching-learning strategy used. Rather it is best used to complement other methods. White (1985: 52) claims that networks consisting of propositions alone can omit large sections of relevant knowledge. For many purposes a more differentiated set of elements may be useful. Pines (1985: 109) suggest that concept maps hide the detail found in other network diagrams. Novak (1985: 204-207) agrees: 'Concept mapping (and Vee mapping) can be helpful but they are not **sufficient** for the improvement of teaching and learning.' (author's bolding). Novak refers to a study by Gurley (1982) which suggested that some pupils found exercises on concept mapping tedious and confusing because they demanded more work and time. Other factors that could pose problems are that

(a) teachers may not adopt new strategies unless they can see that its advantages outweigh the disadvantages;
(b) teachers feel insecure when they use new strategies in the class room;
(c) changes in classroom routine and standard pupil learning methods are difficult and time consuming;
(d) authors are slow to incorporate concept mapping into text books and publishers resist early revision of editions.

However despite these limitations, concept mapping presents itself as a powerful learning strategy. Teaching a topic as conceptually complex as chemical equilibrium, and one as prone to generation of misconceptions, could be facilitated by the use of concept maps. The basis for a concept map for teaching chemical equilibrium will be proposed in Chapter 4.

CHAPTER 2

METHODOLOGY

2.1. CONCEPTS AND PRINCIPLES INVESTIGATED.

The questions in the 'Chemical equilibrium questionnaire'(Appendix B) administered to pupils can be broadly classified under the following captions. However this was deliberately not indicated on the questionnaire:

(a) Identification of closed systems and conventional representations of an equilibrium situation : Q 1 - Q 7;

(b) terminology, conventional representations of energy changes and application of Law of conservation of energy during chemical reactions: Q 8 - Q 14;

(c) interpretation of length of arrows between reactants and products: Q 15 - Q 16;

(d) distinction between concentration and amount: Q 17 - Q 21;

(e) changes in the concentrations of reactants and products as reaction progresses towards equilibrium position: Q 22 - Q 24;

(f) rates of chemical reactions: Q 25 - Q 28;

(g) rate constants and equilibrium constants: Q 29 - Q 33;

(h) unsettling the equilibrium position: Q 34 - Q 37;

(i) the confusion from perceiving the reactants and products as compartmentalised into left hand side and right hand side of a chemical equation: Q 38;

(j) ability to distinguish between static and dynamic equilibrium and between microscopic and macroscopic properties: Q 39 - Q 40.

However one must realise that in spite of this classification, the pupils cannot be said to have understood one concept or principle without internalising their interconnections. In most cases it is the understanding of the 'whole' that contributes to the understanding of the 'part'. Obviously due to this overlapping, a particular question may reveal problems associated with concepts in another related area but the discussion may not address all the aspects due to lack of space.

2.2. THE SAMPLE.

The sample consisted of 112 Transkeian matriculants from four government senior secondary schools in the Southern Transkei. All were taking physical science. The schools have been labelled A, B, C, and D to protect their anonymity. These schools were chosen from three different circuits and lie within a circle of radius 70 km. Schools A and B were from two different circuits while Schools C and D were from a third circuit. The schools were separated from one another by distances of between 25 and 40 km. The author had two primary reasons for choosing these four schools:

(a) easy access due to the good relations between the author and the principals and physical science teachers of these schools;

(b) pupil homogeneity because of the comparatively small geographical area; similar racial, tribal and cultural backgrounds; the rural location of the schools and similar distances from nearby towns; and the fact of the physical science teachers being university graduates. Despite this homogeneity, there were several points of heterogeneity: viz. the difference in the physical space and laboratory facilities in the schools; there appeared to be a difference in the quality of intake influenced by the public image of the schools and the difference in the numbers in physical science classes.

The age and gender distribution data is presented in Tables 3.1-3.3 and Figures A.1 - A.2.

2.3. TEST CONSTRUCTION.

> 'Science is built with facts just as a house is built with bricks, but a collection of facts can not be called a science any more than a pile of bricks can be called a house' (Jules Poincare quoted by Brink and Jones: 1986: 1)

This quote was kept in focus while designing the questions and analyzing the answers. The questions were constructed to effectively test not only the breadth but also the depth of knowledge in the components of the concept of chemical equilibrium. It was envisaged that if the sample's knowledge were just a collection of facts, very few among the sample would correctly answer the given questions. A few questions were at what Bloom calls knowledge/recall level but most of them demanded comprehension, application, analysis, synthesis and evaluation. The questions were designed such that a pupil could not just choose a letter on the answer sheet without carefully reading the stem and all the given options. This was to implicitly demand the sample to first analyse each question and then focus on the relevant content area to choose their answer.

The test consisted of a 40 item multiple choice battery (Appendix. B). Some of these questions were similar to those used in other studies but were redesigned for this particular study. Each question had three distracters. The answers were randomized to avoid patterns and hence guessing. Although it was intended that the answers would be equally distributed amongst the options A, B, C and D, due to an oversight the actual distribution of options A, B, C and D was 9 : 9 : 11 : 11. The pupils were provided with a special answer sheet.

A maximum of 3 hours was allowed for the completion of the questionnaire but no pupil exceeded 2 hours 35 minutes. The greater proportion of the sample took between 2 hours and 2 hours 20 minutes.

Constructing the Chemical Equilibrium Questionnaire with multiple choice questions had advantages as well as disadvantages.

Some of the advantages were :

(a) Easy scoring with higher scorer reliability;
(b) Cover a large area of the content;
(c) Limited scorer interference in the final result;
(d) Tend to include more clearly defined tasks.

Some of the disadvantages were:

(a) Allow students to get credits for guessing;
(b) Not allow for originality or expression on the part of the pupils.

2.4. ANALYSIS OF PUPIL RESPONSES.

The pupil responses were analysed in a number of ways to reveal as much information as possible on the sample's understanding and/or application of a concept. (A concept is a general abstraction of an idea but a principle is characterised by a simple or in most cases, a complex network of inter-relationships among and between concepts)

A comparison of the mark distribution among the schools and the total sample is presented in Table 3.4 and Figure A: 3.1. A comparison of the average mark and average mark % of the individual schools is given in Table 3.5. The gender-mark and gender mark% distribution is given in Table 3.6. The percentage of correct scores per question per school are given in Table 3.7.

Each question was subjected to 'Item Analysis' (Imenda: 1991., Mammen, Imenda and Grewal (in print), Stanley and Hopkins: 1972.) and the item difficulties (p) and the Discrimination Indices (D) were computed. The procedure followed for item analysis consisted of 5 steps:

(a) The 112 pupils in the total sample were ranked in the order of top to bottom overall scores;

(b) Two groups labelled 'top' (high achievers) and 'bottom' (low achievers) each comprising 30 of the top and bottom group pupils respectively were selected, 30 being 27% of the total sample;

(c) The number of pupils from each group who chose the correct option for each question was identified and this data was subsequently used in steps (d) and (e);

(d) the Item Difficulty (p) in percentage was computed as follows:
Item Difficulty (p) =

$$\frac{\text{No.of pupils choosing correct options(top + bottom group)x100}}{\text{No. of pupils (top + bottom groups)}}$$

e) Discrimination Index (D) was computed as follows:
Discrimination Index =

$$\frac{\text{No. of pupils choosing correct options (top group) - No. of pupils choosing correct options (bottom group)}}{\text{No. of pupils(top group) OR No. of pupils(bottom group)}}$$

Table 3.8 shows the number of correct scores from the total sample per question, the percentage of correct scores from the total sample per question, the item difficulty per question and the discrimination index per question.

Table 3.9 shows the distribution of optional choices i.e. A, B, C or D per question by the top 30 and bottom 30 pupils in the total sample together with the correct option, item difficulty and discrimination index.

Tables 3.8 and 3.9 facilitate:

(a) a general comparison of pupil performance on the different questions; and

(b) a comparison of pupil preferences of options from those given per question.

Table 3.9 also provides an opportunity to compare the number and percentage of pupils in the sample who chose a particular wrong (unanticipated) option for each question. The magnitude of the number serves as a measure of either a lack of understanding of a concept/principle and/or an indication of a possible misunderstanding or misconception (or an ambiguous or badly worded question).

The magnitude of the Item difficulty indicates the percentage of pupils among the top and bottom 27% of the sample who chose the correct option for a particular question. A zero value indicates that no pupil from the top or bottom 27% chose the correct option. However this does not mean that no pupil from the total sample gave the correct response. It is quite possible that a pupil not included in the top or bottom group had selected the correct answer.

When the item difficulty is zero, there is a possibility of some major error either in the question or in the teacher's key. A small magnitude, for example 5.00 for item 1, indicates that the item was too difficult for the pupils. This can be due to, inter alia, five major reasons:

(a) the teacher(s) paid little attention to the concept/ principle tested;
(b) teaching did not result in meaningful learning i.e. most of the pupils did not understand or could not apply the concepts/ principles;
(c) the question was wrongly or ambiguously stated;
(d) the language was too difficult for the sample; or
(e) the key for the question was wrong;

A high magnitude for item difficulty, for example 83.33 for item 3, indicates that the item was probably too easy for the pupils.

The magnitude of the discrimination indices (D) vary from -1 to +1 and are indicators of how well an item discriminates between those with a good general understanding of chemical equilibrium and related concepts/principles (the top group or high achievers) and those who do not (the bottom group or low achievers). The correct option for a good question can normally be expected to attract more pupils from the top group in the sample than that from the bottom group. Consequently, when the discrimination index is zero (for example item 4) it can be inferred that the item has no discrimination power i.e. either no pupil among the top or bottom group chose the correct option or an equal number of pupils from both the top and bottom groups chose the correct option. On the other hand, a discrimination index of a low magnitude, for example 0.03 for items 1 or 21, indicates that its discrimination power is very low whereas a discrimination index of 0.40 for item 12 indicates that its discrimination power is reasonably good. However, a negative magnitude of - 0.07, and - 0.10 for items 3 and 25 respectively indicates that it discriminates negatively i.e. more pupils from the bottom than the top group chose the correct option although - 0.07 is effectively a zero discrimination.

Stanley and Hopkins (1972: 270) suggest that:

(a) the potential measurement value of an item is maximum when only 50% of the sample are able to answer them correctly i.e. item difficulty (p) is 50%;
(b) there is little opportunity for an item to assess individual differences if it is too easy or too difficult;
(c) questions in the middle range of difficulty (25 to 75%) have potential for very high discrimination;
(d) being at an appropriate difficulty level does not insure that an item is good; the crucial test for an item is whether the high achiever group agrees with the correct answer of the item to a greater extent than the low achiever group.

However in this study the questions set were not tested for these qualities before being administered. Imenda (1991: 18) recommends items with Item Difficulties 25%-75% and Discrimination indices 0.25-0.75. When the purpose was the diagnosis of the understanding and application of the basic concepts among a sample which traditionally experience great difficulty in grappling with a particular knowledge area, the aspect that became crucial was the ability of the item to expose the conceptual problems and misconceptions rather than its ability to discriminate between low and high achievers (i.e grade pupils). In this study, therefore the effectiveness and efficiency of an item to expose the conceptual problems and misconceptions concerned with the components of the concept of chemical equilibrium was regarded as the basic criteria to judge the quality of the question. Hence those items (questions) which fall outside the above range need not be considered as bad items. For example, an item used by Johnstone et al (1977) had item difficulty 15% and discrimination index 0.22 and yet revealed a number of difficult conceptual areas and misconceptions concerned with chemical equilibrium.

To sum up, the item difficulty (p) serves as an indicator of the relative ease with which the sample succeeded in correctly answering each item while the discrimination index (D) serves as that of the ability of each item to discriminate between the low and high achievers within the sample.

2.5. LIMITATIONS.

(a) because interviews with individual pupils could not be conducted the idiosyncratic explanations for choosing a particular option were not available;

(b) the consistency of any one individual's misunderstandings across the whole paper was not investigated. Hence the study relies on a statistical exposure of types of misunderstandings;

(c) correction for guessing was not calculated;

(d) it is possible that author's own misunderstandings/misconceptions on the component concepts of chemical equilibrium could have influenced the analysis and interpretation of data;

(e) it is possible that badly worded questions could have affected the pupils' ability to answer questions.

CHAPTER 3

ANALYSIS AND INTERPRETATION OF DATA

3.1 INTRODUCTION

This chapter contains tabular presentations by school and total sample of the age and gender data (3.1 -3.3), mark distribution (3.4), average mark (3.5), gender-mark distribution (3.6), percentage of correct scores per question by school (3.7), Correct scores distribution by question (3.8) and item analysis (3.9). Section 3.2 will serve to provide a general description of the sample. For the sake of cohesion in section 3.3, questions dealing with closely associated concepts will be grouped together. A brief introduction and outline of the theory on which the group of questions was based is given in each case.

The discussion of responses to each question in section 3.3 refers to data tabulated in Tables 3.7 (Percentage of correct scores per question by school), 3.8 (Correct score distribution by question) and 3.9 (Item analysis) as well as to Figure A.4 (Percentage of correct scores per question). For immediate reference in the discussion of each question (Section 3.3, p 29ff), the following data is given in respect of that question: **item difficulty (p); discrimination index (D); correct option.**

The sum of the responses for each item is not always 60 because some pupils did not choose one of the given options while others chose more than one, rendering their choice invalid.

The interpretation of data is speculative. Goetz and LeCompte (1984: 173) argue that speculation is the last component of theorising; 'speculation involves playing with ideas probabilistically ... (it) is the basis of hypothesising.' The concept of speculation and probability is relevant in scientific thinking when there are a variety of variables that could affect pupils' choice of options. One should reckon that not only much of everyday problem solving is speculation but also that quantum numbers in physics, genetics in biology and models for weather prediction in meteorology have evolved on the basis of speculation. While **empiricism** assumes that observation and facts precede theories **constructivism** assumes that theories and expectations precede and guide observation as well as influence interpretation. Popper (1957: 46) says that deduction is superior to induction, 'The belief that science proceeds from observation to theory is **still** so firmly held that my denial of it is often met with incredulity.' (author's bolding)

Popper concludes that success of science is not based upon rules of induction but on luck and ingenuity. Science, he suggests, is theory laden and expectation and assumption plays a part in developing scientific theories. Lakatos and Toulmin share Popper's assumption that **theories are bold speculations**. Hodson (1985: 40) rejects the view that observation and induction are pre-requisites for making generalisations. O'Hear (1985: 45) contends:

> 'What we should be doing is always to postulate bold assumptions, and to strive to reject them as fast as possible. ... there can be no thought and no science without interpretations, assumptions and as-yet unquestioned assumptions.'

Unspecifiable subjective feelings which may not have an objective or mathematical basis could serve as a springboard for the development of what Kuhn calls revolutionary paradigms. Bohm and Peat (1987: 7) observe:

> 'Einstein certainly appreciated mathematical beauty very keenly but he did not actually begin from the mathematics, especially in his most creative period.

> Instead, he started with **unspecifiable feelings and a succession of images** out of which more detailed concepts eventually emerged' (author's bolding)

Good (1977: 139) says that Piaget showed that for adults what is possible dominated what is real. He argues that Piaget's research revealed that pupils' wrong answers can reveal lack of assimilation and accommodation as well as specific pathways of thinking.

In the light of the above discussion the speculative discussion adopted **is valid** for this broad statistical survey.

It is possible that the reader may speculate differently using the same data. Essentially that is what the theories of constructivism suggest. Each person makes his own interpretation based on what he already knows. Hanson (1958: 7-8) notes that having seen a lead cylinder in a faintly lit room,

> '... while Tycho sees a mere pipe, Kepler will see a telescope, the instrument about which Galileo has written to him. ... they begin from the same data: they are making the same observation. Differences between them must arise in the interpretations they put on these data.'

Because of the particular connotation of the word "misconception", the word "misunderstanding" has been used in this chapter (Analysis and Interpretation of Data). In Chapter 4 (Conclusion and Recommendations) the word misconception is used where an attempt has been made to see misunderstandings holistically and in terms of their possible origins.

The focus of the discussion will be on the response of the total sample rather than on the sample from each school or on the comparison of performance between schools. Possible sources of misconceptions will be discussed and teaching recommendation for the particular concept/principle will be given wherever possible.

Graphical representations of all data for the total sample, individual schools and questions appear in Appendix A.

3.2 AGE, GENDER AND MARK DATA

3.2.1 GENDER

TABLE 3.1.

GENDER DISTRIBUTION: BY SCHOOL

SAMPLE	MALE	FEMALE	RATIO MALE: FEMALE
SCHOOL A.	20	9	1 : 0.45
SCHOOL B.	14	33	1 : 2.4
SCHOOL C	6	13	1 : 2.2
SCHOOL D	2	15	1 : 7.5
TOTAL.	42	70	1 : 1.7

Table 3.1 shows the gender distribution amongst the individual schools and the total sample: 42 male and 70 female pupils. In the total sample the male to female ratio is 1: 1.7. The considerably higher proportion of male to female pupils in School A was reversed in schools B and C while School D exhibited a marked exception by having 7.5 female pupils for every male pupil.

3.2.2 AGE.

The age range of the total sample was 15 to 28 with an average age of 19.3 years. The average ages of pupils from School A to D were 18.4, 19.6, 19.4, and 20 years respectively. 5 pupils did not indicate their ages in spite of the clear request to do so. However their freedom to withhold personal information was stipulated. Figures A: 1.1 - 1.5 show the age distributions in the total sample and the four individual schools.

3.2.3. AGE-GENDER DISTRIBUTION.

Table 3.2 shows the average age-gender distribution amongst the individual schools and total sample. The average age of male pupils were found to be 20.1 years while that of female pupils were found to be 18.9 years.

TABLE 3.2

AVERAGE AGE-GENDER DISTRIBUTION BY SCHOOL

SAMPLE	MALE (YEARS)	FEMALE (YEARS)
School A	18.8	17.4
School B	21.6	18.6
School C	20.8	18.9
School D	18.5	20.2
Total	20.1	18.9

TABLE 3.3 (p.26) shows the frequency of gender against age in the total sample. Figure A: 2 shows the age-gender distribution amongst the total sample and the individual schools in graphical form. These analyses indicate:

(a) the male to female ratio amongst the physical science group for the four schools varied from 1 : 0.45 to 1 : 7.5 while that for the total sample was 1 : 1.7.;

(b) the age of the sample varied from 15 to 28 years but the average age of the sample per school was in the limited range of 18.4 to 20 years;

(c) the average age of male and female pupils in the total sample were 20.1 and 18.9 respectively.

TABLE 3.3.

AGE-GENDER DISTRIBUTION: TOTAL SAMPLE

AGE	MALE	FEMALE
15	0	1
16	2	7
17	3	14
18	7	11
19	7	12
20	6	9
21	3	8
22	1	5
23	3	0
24	3	1
25	2	0
26	1	0
27	0	0
28	0	1
UNKNOWN	5	

3.2.4 MARK DATA.

3.2.4.1. MARK DISTRIBUTION.

Table 3.4 shows the mark distribution per school and for the total sample. Out of the 40 items given, the highest number of correct scores for any one pupil was 18 (45%) and only 3 pupils (2.7% of the total sample) got this many items correct. While the weakest pupil from School D (also the weakest in the total sample) got just 5 items correct, the weakest pupil from school C got 10 items correct. Figure A: 3 illustrates the mark distribution graphically.

TABLE 3.4

MARK DISTRIBUTION: FREQUENCY OF NUMBER OF PUPILS AND MARKS

MARK	SCHOOL A	SCHOOL B	SCHOOL C	SCHOOL D	TOTAL SAMPLE
5	-	-	-	1	1
6	-	1	-	4	5
7	-	2	-	-	2
8	6	4	-	1	11
9	4	2	-	2	8
10	2	5	1	-	8
11	3	7	6	3	19
12	3	9	3	-	15
13	3	6	3	2	14
14	2	7	-	1	10
15	2	2	1	1	6
16	2	-	3	1	6
17	-	2	2	-	4
18	2	-	-	1	3
TOTAL	29	47	19	17	112

3.2.4.2. AVERAGE MARK.

Table 3.5 shows the comparison of average mark and average mark % of the individual schools and the total sample. The approximately similar but low figures for all samples suggest that the understanding of concepts and principles were generally poor. However, pupils from School C performed slightly better than those from the three other schools. Figure A: 3 shows the average mark distribution graphically.

TABLE 3.5.

COMPARISON OF AV.MARK & AVERAGE MARK %

	TOTAL	SCHOOL A	SCHOOL B	SCHOOL C	SCHOOL D
AV. MARK:	11.68	11.66	11.60	13.05	10.41
AV. %	29.2	29.15	29.0	32.63	26.03

3.2.4.3. GENDER-MARK and GENDER-MARK % DISTRIBUTION.

Table 3.6 shows the gender-mark and gender-mark % distribution which suggests that there was no significant difference between the performance of male and female pupils.

TABLE 3.6

GENDER- MARK AND GENDER-MARK % DISTRIBUTION.

	MALE	FEMALE
Mark	11.5	11.8
Mark %	28.8 %	29.5 %

3.3. PUPIL RESPONSES

3.3.1. INTRODUCTION

The following assumptions will be made while discussing each question:

(a) the statement from the physical science teachers in the four schools that they have completed the teaching and revision of the concepts and principles associated with chemical equilibrium was true;

(b) the pupils were able to read and understand the wording of all the questions;

(c) the pupils made an honest attempt to answer all questions to the best of their ability.

In the discussion of pupil responses to the questions, the response to each option is considered (Table 3.9) in order to investigate possible misunderstandings. The symbol e.g. (1,7 :

13.3%) is an ordered pair referring to the number of pupils in the top band (1) and the bottom band (7) who chose this option followed by the percentage of all the pupils in the top and bottom bands who chose the option (cf. 2.4). General conclusions regarding the whole sample will be drawn based on the data for the 27% of the top and bottom bands. This method is supported by Stanley and Hopkins (1972: 269):

> " Michael, Haertzka, and Perry (1953) have shown that p-values computed directly using all examinees, agree closely with the average of p_H and p_L values."

The discussion will refer to the information presented in Tables 3.7 to 3.9 below.

TABLE 3.7

PERCENTAGE OF CORRECT SCORES PER QUESTION: BY SCHOOL

(Rounded off to whole percentages)

SCHOOL	PUPILS
A	29
B	47
C	19
D	17
TOTAL	112

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
10	14	79	3	17	48	55	48
2	9	68	9	30	28	34	34
0	5	89	21	21	21	21	42
12	12	65	6	24	41	53	35
5	10	80	9	24	34	40	39

Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
41	45	79	59	41	24	17	41
23	38	45	38	47	32	15	38
74	32	74	95	68	42	11	58
24	18	47	24	47	41	18	41
37	36	59	51	49	33	15	43

Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24
28	10	38	7	14	28	28	14
15	13	30	9	11	55	43	38
5	11	47	11	0	53	11	21
12	35	24	12	18	53	6	41
16	15	34	9	11	47	28	29

Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32
17	28	28	34	10	34	24	38
6	28	30	40	9	38	45	23
0	0	16	26	11	37	58	0
18	24	29	29	12	41	12	35
10	22	27	35	10	38	37	25

Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40
28	52	28	21	31	28	24	17
15	79	40	30	15	49	40	23
68	89	79	47	21	68	11	0
0	65	12	24	18	18	35	18
25	71	39	29	21	42	30	17

TABLE: 3.8.

CORRECT SCORES DISTRIBUTION BY QUESTION

Key: p = ITEM DIFFICULTY (%);

N = NUMBER;

R = CORRECT OPTION;

T = TOTAL;

D=DISCRIMINATION INDEX.

QUESTION NUMBER
TOTAL NUMBER OF CORRECT OPTIONS (R) (OUT OF 112 PUPILS)
PERCENTAGE OF CORRECT OPTIONS (100 X R/112)
$p=(N(R)_{TOP}+N(R)_{BOTTOM})$ x $100/(N(T)_{TOP}+ N(T)_{BOTTOM})$ FOR 60 PUPILS
$D = (N(R)_{TOP} - N(R)_{BOTTOM})/N_{TOP}$ or $_{BOTTOM})$ FOR 60 PUPILS

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
6	11	90	10	27	38	45	44
5	10	80	9	24	34	40	39
5.00	11.67	83.33	6.67	23.33	35.00	40.00	43.33
0.03	0.17	- 0.07	0	0.20	0.23	0	0.33

Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
41	40	66	57	55	37	17	48
37	36	59	51	49	33	15	43
36.67	40.00	60.00	46.67	53.33	31.67	21.67	45.00
0.13	0.13	0.33	0.40	0.27	0.30	0.03	0.17

Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24
18	17	38	10	12	53	31	33
16	15	34	9	11	47	28	29
16.67	18.33	30.00	10.00	15.00	43.33	21.67	26.67
0.07	0.10	0.07	0.13	0.03	0.33	0.10	0.20

Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32
11	25	30	39	11	42	41	28
10	22	27	35	10	38	37	25
11.67	31.67	30.00	35.00	11.67	46.67	31.67	28.33
-0.10	-0.10	0.27	0.37	0.03	0.33	0.37	0.17

Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40
28	80	44	33	23	47	34	19
25	71	39	29	21	42	30	17
21.67	73.33	30.00	21.67	21.67	38.33	35.00	18.33
0.03	0.27	0.33	0.37	0.23	0.37	0.37	0.03

TABLE 3.9

ITEM ANALYSIS

Key: A, B, C, D: OPTIONS FOR EACH QUESTION;
TOP: HIGH ACHIEVERS (N=30); BOT: LOW ACHIEVERS (N=30);
C: CORRECT OPTION; p : ITEM DIFFICULTY;
D: DISCRIMINATION INDEX;
N: NUMBER OF SCORES PER OPTION FOR 30 PUPILS;
%: PERCENTAGE OF SCORES PER OPTION FOR 30 PUPILS.

ITEM	A		B		C		D		TOTAL		
No.	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	C	p	D
1. N	1	7	11	6	15	14	2	1	D	5.0	0.03
%	3.3	23.3	36.7	20.0	50.0	46.7	6.7	3.3			
2. N	2	11	11	9	11	5	6	1	D	11.7	0.17
%	6.7	36.7	36.7	30.0	36.7	16.7	20.0	3.3			
3. N	2	0	0	0	24	26	2	4	C	83.3	-0.07
%	6.7	0	0	0	80.0	86.7	6.7	13.3			
4. N	12	8	2	2	3	11	12	9	B	6.7	0
%	40.0	26.7	6.7	6.7	10.0	36.7	40.0	30.0			
5. N	4	2	10	4	4	13	11	9	B	23.3	0.20
%	13.3	6.7	33.3	13.3	13.3	43.3	36.7	30.0			
6. N	5	7	4	7	5	7	14	7	D	35.0	0.23
%	16.7	23.3	13.3	23.3	16.7	23.3	46.7	23.3			
7. N	7	7	3	5	8	6	12	12	D	40.0	0
%	23.3	23.3	10.0	16.7	26.7	20.0	40.0	40.0			
8. N	18	8	6	14	4	4	2	3	A	43.3	0.33
%	60.0	26.7	20.0	46.7	13.3	13.3	6.7	10.0			
9. N	13	9	5	4	8	13	4	3	A	36.7	0.13
%	43.3	30.0	16.7	13.3	26.7	43.3	13.3	10.0			
10.N	3	5	1	1	14	10	10	14	C	40.0	0.13
%	10.0	16.7	3.3	3.3	46.7	33.3	33.3	46.7			

11.N %	23 13 76.743.3	1 4 3.3 13.3	0 1 0 3.3	5 11 16.736.7	A 60.0 0.33
12.N %	20 8 66.726.7	1 9 3.3 30.0	5 6 16.7 20.0	2 6 6.7 20.0	A 46.7 0.40
13.N %	3 9 10.030.0	6 4 20.0 13.3	1 5 3.3 16.7	20 12 66.740.0	D 53.3 0.27
14.N %	0 5 0 16.7	1 4 3.3 13.3	14 14 46.7 46.7	14 5 46.716.7	D 31.7 0.30
15.N %	4 2 13.3 6.7	7 6 23.3 20.0	1 3 3.3 10.0	17 19 56.763.3	B 21.7 0.03
16.N %	2 2 6.7 6.7	16 11 53.3 36.7	3 7 10.0 23.3	0 9 0 30.0	B 45.0 0.17
17.N %	11 11 36.736.7	6 5 20.0 16.7	6 4 20.0 13.3	6 7 20.023.3	C 16.7 0.07
18.N %	4 7 13.323.3	7 5 23.3 16.7	7 4 23.3 13.3	9 13 30.043.3	D key changed: C to D
19.N %	10 8 33.326.7	9 11 30.0 36.7	3 7 10.0 23.3	7 4 23.313.3	A 30.0 0.07
20.N %	5 1 16.7 3.3	11 13 36.7 43.3	7 14 23.3 46.7	4 2 13.3 6.7	A 10.0 0.13
21.N %	4 4 13.313.3	17 15 56.7 50.0	5 4 16.7 13.3	3 7 10.023.3	C 15.0 0.03
22.N %	0 1 0 3.3	18 8 60.0 26.7	10 15 33.3 50.0	0 1 0 3.3	B 43.3 0.33
23.N %	4 4 13.313.3	3 4 10.0 13.3	8 5 26.7 16.7	14 17 46.756.7	C 21.7 0.10
24.N %	11 5 36.716.7	0 9 0 30.0	4 8 13.3 26.7	14 8 46.726.7	A 26.7 0.20
25.N %	10 5 33.316.7	4 8 13.3 26.7	2 5 6.7 16.7	13 12 43.340.0	C 11.7-0.10

26.N %	14 10 46.733.3	8 11 26.7 36.7	2 4 6.7 13.3	5 5 16.716.7	B 31.7-0.10
27.N %	11 9 36.730.0	2 8 6.7 26.7	13 5 43.3 16.7	4 7 13.323.3	C 30.0 0.27
28.N %	3 7 10.023.3	5 11 16.7 36.7	5 7 16.7 23.3	16 5 53.316.7	D 35.0 0.37
29.N %	4 8 13.326.7	21 12 70.0 40.0	1 7 3.3 23.3	4 3 13.310.0	key was incorrect
30.N %	3 7 10.023.3	0 7 0 23.3	8 4 26.7 13.3	19 9 63.330.0	D 46.7 0.33
31.N %	1 6 3.3 20.0	15 4 50.0 13.3	8 14 26.7 46.7	6 5 20.016.7	B 31.7 0.37
32.N %	9 10 30.033.3	8 9 26.7 30.0	11 6 36.7 20.0	2 4 6.7 13.3	C 28.3 0.17
33.N %	20 16 66.753.3	1 4 3.3 13.3	7 6 23.3 20.0	1 2 3.3 6.7	C 21.7 0.03
34.N %	26 18 86.760.0	1 6 3.3 20.0	2 4 6.7 13.3	1 2 3.3 6.7	A 73.3 0.27
35.N %	14 4 46.713.3	3 7 10.0 23.3	6 9 20.0 30.0	5 8 16.726.7	A 30.0 0.33
36.N %	2 2 6.7 6.7	12 13 40.0 43.3	3 11 10.0 36.7	12 1 40.0 3.3	D 21.7 0.37
37.N %	5 9 16.730.0	10 3 33.3 10.0	5 7 16.7 23.3	9 9 30.030.0	B 21.7 0.23
38.N %	4 3 13.310.0	3 14 10.0 46.7	5 6 16.7 20.0	17 6 56.720.0	D 38.3 0.37
39.N %	3 6 10.020.0	2 8 6.7 26.7	16 5 53.3 16.7	9 10 30.033.3	C 35.0 0.37
40.N %	9 5 30.016.7	6 5 20.0 16.7	3 7 10.0 23.3	11 13 36.743.3	B 18.3 0.03

3.3.2. DISCUSSION OF GROUP 1 QUESTIONS.

In Questions 1 to 7 the emphasis was on the assessment of pupil ability to identify, distinguish or describe a chemical equilibrium situation. Several closely related concepts such as 'open and closed' systems, dynamic equilibrium and reversibility, solubility equilibrium, acceptable ways of representing a reversible reaction and the knowledge of the essential characteristics of chemical equilibria were the focus of these questions.

3.3.2.1. THEORY

Most reactions are open systems. In an open system, there is a mass loss (or gain) from (or to) the system/reaction vessel. However, the reaction vessel may remain physically open while its contents are still regarded as a closed system. The single criterion for a closed system is that there is no mass change in the system. In a closed system, the reaction can proceed in both directions. A reaction that can proceed in both directions is called a reversible reaction. Such a reaction can be represented in two ways:

a) $P + Q \rightleftarrows R.$
b) $P + Q \rightleftharpoons R.$

The arrows can be of different length but the arrowheads must point in opposite directions. For equilibrium neither the reactant(s) nor the product(s) should leave the system and this is possible only in closed systems.

A solution cannot be described as saturated unless the dissolved particles are in contact with undissolved solute. In a saturated solution a dynamic equilibrium exists i.e. the rate of dissolution of solid solute equals the rate of its precipitation.

The concentration of reactants and products are rarely equal in chemical reactions. A reversible reaction is a complex activity affected by several factors. Of these only the rates of forward and reverse reactions are equal at equilibrium and not the "reactions" per se which is what many tend to say. Reversibility, closed system and dynamic nature of equilibrium are inseparable.

At equilibrium two opposing processes continue at microscopic (particle) level and consequently the masses of reactants and products remain constant. Concentration is mol/dm^3 and hence pressure changes on gases would change the volume and consequently the concentrations. Concentration and temperature are the two variables that affect all chemical equilibria.

3.3.2.2. DISCUSSION BY QUESTION

Question 1. (p = 5.0%; D = 0.03; Option D)

This question was intended to test the ability to distinguish between the concepts 'open system' and 'closed system'. From Table 3.9:

* Option A - (1,7 : 13.3%) - suggests that about 15% have no understanding of the concept of open/closed systems. If they had one would have expected one of the other options.

* Option B - (11,6 : 28.3%) - suggests that about 30% have rejected the figure IV since there is no cork on the conical flask. It is 'open' from their everyday understanding of the word. It is surprising that figures I and II are not seen as being 'open'. However these pupils are probably recalling and applying two other chemical facts viz. that carbon dioxide is 'heavier than air and therefore sinks' and that hydrogen is 'lighter than air and rises'. Under these circumstances the systems may be seen as 'closed'. Another possibility exists viz. that because of the diagrams the gas collection tubes do not appear to be 'as open' as the conical flask in IV !

* Option C - (15,14 : 48.3%) - suggests that about 50% have been more critical than those who chose option A or B and noticed that only the figure III is physically closed. With a little teacher effort this large group can be helped to understand the difference.

* Option D - (2,1 : 5.0%) - suggests that only about 5% may have successfully conceptualised open and closed systems. Option D is

the only one to include figure IV. It is physically open but the reactants and products are in the liquid phase.

Pupils' confusion arises not only from their everyday understanding of the adjective 'closed' as opposed to its specific meaning in chemistry (Mammen: 1990) but also from the teacher using that same adjective in different contexts while teaching chemical equilibrium. For example, pupils may be asked to observe the change in colour of the dynamic NO_2/ N_2O_4 system in a **closed** test tube. This may be taken to mean that closed systems are always in physically closed reaction vessels and that reactions which take place in open containers are therefore open systems. The very diagrams used in this item could be used to clarify this misunderstanding. It could also be pointed out to the pupils that if the sodium hydroxide in figure IV was replaced by sodium carbonate solution the system would become open because one of the products of the new reaction viz. carbon dioxide can escape the reaction vessel with a resulting **mass loss**.

It is surprising to note that about 85% of the top band chose option C (50.0%) or B (36.7%) thereby rejecting the notion that a neutralisation reaction in an 'open' container is nevertheless a 'closed system'.

<u>Question 2.</u> (p = 11.7%; D= 0.12; Option D)
This question tested the ability to distinguish between reversible and irreversible systems. Although all reactions are theoretically reversible the situations given in this question are standard. The chemically correct question would have been '...in which system(s) is a <u>stable</u> equilibrium condition attained?'. However it was felt that this would confuse the pupils and the technically less correct formulation was used.
From Table 3.9:

* Option A - (2,11 : 21.7%) - suggests that about 20% have little idea. If they had one would have expected at least options B or C or the answer D.

* Option B - (11,9 : 33.3%) - approximately the same number of pupils who gave this answer chose Option B in Question 1. If the reasons for doing so were similar then these pupils have assimilated the fact that 'reversible reactions only take place in closed systems'.
* Option C - (11,5 : 26.7%) - suggests that about 25% have been more critical than those who chose option A or B and noticed that only the figure III is physically closed. With a little effort this group can be made to understand the difference between literally and chemically 'closed'.
* Option D - (6,1 : 11.67%) - suggests that only about 10% have successfully distinguished between reversible and irreversible reactions, and between open and closed systems .

An additional comparison of individual pupils' responses to questions 1 and 2 shows that 32% of the sample chose the options B or C for both questions. Those who did this probably had some consistent ideas which they related to closed system and reversibility even though they chose incorrect options.

A root problem could be that pupils only encounter reversible reactions in chemical kinetics. Most chemical equations are written as being directed towards the products. Hanson (1958) points out that expectation affects observation and hence it is possible that pupils do not take particular note of reversible arrows and 'see' instead, the accustomed single arrow.
This analysis illustrates the importance of seeing related concepts as nested or networked. There can be no meaningful understanding until all related terminology and ideas are known and understood.

The data from Table 3.7 indicates that there were more pupils in all schools who chose the correct option for item 2 than for item 1. This suggests that the concepts of 'reversibility of a chemical reaction' and 'closed system' are taught as unrelated items. The responses could not have been this way if the latter were seen as a precondition for the former.

Question 3. (p = 83.3%; D = - 0.07; Option C)
This question tested the pupil's ability to recognise acceptable ways of representing a reversible reaction. It was thought that the pupils would easily recall two arrows of equal length with arrowheads in opposite directions and this option was not given. From Table 3.9:

* Option A - (2,0 : 3.3%) - suggests that about 5% have little idea of the representation.

* Option B - (0,0 : 0%) and

* Option C - (24,26 : 83.3%), which is the correct answer, differ in that statement I appears in option B only. This suggests that most pupils do understand the **symbolism** of forward and reverse reactions.

Option D - (2,4 : 10%) - suggests that only 10% hold that the term 'reversible' refers to the reverse reaction only.

This was the easiest of the 40 items and suggests that the terminology was taught adequately by teachers from all schools (Figure A.4).

Question 4. (p = 6.7%; D = 0; Option B)
This question tested the ability to apply the principles of reversibility, closed systems and the effect of temperature to solubility equilibria. From Table 3.9:

* Option A - (12,8 : 33.3%) - suggests that about 35% hold that the presence of undissolved solute **and** reversibility are not necessarily conditions for saturation.

* Option B - (2,2 : 6.7%) - suggests that only about 5% have successfully applied chemical equilibrium principles to solubility equilibria whereas

* Option C - (3,11 : 23.4%) - suggests that about 25% recalled the definition of a saturated solution but may hold that a chemical equilibrium is not involved in a saturated solution. (Refer to discussion on the 'common ion effect' below).

* Option D - (12,9 : 35.0%) - suggests that about 35% recognised the reversibility and equal rates of forward and reverse

reactions but that they probably hold that reversibility is unaffected by temperature changes.

Many pupils did not know the definition of a 'saturated solution' (i.e. the 35% who answered D) let alone that the equilibrium shifts as the temperature changes. Possibly this is because the Xhosa word for 'saturated' (see Appendix C), like its meaning in English, is related to the concept of 'fullness' as in a container being 'full'. A possible origin of this misunderstanding is the demonstration where a precipitate is filtered off a saturated solution to show the 'common ion' effect. Pupils see a precipitate reappearing in a **clear, saturated** solution upon addition of the common ion. Misunderstandings might be avoided if teachers drew attention to the fact that the clear filtrate is saturated only so long as the room temperature does not increase during the demonstration.

Question 5. (p = 23.3%; D = 0.20; Option B)
This question attempted to test the pupils' ability to recall all the fundamental characteristics of chemical equilibrium. Statement II is stated in terms of the usual textbook definition: '...when the rate of the forward reaction is exactly equal to that of the reverse reaction a state of dynamic equilibrium is established' (e.g. Brink and Jones, 1979: 136). However, to be chemically correct the statement should have read: '...the rate at which reactants are used up is equal to the rate at which reactants are reformed'. If this statement was used there would have been no ambiguity even for a reaction of the form $2A \rightleftharpoons B$.
From Table 3.9:
* Option A - (4,2 : 10%) - suggests that about only 10% hold the wrong idea that the concentration of the reactants and products are equal at chemical equilibrium;
* Option B - (10,4 : 23.3%) - suggests that only about 25% chose the correct statements describing a chemical equilibrium or spotted that III and V were wrong.
* Option C - (4,13 : 28.3%) - suggests that about 30% hold views similar to those who chose option A, i.e. the concentration of

reactants and products are equal at equilibrium. They also hold another misunderstanding that the statements 'rates of forward reaction equals the rate of reverse reaction' and 'the forward reaction equals the reverse reactions' are similar and/or identical. Personal experience has shown that this last misunderstanding is prevalent in the two schools and the college of education where the author taught in the Transkei. Pupils do not recognise that one can only compare a particular aspect of a reaction and not the reaction per se as there are a multitude of factors that affect a reaction. Introducing rates of reaction with examples from everyday experiences might help (e.g. rate of burning, rate at which iron rusts, rate of souring of milk, rate of brewing home made beer etc.)

* Option D - (11,9 : 33.3%) - suggests that about 35% failed to recognise the necessity for a closed system, interdependence of reversibility and closed system and the equality of the rates of consumption of reactants and formation of products (see discussion above on the theory underpinning this question). Both the characteristics they chose did not apply to chemical equilibrium.

<u>Question 6.</u> (p = 35.0%; D = 0.23; Option D)

This question tested the ability to recognise that neither the forward nor the reverse reaction ceases at equilibrium. From Table 3.9:

* Option A - (5,7 : 20.0%) - suggests that about 20% hold the misunderstanding that at equilibrium, the product does not decompose (react).

* Option B - (4,7 : 18.3) - suggests that about 18% hold that at equilibrium the masses of all chemical species are not constant.

* Option C - (5,7 : 20.0%) - suggests that 20% misunderstood that pressure changes at equilibrium would not affect the concentration of gaseous chemical species.

* Option D - (14,7 : 35.0%) - suggests that 35% recognised that at equilibrium, neither the forward nor the reverse reaction ceases.

Question 7. (p = 40.0%; D = 0; Option D)
This question tested the sample's ability to identify the two factors which affected all chemical equilibria. From Table 3.9:
* Option A - (7,7 : 23.3%) - suggests that about 25% hold that pressure or volume changes affect all chemical equilibria. This could either be because they were not provided with opportunities to familiarise with equilibria other than those involving gases or the teachers and/or text books are biased more towards explaining the effect of only pressure/volume changes on gaseous equilibria. Excessive use of one particular variable at the expense of other variables can therefore pose problems for the pupil.
* Option B - (3,5 : 13.4%) - suggests that about 15% think not only that pressure changes affect all chemical equilibria but also that concentration changes do not affect all chemical equilibria. The sources of misunderstanding are possibly the same as that for those who chose option A.
* Option C - (8, 6 : 23.4) : This suggests that about 25% consider that pressure changes do affect all chemical equilibria while temperature does not.
* Option D - (12, 12 : 40.0%) : this suggests that about 40% could identify concentration and pressure changes as the two variables that influence all chemical equilibria.

These misunderstandings arise possibly because most of the examples used by text books and teachers refer to gaseous equilibria resulting in the wrong view that all equilibria are affected by pressure/volume changes.

3.3.2.3. CONCLUDING GROUP 1 QUESTIONS

Questions 1, 2, and 4-7 assessed closely related principles differently but there was no consistency amongst the item difficulties. There is no point in proceeding to teach Le Chatelier's principle without the pupils understanding certain fundamentals because they cannot assimilate new ideas without these conceptual hooks.

> 'Pre-conceptions are an essential part of our mental equipment, but we are mostly unaware of them ... A good deal of the contents of the mind are taken in unconsciously ...(but) it strongly influences the way in which new ideas are taken in.' Abercrombie (1983: 101)

The concept of an open/closed system is crucial to applying Le Chatelier's principle (Bradley et al (1989 a : 8). Moreover learning Le Chatelier's principle without having understood the fundamental principles possibly generates more misconceptions. Osborne and Wittrock (1985: 64) contend that ' ... people tend to generate perceptions and meanings that are consistent with their prior learning.'

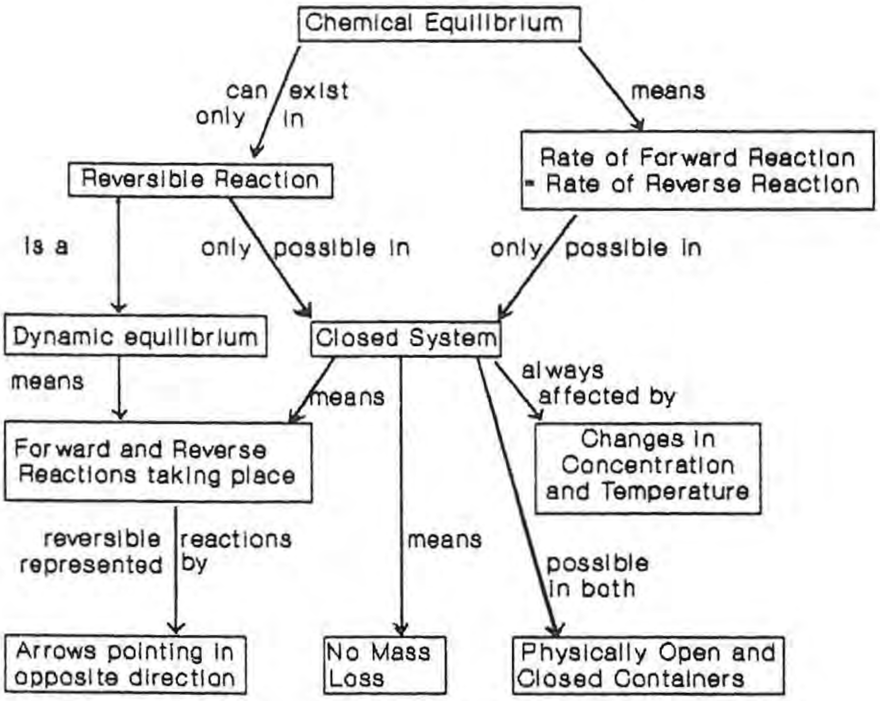
3.3.2.4. SUGGESTIONS

Assignments involving concept mapping could have helped the teachers to expose some of their pupils' misconceptions. If pupils had understood the principles, their maps would have been similar to the one below. A discussion of the maps of different pupils and their comparison with a map made by the teacher would have helped not only to develop the interrelationships between the concepts but also what Abercrombie (1983: 102) calls 'associative discussion'.

> '... Its (associative discussion) method involves introspection ... It focuses on the inner world, increasing one's understanding of one's own by comparing one's reaction to a given stimulus pattern with those of other people.'

Such discussions would motivate pupils to disregard their egocentric views more easily. This enables them to not only open up and willingly revise personal assumptions but also to accept that the same word has a meaning in science different from the one learned from everyday experiences.

PROPOSED MAP FOR CONCEPTS ADDRESSED BY GROUP 1 QUESTIONS



Inclusion of concept mapping in the syllabi, text books, matric examination question papers and in-service courses could catalyse their use in the class rooms.

3.3.3. DISCUSSION OF GROUP 2 QUESTIONS

In Questions 8 to 14 the emphasis was on the assessment of pupil familiarity with terminology, conventional representations of energy changes during chemical reactions and application of the Law of Conservation of Energy. Closely related concepts such as endothermic and exothermic reactions and heat of reaction, ΔH were the focus of these questions.

3.3.3.1. THEORY.

In a chemical reaction heat energy is generally either released into the surroundings or absorbed from them. Thus the total energy content of the reactants is not equal to that of the products. The heat energy lost from the reactants or gained by the products is conveniently denoted by the heat of reaction (symbol Δ H). The value of ΔH is calculated, as follows:

Heat of reaction = Energy of products - Energy of reactants;

using symbols, $\Delta H = E_{(products)} - E_{(reactants)}$

A chemical reaction in which heat energy is released to the surroundings is called an exothermic reaction. Applying the Law of Conservation of Energy, since energy is lost from the system in an exothermic reaction, the heat of reaction $\Delta H < 0$. Alternatively, since energy is also a product of the reaction, it can be written along with the product(s).

There are two ways of representing such a reaction:

a) $P + Q \longrightarrow R$; $\Delta H < 0$

b) $P + Q \longrightarrow R$ + heat.

A chemical reaction in which heat energy is absorbed from the surroundings is called an endothermic reaction. To emphasize the principle that if the forward reaction is exothermic, the reverse reaction (i.e. the same reaction in the opposite direction) must be endothermic, the same example as above will be used to illustrate the two ways in which an endothermic reaction can be represented:

a) $R \longrightarrow P + Q$; $\Delta H > 0$

b) R + heat $\longrightarrow P + Q$.

Therefore in an exothermic reaction, the product(s) has less energy content than the reactant(s) and conversely in an endothermic reaction, the product(s) has more energy than the reactant(s). Thus the magnitude of Δ H for an exothermic reaction has a negative value i.e. $\Delta H < 0$. Similarly, ΔH for an endothermic reaction will have a positive value i.e. $\Delta H > 0$. The unit of ΔH is kJ/mol. Thus the ΔH values show the quantity of energy which is released or absorbed for each mole of product.

For the reaction $H_2(g) + F_2(g) \longrightarrow 2\,HF$; $\Delta H = -268$ kJ/mol i.e. 268 kJ of energy is given out for every mole of HF formed. The total energy released in the above reaction is 536 kJ. Convention allows the expression of ΔH value for the reaction as written but in such cases, '/mol' (mol^{-1}) is omitted.
$H_2(g) + F_2(g) \longrightarrow 2HF$; $\Delta H = -536$ kJ. is more realistic for the pupil.

3.3.3.2. DISCUSSION BY QUESTION

Question 8. (p = 43.3; D = 0.33; Option A)
This question tested the ability to correctly label an exothermic reaction. From Table 3.9:

* Option A - (18,8 : 43.4%) - suggests that about 45% could correctly label the terminology. However, on a question that required the pupils to recall correct terminology, this cannot be recognised as satisfactory.

* Option B - (6,14 : 33.3%) - suggests that about 35% misunderstood that during an exothermic reaction the products have more energy than the reactants implying absorption of energy during an exothermic process.

* Option C - (4,4 : 13.3%) - suggests that only about 15% appear to be unfamiliar not only with the exo and endo terminology but also with the fundamentals of energetics.

* Option D - (2,3 : 8.35%) - suggests that only about 10% hold that when the product(s) are at a higher energy level than the reactants, the reaction is 'redox', a terminology associated with transfer of electrons!

Despite 'endo' and 'exo' being common adjectives in science terminology, a large percentage of matric science students are unfamiliar with their meanings. This suggests the absence of deliberate attempts to compare the energies associated with the products and reactants. An example or two might assist the top group pupils but the weaker pupils probably need more examples and exemplars. The type of teaching and learning to recall fundamental terminology such as exothermic and endothermic without really knowing their meanings may contribute to the origin of misconceptions in other component concepts of chemical equilibrium.

<u>Question 9.</u> (p = 36.7%; D = 0.13; Option A)
This question tested the ability to identify the correct representations of an exothermic reaction. From Table 3.9:

* Option A - (13,9 : 36.7%) - suggests that about 35% could correctly identify the acceptable representations of an exothermic reaction. However one would have expected at least most of those from the top group (60%) who chose the correct option for question 8 to choose correctly in this question also. This shows that one cannot expect that the pupils who can correctly recall the difference in energy content between reactants and products in an exothermic reaction can also correctly represent an exothermic reaction. These skills appear to be independent and need to be taught concurrently to aid comprehension.
* Option B - (5,4 : 15%) - suggests that only about 15% hold that in an exothermic reaction although Δ H is negative, heat is absorbed by the system.
* Option C - (8,13 : 35%) - suggests that about 35% hold the misunderstanding that in an exothermic process although energy is released along with the products, Δ H is positive.
* Option D - (4,3 : 11.65%) - suggests that only about 10% hold that in an exothermic reaction energy is absorbed by the system and the Δ H is positive.

Despite the fact that 44 pupils among the total sample chose the correct option for question 8, only 41 (37%) could choose the correct option for question 9 (Figure A: 4). School C did exceptionally well on this question with 74% of the pupils choosing the correct answer. However, it is ironic that only 42%

of the same pupils scored correctly on question 8!. This suggests that many of these pupils were familiar with representations but they could not relate the implicit energy associations.

Question 10. (p = 40.0%; D = 0.13; Option C)
This question tested if the sample knew that a reaction that is exothermic in the forward direction will be endothermic in the reverse direction. From Table 3.9:
* Option A - (3,5 : 13.4%) - suggest that about 15% did not have a clear idea of the concept of the Law of conservation of energy.
* Option B - (1,1 : 3.3%) - suggests that about 5% at least recognised that the reverse reaction is exothermic but could not correctly recognise the negative magnitude of Δ H.
* Option C - (14,10 : 40.0%) - shows that 40% chose the correct option C. They appreciated not only that it is the reverse reaction that is exothermic but also that the heat of reaction is of a negative magnitude.
* Option D - (10,14 : 40.0%) - suggests that 40% knew only one way of representing an exothermic reaction; otherwise option A is similar and they would have considered both option A and D as distracters. They consider that just the way an equation is represented on paper makes it either exothermic or endothermic. Option D was a good distracter and 40% choosing it clearly shows a lack of appreciation of the Law of Conservation of Energy.

The emphasis was on the successful application of the Law of Conservation of Energy. However those who knew how to successfully apply the Law of Conservation of Energy could not score on this question if they were unfamiliar with the two acceptable methods of representing an exothermic reaction.

Question 11. (p = 60.0%; D = 0.33; Option A)
This question tested the ability to recall convention. From Table 3.9:
* Option A - (23,13 : 60.%) - 60% chose the correct option A.
* Option B - (1,4 : 8.3) and

* Option C - (0,1 : 1.7%) - suggest that only 10% held little idea of the concept.
* Option D - (5,11 : 26.7%) - suggests that about 25% hold that Δ H represents $\text{Energy}_{(\text{reactants})}$ - $\text{Energy}_{(\text{products})}$.

This was one of the very easy questions among the 40 in the questionnaire (Figure A: 4). The 40% who chose wrong options paid inadequate attention to convention.

<u>Question 12.</u> (p = 46.7%; D = 0.40; Option A)
This question demanded recall of the definition of heat of reaction. From Table 3.9:
* Option A - (20,8 : 46,7) - suggests that about 45% correctly recalled the definition of heat of reaction.
* Option B - (1,9 : 16.7%) - suggests that about 15% hold the misunderstanding that heat of reaction only represents energy liberated when bonds are formed.
* Option C - (5,6 : 18.3%) - suggests that about 20% hold that the heat of reaction only represents the energy supplied (implying energy absorption by the reaction) to the reaction to keep it going.
* Option D - (2,6 : 13.3%) - suggests that about 15% think that heat of reaction represents the energy required (implying absorption) to break bonds during a reaction.

A total of 28 high and low achievers i.e. 48.33% of the sample chose the options B, C or D exhibiting either little knowledge of the concept heat of reaction or confused it with bond energy.

<u>Question 13.</u> (p = 53.3%; D = 0.27; Option D)
This question tested the ability to express the magnitude of heat of reaction. From Table 3.9:
* Option A - (3,9 : 20%) - suggests that 20% hold that a + sign for Δ H represents release of heat.
* Option B - (6,4 : 16.7%) - and
* Option C - (1,5 : 10.0%) - suggests that about 27% neither knew that the sign for the heat of reaction differs in exo and

endothermic reactions nor that the magnitude of heat of reaction is dependent on the number of moles of product.

28 of the 60 high and low achievers i.e. 46.7% of the sample chose the distracters A, B or C. As heat of reaction is a fundamental concept not only in kinetics but also in thermodynamics, this performance calls for a constructive criticism of the teaching methods.
- Option D - (20,12 : 53.4%) - suggests that only just above 50.0% chose the correct option D.

Lack of understanding of not only the concepts mole and the heat of reaction but also superficial knowledge of the Law of Conservation of Energy appear to have cumulatively posed difficulty to the pupils.

<u>Question 14.</u> (p = 31.7%; D = 0.30; Option D)
Although this question tested the same ability as in question 13, it was included to assess whether the pupils could apply their knowledge consistently irrespective of the number of moles of product. From Table 3.9:
* Option A - (0,5 : 8.33%) - and
* Option B - (1,4 : 8.3%) - 16.7% chose either option A or B. They neither knew the correct representation of an exothermic reaction (and the negative magnitude for heat of reaction when there is release of energy) nor recognised that the magnitude of heat of reaction can be written without '/mol' when there is a single mole of product.
* Option C - (14,14 : 46.7%) - suggests that about 45% are not used to representing heat of reaction per mole.
* Option D - (14,5 : 31.7) - suggests that although about 55% chose the correct option for question 13, only about 30% could consistently choose correctly in the paired questions. This suggests that in question 13 also, if statements were not paired, at least about 20% of those who chose the correct option would have fallen away. (p: Q. 13 ,53.3; Q. 14, 31.7!). The inconsistency is particularly significant in the top group: While 66.7% of

the top group chose correctly for question 13, only 46.7% did so for question 14 suggesting that about 20% of the high achievers were not sure of their answer. This observation supports Wheeler and Kass's (1978) claim that a conclusion regarding the understanding of a concept based on the answer to a single multiple choice item is invalid.

3.3.3.3. CONCLUDING GROUP 2 QUESTIONS

The item difficulty of Questions 11-14 ranged from 31.7 to 60.0. This indicates that the sample did not possess a sound foundation on thermochemical and thermodynamic principles encountered in the learning of chemical equilibrium.

'Energy and energy changes' pose problems to school children all over the world. This is possibly because pupils come with misconceptions from earlier experiences. This suggestion is supported by other studies:

(a) Gilbert and Watts (1983: 75-76) claim that children use energy interchangeably with other terms such as force and voltage in electric current;

(b) pupils become confused with **conservation** of energy. This is due to the different meanings for conservation in their everyday experience and in school. Solomon (1983: 49) suggests that pupils' "socialised knowledge" tells them that energy is 'used up' during useful processes such as burning. Also, sometimes teachers use the word conserve to mean different ideas. For example, " In a closed system, energy is conserved" and "Fuels are sources of energy and we must conserve them". Because concepts emerge from experience and because every experience takes place in the context of cultural assumptions (Hewson, 1985: 155), the meaning 'not wasting' is given preference over the scientific meaning.

It is possibly those pupils who associated the + sign with exothermic reactions who had problems differentiating between the different ways of representing the exothermic reaction. They appear to associate the + sign in $\Delta H = +$ with + **energy** written along with products and consequently consider the latter also as endothermic. Another possibility is that since in an endothermic reaction energy is added (absorbed), the + sign is interpreted as addition and hence an endothermic reaction.

Unless teachers specifically ask pupils to observe a particular event during an experiment and make that event explicit, pupil observation can be shady. If the focus of the experiment is the release of energy, there is no point in pupils observing that a brown gas was evolved. It is the endothermic reactions that pupils are unfamiliar with. Even in a school with no laboratory, the teacher can easily demonstrate the endothermic dissolution of ammonium nitrate in water (the cool pak used by campers).

Experiments that end with an observation but not a discussion can generate a misunderstanding or even a resistant misconception. For example, it is usually difficult for a matric pupil to reconcile the observation that a reaction mixture warms up with the teacher's statement 'this observation shows the release of heat energy'. Pupils' everyday experience tells them that for something to warm up, it must absorb energy from the surroundings (e.g. the pot on the stove; the scrap metal in the sun etc.). It is therefore natural for the pupils to think that the reaction mixture absorbs energy from the surroundings (or is it not unnatural for the teacher to expect that the pupil will find out that it is the release of energy that warms up the mixture without any discussion or explanation?). The essence of the matter is that the formation of bonds stronger than those in the reactants result in the release of energy; this in turn increases the kinetic energy of the molecules (and warms them up); and thus enabling the pupils to observe that the mercury level on the thermometer rises. The container warms up due to the heat flowing from the warm (hot) reaction mixture to the comparatively less warm (cold) container. Finally the reaction mixture (and the container having lost heat to the surroundings) cools down to room temperature. It is at this stage the energy has been released to the surroundings. The sequence of events has been one involving a release of energy from the reaction mixture. The author sometimes get irritated when colleagues say that in spite of demonstrating an exothermic reaction (or some teachers say: don't they see burning from childhood; how does their food get cooked!) the pupils just could not grasp the concept - it is a concept for the "clever". The question is, did the pupils discuss the demonstration with the teacher and/or did the teacher explain the sequence of events? The conscientious teachers are also empathetic i.e. they go down to the level of the pupil and try to see the problem from pupils' conceptual goggles. It is an approach like this that is needed in science education, especially in the so-called black schools.

Teacher explanations of collision theory can implicitly generate problems on the understanding of the Law of Conservation of Energy. For example, some explanations of collision theory imply that energy is created during collisions. The every day experience tells pupils that when two objects collide, they become warm and sometimes one object becomes warmer than the other. Teachers must deliberately explain to pupils that only exchanges of energy take place in inelastic collisions and if one set of molecules acquires an unusually large amount of energy, it is only at the expense of another set of molecules.

(Another common misunderstanding is that pupils think that exothermic reactions are spontaneous i.e. the reaction commences the moment the reactants are brought together. This was not tested in this research but experience shows that demonstration of combustion of hydrogen helps to dispel this misunderstanding)

The analysis reveals that the sample holds several misunderstandings regarding reaction energetics similar to those revealed in other studies.

3.3.3.4. SUGGESTIONS

Specific assignments that involve the representations of exothermic and endothermic reactions must be given to diagnose which aspects are difficult for pupils. It is not that they do not understand any aspect of the concept but that the different aspects do not link together. Remedial work would go a long way in solving this type of problem. Network diagrams Pines (1985), concept maps (Long, 1988) and word associations (Gussarsky and Gorodetsky, (1988) and experiments with **direction, discussion and explanation** would profit the teachers who are concerned with the learning by their pupils.

3.3.4. DISCUSSION OF GROUP 3 QUESTIONS

In Questions 15 and 16 the emphasis was the assessment of pupil familiarity with the meanings of the different lengths of arrows used to represent reversible reactions.

3.3.4.1. THEORY.

Sometimes the length of the arrows in opposite directions vary. Such a notation is used to denote the realistic concentration of the reactants and products when chemical equilibrium is actually reached at a particular temperature.

$$P + Q \underset{\leftarrow}{\xrightarrow{\qquad}} R \qquad \text{OR} \qquad P + Q \underset{\longleftarrow}{\xrightarrow{\qquad\qquad}} R$$

The longer arrow denotes that there is higher concentration of R than P and Q in that reversible reaction at equilibrium. Converse arguments would apply in the case of shorter arrows.

3.3.4.2. DISCUSSION BY QUESTION

Question 15. (p = 21.7% D = 0.03; Option B)

This question tested the meaning pupils assigned to the length of arrows in representations of chemical reactions. (It was noted afterwards that in this question the arrows denoting the reactions were reversed from the convention i.e. top arrow represents the forward reaction. The assumption, possibly erroneous, was made that this would have no effect on the pupils' answers). From Table 3.9:

* Option A - (4,2 : 10.0%) - suggests that 10% misunderstood that at equilibrium, the concentrations of reactants and products in all reactions are equal. (A general equation was given)
* Option B - (7,6 : 21.65%) - shows that only about 20% chose the correct option.
* Option C - (1,3 : 6.65%) - suggests that about 5% related the question to ionization which was acceptable but an option 'P and Q is more ionised than R' was not given. They chose a wrong interpretation and have little idea of the concept.
* Option D - (17,19 : 60.0%) - suggests that 60% have been victims of the misunderstanding that the length of arrows are a measure of the rates of reactions.

17 pupils (15%) among the total sample chose the correct option (Figure A: 4); but p = 21.7, suggesting that, although in most cases the item difficulty calculated compares favourably with that for the total sample, there can be instances with a difference; for example a percentage difference of plus 6% as in this case. The difficulty level was high in all four schools.

Difficulty probably arises from the belief that the length of arrows represent the magnitude or some measure of the rate of reaction. Only about 20% applied their knowledge that the rates of forward and reverse reactions at equilibrium are equal. Such arrows of unequal length are later necessary in acid/base equilibria to show the relative concentrations of ionised/unionised acid and dissociated/undissociated bases. Therefore if the misunderstanding is not overcome while introducing chemical equilibrium, there will be a seeding of misunderstanding rather than understanding of acids and bases.

<u>Question 16.</u> (p = 45.0; D = 0.17; Option B)
This was paired to question 15 and tested if pupils were consistent in their thinking. From Table 3.9:
* Option A - (2,2 : 6.7%) and
* Option C - (3,7 : 16.67%); - suggest that about 25% have little idea of the meaning conveyed by the size of arrows. The formula

for the calculation of K_c was given in the question; hence the lack of knowledge of equilibrium constant could not have influenced the pupil choices.

* Option B - (16,11 : 45.0%) - shows that less than half the sample chose the correct option B.

* Option D - (0,9 : 15%) - suggest that 15% possibly thought that at equilibrium the concentration of reactants and products are equal. (10 % of the sample exhibited this misunderstanding in question 15).

Difficulty probably arises from the inability to relate the size of arrows to the corresponding concentrations.

3.3.4.3. CONCLUDING GROUP 3 QUESTIONS

One would have expected similar magnitudes of item difficulty and discrimination indices for questions 15 and 16. However this was not the case. The inconsistent figures suggest that although some pupils could memorise that at equilibrium the rates of forward and reverse reactions are equal, they tend to think that the rates are unequal simply because the arrows are of different length. Thus their knowledge of equal but opposite rates for the forward and reverse reactions are superficial.

Pupils are more familiar with rate rather than concentration in their every day experience (How soon will we reach Cape Town?). When the idea is introduced the teachers usually talk about rate first and then say that rate is proportional to concentration. Moreover, because the standard 9 topics have more physics content and teachers spend a good part of the first semester in standard 10 with physics topics, pupils are more familiar with the word 'rate' (e.g. rate of change of distance: speed; rate of change of velocity: acceleration; rate at which work is done: power). Teachers also use the words 'speed', and 'velocity' to refer to rate and this precipitates an idea that the reaction is going somewhere. The arrows reinforce this idea that the reaction is going somewhere and the pupils would think of speed, velocity or rate rather than concentration. Probably starting the discussion with the concept of concentration and then introducing the idea that the 'rate of reaction is proportional to concentration' might be better.

Pupils also tend to think that the concentrations of reactant(s) equal that of the product(s) when a system is at equilibrium. This probably arises from associating **equilibrium** with **equality** and the inability to see that there is equality only in the rates of forward and reverse reactions.

The analysis suggests that the sample of Transkeian matriculants also hold misunderstandings of the size of arrows similar to those revealed in other studies. (Bradley, J.D, Gerrans, G.C. and Long, G.C.: 1989 a; Brand, M: 1990)

3.3.4.4. SUGGESTIONS

Teachers must explain explicitly that the size of arrows represent the shift in equilibrium and concentration **qualitatively** and has nothing to do with the magnitudes of the rates of forward and reverse reactions.

3.3.5. DISCUSSION OF GROUP 4 QUESTIONS

In Questions 17 to 21 the emphasis was on the assessment of pupil ability to distinguish between concentration and amount.

3.3.5.1. THEORY.

[ ] represents molar concentrations. Thus for the reaction $P + Q \rightleftharpoons R$:

[P] represents the molar concentration of P;
[Q] represents the molar concentration of Q;
[R] represents the molar concentration of R.

Amount is the mass per molar mass of a substance. It is measured in mole and the unit is abbreviated to mol. On the other hand concentration is amount per unit volume. It is measured in mol dm^{-3}.

The concentration of solids and pure liquids in a reaction remains constant during the reaction. When more solid substance is added (removed), although the mass as well as the amount is increased (decreased) the concentration (amount/unit volume) remains unchanged. For example, if 0.5 mol of zinc had a volume of 0.5 dm^3, 1 mol of zinc would have a volume of 1 dm^3. In both cases the concentration remained 1 mol dm^{-3}.

Just because an ion common with those in the reaction system is added, the concentration does not necessarily change. It depends also on the concentration of the ion in the added sample. For example, a saturated solution of sodium chloride at room temperature has a fixed concentration of chloride ions, approximately 6 mol Cl^- ions per dm^3. Even a 50% solution of hydrochloric acid has a concentration less than 6 mol Cl^- ions per dm^3. Concentrated hydrochloric acid has a concentration of 12 mol Cl^- ions per dm^3. Addition of dilute hydrochloric acid therefore decreases the concentration of chloride ions.

Although a reduction in the volume occupied by a gas does not affect either its mass or amount (moles), the concentration increases.

3.3.5.2. DISCUSSION BY QUESTION

Question 17. (p = 16.7%; D = 0.07; Option C)
This question tested the ability to correctly calculate concentration. From Table 3.9:

* Option A - (11,11 : 36.7%) - suggests that about 35% misunderstood that concentration can either be mass per unit volume or amount per any volume. To them neither the different units in the numerator nor the substitution of 'molecules' (O_2) with moles did make any difference.

* Option B - (6,5 : 18.35%) - suggests that about 20% recognised that the unit for the numerator in all cases must be mol but hold the misunderstanding that the unit volume is 2 cubic decimeters (or the volume does not matter!)

* Option C - (6,4 : 16.65%) - suggests that about 15% correctly distinguished between amount and concentration.
* Option D - (6,7 : 21.65%) - suggests that not only did about 20% accept the wrong substitution of unit of mass (g) with 'mol' but also did not observe that the container volume was 2 cubic decimeter.

A large percentage of the sample thinks that gram and mole can be used interchangeably. Difficulty probably arises from a lack of appreciation that the units of mass, amount and concentration are gram, mole and mol/dm^3 respectively.

Question 18. (wrongly worded; answer changed from C to D)
This question was intended to test pupils' ability to appreciate that the addition of more of the same chemical in the solid (or liquid) phase does not increase its concentration. But there was error in the question itself. However, from Table 3.9:
* Option A - (4,7 : 18.3%) - suggests that about 20% hold the misunderstanding that the increase in concentration of hydrochloric acid would not increase the rate of production of hydrogen gas.
* Option B - (7,5 : 20.0%) - suggests that about one fifth either did not recognise that a fixed mass of zinc powder had more surface area than an equal mass of zinc pellets or held the misunderstanding that increased surface area had no effect on the rate of a reaction (rate of production of hydrogen gas).
* Option C - (7,4 : 18.3%) - suggests that about 20% hold that addition of more solid pellets did not increase the surface area and the rate of reaction.
* Option D - (9,13 : 36.7%) - suggests that about 35% appreciated that an increase in the concentration of hydrochloric acid and the increase in surface area would increase the rate of production of hydrogen.

Constancy of concentration of solids can be reinforced best through experimentation involving the measurement of the rate of reaction which pupils can experience.

Question 19. (p = 30.0%; D = 0.07; Option A)

This question tested the ability to not only distinguish concentration from amount but also the ability to appreciate that by adding dilute hydrochloric acid the concentration of the 'common' chloride ion would be lowered. From Table 3.9:

- * Option A - (10,8 : 30.0%) - 30% chose the correct option A.
- * Option B - (9,11 : 33.4%) - suggests that about 35% recognised the distinction between amount and concentration but did not know the effect of change in concentration on precipitation.
- * Option C - (3,7 : 16.7%) - suggests that about 15% did not recognise that II and III are contradictory statements.
- * Option D - (7,4 : 18.3%) suggests that about 20% could not distinguish between the concepts amount and concentration.

An experimental approach might help pupils to internalise this concept.

Question 20. (p = 10.0%; D = 0.13; Option A)

This question tested not only the ability to apply the knowledge of concentration as moles per cubic decimeter but also the ability to do calculations involving mole ratios encountered in chemical equilibrium. From Table 3.9:

- * Option A - (5,1 : 10.0%) - shows that only 10% chose the correct option A.
- * Option B - (11,13 : 40.0%) - suggests that 40% argued that since according to the given stoichiometry 2 moles of R produces 1 mol each of P and Q, 1 mole of R would produce 0.5 mol each of P and Q. Neither could they distinguish between amount and concentration nor could recognise that 50% of R remain unreacted.
- * Option C - (7,14 : 35.0%) - suggests that 35% recognised that 50% of R remained unreacted and therefore only 0.25 moles each of P and Q are produced but hold the misunderstanding that mole represents concentration (as they did not divide the number of moles with volume).
- * Option D - (4,2 : 10.0%) - suggests that 10% calculated correctly but failed to recognise that the unit for concentration is mol dm^{-3} and not mol.

Difficulty is mainly based on the lack of understanding of concentration as moles per cubic decimeter rather than the ability to perform calculations with mole ratios. The pupils had to recognise that the volume of the container was 2 dm^3. Hence although the amount of P and Q produced were each 0.25 moles, the concentration was only 0.125 $mol.dm^{-3}$.

Question 21. (p = 15.0%; D = 0.03; Option C)
This question also tested pupils' appreciation of the meaning of concentration as amount per unit volume. From Table 3.9:

* Option A - (4,4 : 13.3%) and
* Option D - (3,7 : 16.7%) - suggests that about 30% appear to have little idea of the fundamentals concerning the gas phase.
* Option B - (17,15 : 53.4%) - suggests that about 55% have equated amount with concentration and did not recognise that the reduction in volume would affect the concentration. This again shows the misunderstanding that amount and concentration are synonyms.
* Option C - (5,4 : 15.0%) - shows that only 15% recognised that as the volume of a gas decreases, although the amount of gas remains constant, its concentration increases.

Difficulty probably again arises from the inability to distinguish between amount and concentration. The stoichiometry of the reaction indicated that the pressure (or volume) changes did not affect the equilibrium. Thus the amount of A and B remained the same. However, the reduction in volume caused by the movement of the piston from position X to Y decreased the denominator in the formula concentration = amount/unit volume. Consequently the concentration of both gases A and B increased.

There is also another possibility. If pupils have experimented with the NO_2/N_2O_4 equilibrium in a syringe, the colour becomes **darker** when the syringe is pushed in on the system in equilibrium. Based on correct prediction applying Le Chatelier's principle, the colour should have become lighter but their actual observation is contradictory: 'seeing is believing'. (Because the concentration of both the gases are increased, the actual colour initially becomes darker and **only after some time** the colour will become lighter as predicted by the principle since the shift in equilibrium takes time; but the author's observation has been that the final colour is still darker than that before pushing in the piston.) If the observation is not explained on the basis of increased concentration pupils leave the laboratory confused, believing their observation and rejecting Le Chatelier's principle. Such experiences could have affected the choice of options although the reactant and product in the question were one mole each of gases A and B respectively.

3.3.5.3. CONCLUDING GROUP 4 QUESTIONS

At school C there was a major problem as not a single pupil could recognise that reduction in volume would increase concentration. It could be that none of them understood the fundamentals of the gas phase. This observation causes alarm. Not only the different phases are a major part of the primary and junior secondary science syllabuses (School C's standard 8 intake is from neighbouring junior secondary schools) but also the standard 8 and 9 syllabuses deal fairly well with the characteristics of the gas phase.

Pupils had difficulty in distinguishing between amount and concentration. Hobden and Bradley (1984: 14) state that the inclusion of the word "stress" in the statement of Le Chatelier's principle could cause the pupils to incorrectly substitute number of moles for concentration.

There are experiments which do not produce explicit observations as predicted by theory. Teachers must address these with deliberate explanations.

The item difficulties varied between 15.0 to 30.0 indicating that pupils find it generally difficult to distinguish between amount and concentration. The magnitude of item difficulties for items 20, 21, and 17 were 10, 15 and 16.7 respectively show that most pupils have not understood the concepts amount and concentration in a meaningful manner. The discussion of the questions suggest the existence of a number of misunderstandings on the component concepts of chemical equilibrium.

3.3.5.4. SUGGESTIONS

Teachers need to make deliberate attempts to design their teaching in such a way that the distinction between amount and concentration becomes explicit. Group discussions using questions such as those used in this questionnaire would be a good starting point. Further, units for measurable quantities need to be emphasized. If the classroom experience provided opportunities to calculate concentration from given masses and volumes, pupils would have gained experience in converting masses to moles and moles to concentrations. This would have exposed them to the idea that in a closed system when gas volumes change with no change in the number and nature of particles, the mass (unit: kg) and the amount (unit: moles i.e. mass in g/molar mass) remain constant but concentration i.e. amount/unit volume (unit: mol/dm^3) would change.

Teachers must also tell the pupils that they should not confuse the symbolism, say [P], which is the concentration of P with the use of square brackets as in the case of writing the formulae of complex ions.

3.3.6. DISCUSSION OF GROUP 5 QUESTIONS

In questions 22 to 24 the emphasis was the assessment of pupils' understanding of the change in concentration of reactants and products as the reaction proceeds, i.e. assessing the extent of appreciation of the Law of Conservation of Mass during chemical reactions.

3.3.6.1. THEORY

In any chemical reaction, whether open or closed, at the beginning of the reaction, the concentrations of the reactants are high and that of the products are zero. Thus, at the beginning of the reaction when t = 0, [P] and [Q] are high and [R] = 0. Only as the reactants are used, can the products be formed. In a closed system, since the products do not leave the system (i.e. no mass loss), there is a gradual increase in the concentration of the products corresponding with the gradual decrease in concentration of the reactants. The relative loss of mass and concentration of the reactants simultaneously account for the relative gain of mass and concentration of the products.

3.3.6.2. DISCUSSION BY QUESTION

Question 22 (p = 43.3%; D = 0.33; Option B)

This question tested the ability to recognise that just before the reactants begin reacting, the concentration of the product is zero. Although this is a standard formulation for this kind of question it may be confusing to the better pupils that there is no explicit mention of [R] = 0 as a starting condition. This was, however, not assumed to be the case in this discussion. From Table 3.9:

* Option A - (0,1 : 1.7%) and

* Option D - (0,1 : 1.7%) - These options each attracted only one pupil and so were not good distracters.

* Option B - (18,8 : 38.4%) - suggests that about 40% understood the concept that the concentration of reactants is greater than that of the products at the beginning of the reaction.

* Option C - (10,15) - 41.7%) - suggests that about 40% hold the misunderstanding that the concentration of the product was greater than those of the reactant at the time of mixing the reactants.

In terms of p and D values this was a reasonably good question. Difficulty probably originates from the presence of the product in the **equation**. As the sample lack much laboratory experience, the presence of product in the equation makes them accept its presence in the reaction mixture without realising that when t = 0, [P] and [Q] are each 1 mole and [R] is zero.

Question 23 (p = 21.7%; D = 0.10; Option C)

This question tested the understanding of the change in the concentration of the reactants and products as time increases from the start of mixing the reactants. From Table 3.9:

* Option A - (4,4 : 13.3%) - suggests that about 15% hold the misunderstanding that as the reaction proceeds to equilibrium the concentration of the reactants increases.

* Option B - (3,4 : 11.7%) -suggests that about 10% hold the misunderstanding that as the reaction proceeds to equilibrium the concentration of the products decreases.

* Option C - (8,5 : 21.7%) - suggests that only about 20% recognised that as a reaction progresses towards equilibrium, the concentration of reactants progressively decrease and that of the products simultaneously increases.

* Option D - (14,17 : 51.7%) - suggests that about half of the sample hold a misunderstanding that being a reversible reaction, the concentration of both the reactants and products continue to increase as the reaction proceeds to equilibrium. This in its turn revealed the lack of appreciation of the Law of Conservation of Mass/Energy.

31 pupils (28%) amongst the total sample chose the correct option (Figure A: 4). Thus the p-value for the whole sample is 6% more than the one in Table: 3.9.

Question 24. (p = 26.7%; D = 0.20; Option A)

This question tested not only the consistency in the pupil responses with question 22 and 23 but also the existence of two misunderstandings:

(a) at equilibrium, the concentrations of all chemical species present are equal; (also questions 15 and 16 revealed this)

(b) change in temperature is the only variable that affects the concentration of the chemical species in a reversible reaction. From Table 3.9:

* Option A - (11,5 : 26.7%) - suggests that only about 25% recognised that concentration of products is zero when t = 0 and

that the concentration of all chemical species need not be equal at equilibrium.

* Option B - (0,9 : 15.0%) - suggests that about 15% could not recognise the contradictory nature of the statements.

* Option C - (4,8 : 20.0%) - suggests that 20% hold the misunderstanding that temperature is the only variable that can affect the concentration as the reaction proceeds. Even though the question gave both the reactants as gases, the effect of even changing pressure went unrecognised.

* Option D - (14,17) : 51.7%) - suggests that about half the sample hold misunderstandings similar to those who chose option C but differ from them in that they rejected both statements II and III.

33 pupils (29%) amongst the total sample chose the correct option showing that the item difficulty was higher for the total sample (Figure A: 4). Difficulty probably originates from associating the concept of equilibrium to the equality of concentrations. Temperature was probably correctly taught as the only variable that determines the value of the equilibrium constant K_c. However, it appears that many pupils were not made to recognise that although the magnitude of equilibrium constant at a particular temperature remains unchanged, it was the changing concentrations of the reactants and products that achieve this.

3.3.6.3. CONCLUDING GROUP 5 QUESTIONS

The inconsistency in both the item difficulties and the discrimination indices show that pupils do not appreciate the variation of the concentration of the reactants and products from the start of reaction to the time equilibrium is attained. Thus the majority of pupils do not appreciate the Law of Conservation of Mass. The analysis suggests the existence of four misunderstandings:

(a) even at the time of mixing the reactants, some amount of product is present;

(b) at equilibrium, there are equal concentrations of all chemical species;

(c) only changing temperature can vary the concentration of the reactant or product;

(d) in a reversible reaction, from the start of the reaction, the concentration of both reactants and products continue to increase until equilibrium is attained.

3.3.6.4. SUGGESTIONS

Even if individual experiments are not possible, teachers must demonstrate chemical reactions that show the decrease in the concentration of reactants and increase in the concentration of products. The starch-iodate reaction provides an exciting opportunity for this in a school laboratory as pupils can see the gradual development of colour. The use of graphs to show the decrease in the concentration of reactants and increase in the concentration of products as the reaction progresses towards equilibrium might be helpful.

3.3.7. DISCUSSION OF GROUP 6 QUESTIONS

In questions 25 to 28 the emphasis was the assessment of the pupils' understanding of the concept of reaction rate and the variables that affect it.

3.3.7.1. THEORY

The rate of a chemical reaction is determined by a number of variables. Rate refers to the amount (in moles) of reactants used or products formed per unit time. What one is concerned with at matric level is the average rate rather than the instantaneous rate. Thus for the reaction $P + Q \rightleftharpoons R$

$$\text{the average rate for the forward reaction} = \frac{\text{number of moles of P or Q used up}}{\text{reaction time in seconds}}$$

$$\text{or} \quad = \frac{\text{number of moles of R produced}}{\text{reaction time in seconds}}$$

Conversely, the average rate for the reverse reaction would have number of moles of R used up or the number of moles of P or Q produced as the numerator in the above equation.

The variables that affect the reaction are:

(a) the physical state of the reactants: powder has more surface area than a solid lump to enhance contact with other chemicals. Similarly, particles in solution have more surface area than when in solid form. Consequently, the powder of a solid and the particles in the solution of a solid will react faster than the same quantity of the same substance in lump form or solid phase. This variable affects heterogeneous reactions, i.e. reactions in which reactants and products are not in the same phase;

(b) chemical nature of the substance: different substances react at different rates even when all other variables affecting the rate of reaction are held constant. Thus the rate of reaction, for example, of 0,001 mole of potassium with excess water at 25^0C differs from that for the same amount of sodium under similar conditions. The type of bond in the chemical plays a part in determining the rate of a chemical reaction. The ions in an ionic substance dissociate in water, and reactions involving ionic substances take place very rapidly proceeding at a fast rate. On the other hand, reactions between covalent compounds involve the breaking of covalent bonds and consequently the reaction between covalent compounds are rather slow. In general most inorganic reactions proceed relatively quickly and organic reactions take place at a considerably slower rate;

(c) concentration: the rate of a chemical reaction is directly proportional to the concentration of the reacting substance(s).

Considering the closed system $P + Q \rightleftharpoons R$, when t = 0 [P] and [Q] are high and [R] is zero.

As the reaction proceeds, [P] and [Q] decreases when P and Q react to form R and [R] increases. Thus the rate of the forward reaction decreases as the rate of the reverse reaction increases. A stage is reached when the rate of the forward reaction equals that of the reverse reaction and then [P], [Q] and [R] remain unchanged. This state is called a dynamic equilibrium.

Dynamic equilibrium is characterised by the constancy of the observable and measurable properties (macroscopic properties) and opposing unobservable processes which continue at the same rate at particle level (microscopic properties). The two pre-conditions to achieve dynamic equilibrium are a closed system and a reversible change. Thus a chemical equilibrium is a dynamic process which consists of two opposing reactions which occur at the same rate but in opposite directions. All dynamic equilibria are influenced by concentration and temperature.

3.3.7.2. DISCUSSION BY QUESTION

Question 25 (p = 11.7%; D = - 0.10; Option C)

This question tested the understanding of the concept 'rate of a reaction' as well as the identification of the variables to be measured in order to calculate it. From Table 3.9:

* Option A - (10,5 : 25.0%) - suggests that about 25% did not recognise one of the most fundamental concepts in chemistry that the mole is the unit of amount of a substance.

* Option B - (4,8 : 20.0%) - suggests that besides having the same problem as those who chose option A, 20% hold the misunderstanding that the order in which a reactant is written in the equation dictates its behaviour in the reaction.

* Option C - (2,5 : 11.7%) - suggests that only about 10% could relate mole as the unit of amount of substance.

* Option D - (13,12 : 41.7%) - suggests that about 40% had the same problem as those who chose options A and B in that they also did not know that the mole is the unit of amount of substance.

Difficulties probably originate from a number of factors. There were those who held the misunderstanding that the rate at which the reactants were used up was unequal to the rate at which the products were formed and therefore either of them could not be correctly used in the calculation. There was a second group who held the misunderstanding that the mole was not the unit for the amount of a substance. This was also revealed by the Group 4 questions. There was also a third group who held that the calculation must always be done using the rate at which the first reactant in the equation was used up.

<u>Question 26.</u> (p = 31.7&; D = - 0.10; Option B)
This question tested whether the sample could apply their knowledge that as the rate of reaction is proportional to the concentration of the substance, the rate of forward reaction decreases and that of reverse reaction increases until equilibrium is attained. From Table 3.9:

* Option A - (14,10 : 40.0%) - suggests that 40% by selecting statement I and at the same time rejecting statement II maintain that rate of reverse reaction can be lower than that of the forward reaction but cannot be zero when t = 0. By rejecting statement III they exhibited their lack of understanding and possibly a misunderstanding of the variation of the rates of the forward and reverse reactions from the start until equilibrium is attained.

* Option B - (8,11 : 31.7%) - suggests that by rejecting statement IV about 30% showed that their choice of statements I, II and III as correct was not guesswork.

* Option C - (2,4 : 10.0%) - suggests that 10% either did not recognise that statements I, II and III contradicted statement IV or simply took a chance by choosing one of the given options.

* Option D - (5,5 : 16.7%) - suggests that about 15% have not only little idea of the concept of rate of reaction and associated principles, but also hold a misunderstanding that the rate of the forward reaction continue to increase until equilibrium is attained.

Pupils' difficulties originate from their lack of understanding of the rate of reaction, its relationship to concentration, the initial concentrations of reactants and products and the variation of concentration as the reaction progresses to equilibrium.

Hackling and Garnett (1985: 207) attribute this type of misconception to the pupils previous experience with chemical reactions which do in fact show an increase in rate as the reaction takes place. They cite two examples which are relevant for the Transkeian sample also. (At the Junior school level the Science Education Project (SEP) has supplied kits to perform simple experiments and science teachers use these.)

(a) when a piece of magnesium ribbon is placed in dilute acid it takes several seconds before the surface oxide layer is dissolved and rapid evolution of hydrogen take place.

(b) for some exothermic reactions such as the burning of magnesium, pupils perceive a delay between placing the magnesium ribbon in the flame and the rapid rate of reaction which follows.

In these reactions there are particular factors which are responsible for the increase in reaction rate as the reaction progresses. However pupils possibly do not consider these special factors but instead develop a misconception that the rate of a chemical reaction increases as the reaction progresses and come with these misconceptions to instruction on chemical equilibrium.

Only 25 pupils (22%) among the total sample chose the correct option, showing that the item difficulty for the total sample was about 9% less than on Table: 3.6 (Figure A: 4). More pupils from the bottom group got the item correct as the discrimination index was - 0.10 (Figure 6.26).

<u>Question 27.</u> (p = 30.0%; D = 0.27; Option C)
This question tested the ability to identify the single variable that would affect the rate of all reactions. From Table 3.9:
* Option A - (11,9 : 33.4%) - suggests that about 35% did not understand that the rate of forward reaction is directly proportional to the concentration of the reactants.
* Option B - (2,8 : 16.7%) - suggest that about 15% hold the misunderstanding that not only the addition of a reactant or product in any phase increases the rate of reaction, but also

that in the case of exothermic forward reaction, heating would favour the reversible endothermic reaction.
* Option C - (13,5 : 30.0%) - suggests that 30% could correctly identify that an increase in the concentration of reactants increases the rate of all forward reactions.
* Option D - (4,7 : 18.3%) - suggests that about 20% hold the misunderstanding that amount and concentration are synonyms.

Difficulties probably originate from several factors. Many pupils appear to think that the rate of all reactions can be increased by a catalyst and/or by heat. This may be attributed to everyday experiences or a lack of teacher effort to deliberately show that the catalyst increases the rate of forward and reverse reactions equally. There are also those who misunderstand that the amount of substance and concentration are synonyms and consequently choose wrong options.

<u>Question 28.</u> (p = 35.0%; D = 0.37; Option D)
This question tested the existence of the misunderstanding not only that when the system attempts to re-establish equilibrium, either of the forward or reverse reactions cease until equilibrium is attained but also that reactions cease at low temperatures. From Table 3.9:
* Option A - (3,7 : 16.7%) - suggests that about 15% hold the misunderstanding that when the forward reaction is favoured, the reverse reaction comes to a standstill forgetting that the rate of reverse reaction is directly proportional to the existing concentration of the product.
* Option B - (5,11 : 26.7%) - suggests that about 25% failed to recognise that the statements I and III are contradictory.
* Option C - (5,7 : 20.0%) - suggests that 20% failed to recognise that as the temperature changed, a new equilibrium state has to be achieved and that this is actually achieved by a faster rate of forward reaction as seen through the colour change.
* Option D - (16,5 : 35%) - suggests that 35% understood that when there was a shift in equilibrium neither the forward nor the

reverse reaction ceased and only the rate of one reaction was greater than the other.

Difficulty arises possibly from two aspects. The first is that some pupils fail to recognise that although the forward reaction is favoured, there is already present at the time of disturbing the equilibrium, a certain concentration of the product and this influences the rate of reverse reaction. The second aspect is the inexperience at observing reactions at low temperatures. Low temperature is usually associated with inactivity and hence many pupils think that reactions come to a standstill or chemicals 'sleep'.

3.3.7.3. CONCLUDING GROUP 6 QUESTIONS

Most pupils did not see statement III in Question 28 as false. This is possibly because their everyday experience tells them that when it is cold, people tend to be inside rooms or, in bed i.e. there is little activity. Some experiments also could serve as sources of misconception that at low temperature no reactions take place. For example, the magnesium wire is heated before it starts burning.

Pupils do not appreciate the Law of Conservation of Mass. There is a misunderstanding of the variation of the rates of the forward and reverse reactions from the start of the reaction until equilibrium is attained. This was also revealed by Group 5 questions.

Most pupils were unable to grasp the way in which the forward and reverse reactions changed as the reaction proceeded to equilibrium. Although the emphasis was on rates of reactions, pupils' lack of other fundamentals of chemical equilibrium greatly contributed to the poor performance on these questions.

There was inconsistency not only in the item difficulties but also in the discrimination indices of the group 6 questions. Questions 25 and 26 had negative discrimination indices indicating that more low achievers than high achievers chose the correct options.

3.3.7.4. SUGGESTIONS

It is evident that any effort at developing an understanding of the rate of reaction without first understanding the component concepts such as amount, concentration, units of amount and concentration, reversibility and the dynamic nature of reversible reactions will fail as pupils need prior conceptual hooks to grasp the concept of the rate of reaction. So teaching of the rate of reaction should take place only if and when the understanding of these other fundamentals is established.

3.3.8. DISCUSSION OF GROUP 7 QUESTIONS

In questions 29 to 33 the emphasis was on the assessment of pupils' understanding of the rate constants and equilibrium constant.

3.3.8.1. THEORY

For the reversible reaction $P + Q \rightleftharpoons R$

the average rate of the forward reaction ($\overrightarrow{v}$) $\propto [P]\,[Q]$

$= k_1\,[P]\,[Q]$

the average rate of the reverse reaction ($\overleftarrow{v}$) $\propto [R]$

$= k_2\,[R]$

At equilibrium, $\overrightarrow{v} = \overleftarrow{v}$ and hence $k_1\,[P]\,[Q] = k_2\,[R]$

Therefore $\dfrac{[R]}{[P][Q]} = K_c$ where K_c is the equilibrium constant in terms of concentration.

For $P + Q \rightleftharpoons R + S$,

$\overrightarrow{v} = k_1\,[P]\,[Q]$ and $\overleftarrow{v} = k_2\,[R] + [S]$

and $K_c = \dfrac{[R]\,[S]}{[P]\,[Q]}$

For a given chemical reaction, the equilibrium constant has a constant value at a given temperature irrespective of the change in all the other variables or conditions. Change in variables such as pressure or concentration disturb the equilibrium but hen the new equilibrium is eventually established, the concentrations of all the chemical species would have altered to keep the value of K_c constant. A large value of K_c indicates a high yield and a low value, a low yield where yield refers to high concentration of products.

When a system in equilibrium is heated, the magnitude of the equilibrium constant changes to a new value. During the process, for example, if the forward reaction is exothermic, K_c decreases. This means that the ratio (k_1/k_2) of the rate constants for the forward and reverse reactions decreases and not that k_1 decreases and k_2 increases. To see it this way is to commit a common error.

There are homogeneous and heterogeneous equilibria. In homogeneous equilibria, all the substances are in the same phase while in heterogeneous equilibria all the substances are not in the same phase. In the case of heterogeneous equilibria, the concentrations of solids and pure liquids (solvents) remain constant and hence do not feature in the equilibria equations. The essence of the matter is that the addition of solid or pure liquid does not increase the concentration since if one mole has a volume of say one cubic decimeter, half mole has a volume of half cubic decimeter and consequently, the concentration in both cases would remain constant i.e. 1 mole per cubic decimeter.

3.3.8.2. DISCUSSION BY QUESTION

Question 29. (No correct option: see below)

This question was intended to test the pupils' ability to appreciate that when a system in equilibrium is heated, the magnitude of K_c changes to a new value and during the process how the magnitude of the rate constants are affected. From Table 3.9:

* Option A - (4,8 : 20%) - suggests that 20% hold the misunderstanding that despite heating a system in equilibrium, the rate constants in both directions remained equal.

* Option B - (21,12 : 55%) - suggests that 55% hold the misunderstanding that despite heating a system in equilibrium, the rate constants remained constant.

* Option C - (1,7 : 13.3%) - suggests that about 15% hold the misconception that on heating a reaction that is exothermic in the forward direction, the rate constant for the forward reaction increased and the rate constant for the reverse reaction decreased,

* Option D - (4,3 : 11.7%) - suggests that about 10% hold the misunderstanding when an equilibrium system that is exothermic in the forward direction is heated, the rate constant for the forward reaction increased and that for the reverse reaction decreased.

Question 29, as set out in the questionnaire, was based on the incorrect understanding by the author that it is the <u>decrease</u> of k_1 and the <u>increase of</u> k_2 that decrease K_c. The fact is that since $K = A \exp(-E_a/RT)$, any increase in temperature causes both forward and reverse reactions to increase. However k_2 will increase more than k_1, hence k_1/k_2 <u>decreases</u>. This misconception was also found in an examination paper (OFS, 1985; Physical Science [HG] Paper II; Section A: Q.16). As a result of this misconception by the author there was no correct option in Q.29.

<u>Question 30.</u> (p = 46.7%; D = 0.33; Option D)

This question tested the ability to identify temperature as the only variable that determine the magnitude of the equilibrium constant, K_c. From Table 3.9:

* Option A - (3,7 : 16.7%) - suggest that about 15% not only misunderstood that a catalyst influenced the magnitude of the equilibrium constant but also did not identify temperature as at least a variable that influenced it.

* Option B - (0,7 : 11.7%) - suggests that about 10% hold misunderstandings similar to those who chose option A. They also hold that concentration and pressure also are variables that influence the magnitude of the equilibrium constant.

* Option C - (8,4 : 20%) - suggest that 20% appear to hold the misunderstanding that change in any variable would change the magnitude of the equilibrium constant.

* Option D - (19,9 : 46.7%) - suggest that about 45% identified change in temperature as the single variable that determine the magnitude of the equilibrium constant.

42 pupils (38%) among the total sample chose the correct option. The item difficulty for the total sample was therefore about 9% less than that in Table: 3.6 (Figure A: 4). The item had a reasonably good discrimination index at 0.33. The main difficulty probably arises from the thinking that a change in any variable that affects a system in equilibrium also affects the magnitude of equilibrium constant.

Question 31. (p = 31.7%; D = 0.37; Option B)
This question tested the ability to predict how the addition of a gaseous chemical would affect the concentration of other chemical species with which it is in equilibrium and also how this in turn would affect the magnitude of the equilibrium constant. From Table 3.6:
* Option A - (1,6 : 11.7%) - suggests that about 10% recognised correctly that the concentration of P would decrease but held the misunderstanding that the magnitude of K_c also would simultaneously decrease.
* Option B - (15,4 : 31.7%) - suggests that about 30% correctly understood that although [P] decreases, the K_c remained unchanged.
* Option C - (8,14 : 36.7%) - suggests that about 35% hold the misunderstanding that the addition of one of the reactants increased the concentration of the other reactant as well as the value of the equilibrium constant.
* Option D - (6,5 : 18.4%) - suggests that about 20% hold the misunderstanding that the addition of one reactant would decrease the concentration of the other reactant and simultaneously increase the value of the equilibrium constant.

41 pupils (37%) among the total sample chose the correct option (p-value on Table 3.6 was 31.7). Teachers must emphasise that the

magnitude of equilibrium constant is determined only by temperature.

Question 32. (p = 28.3%; D = 0.17; Option C)
This question tested if pupils knew how to correctly write the expression for K_c and make correct substitution of measurements into that expression. From Table 3.6:
* Option A - (9,10 : 31.7%) - suggests that about 30% did not square $[NO_2]$.
* Option B - (8,9 : 28.4%) - suggests that about 30% appear to have chosen this option just for the sake of choosing one or they consider $K_c = [NO_2]/[N_2O_4]$.
* Option C - (11,6 : 28.3%) - suggests that about 30% not only understood the correct formulation of the expression for K_c but also knew how to correctly substitute into the formula.
* Option D - (2,4 : 10%) - suggests that 10% recognise the need to square the concentration of nitrogen dioxide but hold the misunderstanding that the concentration of reactants is the numerator in the K_c expression.

28 pupils (25%) among the sample chose the correct option (Figure A: 4). Difficulty probably originates mainly from the inability to write correct expressions when there are bimolar species in the equation rather than correct substitution.

Question 33. (p = 21.7%; D = 0.03; Option C)
This question tested the ability to recognise that only the concentration of substances in the gaseous and aqueous phases are included in the K_c expression because the addition of solids or liquids do not alter their concentration. From Table 3.9:
* Option A - (20,16 : 60.0%) - suggests that about 60% hold that all phases are included in the K_c expression.
* Option B - (1,4 : 8.3%) - suggest that only about 10% hold that the liquid phase is excluded but the solid phase is included in the K_c expression.
* Option C - (7,6 : 21.7%) - suggest that about 20% could correctly write down a K_c expression for any reaction.

* Option D - (1,2 : 5%) - suggest that about 5% hold that the liquid phase is included but the solid phase is excluded in the K_c expression.

28 pupils (25%) among the total sample chose the correct option (Figure A: 4). Difficulty probably originates from a lack of appreciation that solids and liquids are condensed phases.

3.3.8.3. CONCLUDING GROUP 7 QUESTIONS

About 45% successfully identified temperature as the single factor that determines the magnitude of the equilibrium constant.

3.3.8.4. SUGGESTIONS

Experimental determination of equilibrium concentration data for some simple reactions and using these to calculate the rate constants and equilibrium constants may be helpful.

3.3.9. DISCUSSION OF GROUP 8 QUESTIONS

In Questions 34 to 37 the emphasis was on the assessment of variables that unsettle the equilibrium: i.e. the application of Le Chatelier's principle.

3.3.9.1. THEORY

Once dynamic (chemical) equilibrium is reached as in the case of reversible reactions Le Chatelier's principle comes into play.

Le Chatelier's Principle

Henri Louis Le Chatelier (1850-1931) derived a rule that can be used to predict the change in the physical or chemical equilibrium of a system when the conditions affecting the equilibrium are changed. This principle is expressed in different ways such as: 'If the conditions (temperature, pressure, concentration) of an equilibrium system are changed, a process takes place which tends to oppose or cancel the effect of change'; or: 'When a system in equilibrium is subjected to external influences, the system will act in such a way as to nullify the effect of the influence'. It has been shown that textbook statements of the principle are problematic (Allsop and George: 1984; Gold and Gold: 1985). Hobden and Bradley (1984: 14) suggest that to avoid misconception, the principle in respect of chemical systems be stated: 'If a system in equilibrium is subjected to a change of temperature, concentration or pressure, processes occur within the system which tend to counteract the change imposed.' They note that if the general word 'stress' is used in the statement instead of temperature, concentration and pressure specifically, there is a danger that 'heat' could be incorrectly substituted for 'temperature' and 'number of moles' could be incorrectly substituted for 'concentration'.

Pressure affects reactions involving gases. An increase in pressure tends to decrease the overall volume and therefore increase the concentration, which in its turn increases rates of reaction. If there are more reactant molecules than product molecules, increased pressure favours the formation of the product (i.e. the reaction which will reduce the overall number of molecules and hence the pressure). Conversely, reduced pressure favours the reaction which increases the overall number of molecules (in this case the reverse reaction). In the first case the equilibrium adjusts in such a manner that there is a decrease in the pressure exerted by the reacting gas molecules in the container. If the mole ratio of reactants to products is unity then change in pressure (or volume) will have no effect on the equilibrium.

Generally, an increase in temperature increases the rate of most chemical reactions encountered in school chemistry. However increase in temperature (heating) causes the equilibrium in a closed system to move in the direction which leads to the absorption of heat, thereby reducing the increased temperature so as to get rid of the excess energy. On the other hand, a decrease in temperature (cooling) will cause the equilibrium to shift in such a direction as to compensate for the loss of energy. Thus cooling will favour the exothermic direction(where $\Delta H < 0$) and heating will favour the endothermic direction (where $\Delta H > 0$) of the reaction.

A catalyst is viewed as a substance which changes the rate of a chemical reaction. Positive catalysts increase the rate while the negative catalysts inhibit the rate of a reaction. A catalyst will not affect the chemical equilibrium position in a reversible reaction. This is because it will affect the rate of the forward and reverse reactions to the same extent and thus simply enable the establishment of the chemical equilibrium position more quickly.

3.3.9.2. DISCUSSION BY QUESTION

Question 34. (p = 73.3%; D = 0.27; Option A)
This question tested the ability to apply Le Chatelier's Principle when the variable concentration of reactant changed.
From Table 3.9:
* Option A - (26,18 : 73.3) - suggests that about 75% were able to apply the principle correctly when the concentration of the reactant changed.
* Option B - (1,6 : 11.7%);
* Option C - (2,4 :10.0%) and
* Option D - (1,2 : 5.0%) - suggests that about 25% could not recognise the contradictory nature of the different statements.

This was the second of the easiest questions (Figure A: 4). The item difficulty was 73.3 and discrimination index was 0.26.

Difficulty probably originates from the inability to appreciate that the system will react in such a way as to restore balance at a constant temperature. This is possible only by the increase in [R] and for this to happen P and Q would react faster than before thus decreasing the [P] and [Q].

Question 35. (p = 30.0%; D = 0.33; Option A)
This question was similar to question 34 in that it tested the ability to correctly apply Le Chatelier's principle but when the

variable pressure changed in the place of concentration. From Table 3.6:

* Option A - (14,4 : 30%) - suggests that about 30% understood the application of Le Chatelier's principle when pressure changed.

* Option B - (3,7 : 16.65%) - suggests that about 15% held the misunderstanding that when pressure increased on a gaseous system that has a reduction in volume in the forward direction, the reverse reaction got accelerated.

* Option C - (6,9 : 25%) - suggests that about one quarter held the misunderstanding that an increase in pressure, on a gaseous system that has a reduction in volume in the forward direction, tend to decrease the temperature of the system.

* Option D - (5,8 : 21.7%) - suggests that about 20% held the misunderstanding that when pressure increased on a gaseous system that has a reduction in volume in the forward direction, more reactants were formed.

Those who chose options B and D also held the misunderstanding that acceleration of the reverse reaction did not result in the production of more reactants or that the production of more reactants was not related to the acceleration of the reverse reaction respectively. Otherwise they would have chosen options A or C.

44 pupils (39%) among the total sample chose the correct option although p calculated was 30.0% (Figure A: 4). In terms of item difficulty and discrimination index this was a reasonably good item.

Difficulty probably originated from a lack of appreciation that to counteract the increased pressure, the reaction that reduces the number of gas molecules would be favoured. The root cause for this is the lack of appreciation that changes in pressure or volume of a gaseous system in equilibrium are related to concentration changes.

Question 36. (p = 21.7%; D = 0.37; Option D)
This question attempted to test the ability to recognise that a catalyst is not a variable that affects the equilibrium position i.e. the effect of a catalyst is outside the scope of Le Chatelier's principle. From Table 3.9:

* Option A - (2,2 : 6.7%) - suggests that about 5% appear to have no understanding of the concept of a catalyst.
* Option B - (12,13 : 41.7%) - suggests that about 40% hold the misunderstanding that the catalyst lowers the activation energy in order to decrease the rate of an exothermic reaction.
* Option C - (3,11 : 23.4%) - suggests that about 25% hold the misunderstanding that in a closed system the catalyst affects the rates of forward and reverse reactions unequally.
* Option D - (12,1 : 21.7%) - suggests that only about 20% correctly understood the effect of a catalyst on a reversible reaction.

Difficulty probably originates from one or more misunderstandings such as a catalyst:

(a) only affects the rate of forward reaction;
(b) affects the magnitude of the equilibrium constant;
(c) decreases the rate of exothermic reaction.

Question 37. (p = 21.7%; D = 0.23; Option B)
This question was intended to test if there was consistency in the understanding of the effect of a catalyst on a reversible reaction. From Table 3.9:

* Option A - (5,9 : 23.4%) - suggests that about 25% held the misunderstanding that catalysts could be used to drive the equilibrium in the forward direction and hence produce a higher percentage of the product in the reaction mixture.
* Option B - (10,3 : 21.7%) i.e about 20% understood the function of a catalyst in a reversible reaction.
* Option C - (5,7) : 20.0%) - suggests that about 20% held the misunderstanding that catalysts not only had no effect on the reverse rate but they also produced a higher percentage of the product in the equilibrium mixture.

* Option D - (9,9 : 30.0%) - suggests that about 30% did not recognise the contradictory nature of the statements I and II.

Difficulties possibly originate from the same sources as for question 36.

3.3.9.3. CONCLUDING GROUP 8 QUESTIONS

Group 8 questions reveal that pupils cannot apply Le Chatelier's principle consistently. While the item difficulty for question 34 was 73.3% that for 35 to 37 were 30.0, 21.7 and 21.7 respectively.

It could be that the teachers use the words "stress" or "constraint" in the statement instead of the actual variables concentration, temperature and pressure. When this happens and only the change in concentration is explained, pupils would not be able to account for the effect of changing variables such as temperature and pressure.

In order to successfully apply Le Chatelier's principle pupils should have a sound grasp of several other fundamental concepts and the analysis of the earlier questions revealed that this is not the case.

A number of misunderstandings were identified with respect to the function of catalysts in a reversible reaction:

(a) catalysts have no effect on the reverse rate;
(b) catalysts decrease the reverse rate;
(c) catalysts cause the formation of a higher percentage of product in the equilibrium mixture;
(d) catalysts can be used to drive the equilibrium in the desired direction.

3.3.9.4. SUGGESTIONS

Teachers cannot expect that illustrating Le Chatelier's principle through just the changing concentration would enable the pupils to predict the effect when other variables come into play. Giving pupils examples of misconceptions and explaining why they are wrong would be helpful in some cases.

3.3.10. DISCUSSION OF GROUP 9 QUESTIONS

There was only question 38 in this section although it is labelled a 'group'. In this question the emphasis was on the assessment of confusion that arises from the pupils viewing the system not as a whole unit but rather as having two compartments; the left hand side and the right hand side.

3.3.10.1. THEORY

Although the reactants and products are written respectively on the left and right hand side of the arrow, the system remains as a single unit. One cannot apply a constraint to only the reactant(s) or the product(s). Thus for example, it is neither possible nor practicable to heat only the reactant or increase the pressure of only the product.

3.3.10.2. DISCUSSION BY QUESTION

Question 38. (p = 38.3%; D = 0.37; Option D)
This question attempted to test if pupils considered the system in equilibrium as a whole unit or as compartmentalised parts. From Table 3.9:

* Option A - (4,3 : 11.7%) - suggests that about 10% held the misunderstanding that not only it is possible to heat only the products but also that change in temperature did not affect the equilibrium position.

* Option B - (3,14 : 28.4%) and

* Option C - (5,6 : 18.4%) - the total of those who chose options A, B or C suggests that about 58% held the misunderstanding that it is possible to heat only the product.

* Option D - (17,6 : 38.3%) - suggests that about 40% understood the wholeness of a system in equilibrium.

The item difficulty and the discrimination index of this item were reasonably good. Difficulty probably originated from viewing the left hand side and right hand side of the equation as two compartments in the reaction mixture.

3.3.10.3. CONCLUDING GROUP 9 QUESTIONS

It is clear that a large percentage of students view the reactants on the left hand side and the products on the right hand side compartments in the reaction mixture and some of them may even be imagining that an arrow is present in the reaction mixture!. Johnstone et al (1977) found that on a question that assessed the conceptual difficulty on 'left and right handedness' among the higher grade chemistry students (Scottish Certificate of Education), the item difficulty was 21%. In the Transkeian sample the item difficulty was 38.3%.

The misunderstanding of two sides to a reaction is sometimes created or, in other cases, reinforced by the use of reaction coordinate diagrams drawn to aid explanation of activation energy where the 'energy hump' separates reactants and products.

It is rather difficult to explain or discuss chemical equilibrium without frequently referring to reactants and products, forward and reverse reactions and the left and right side of the equation and pupils see the equation as the reaction itself. However one must realise that in a heterogeneous reaction where there are different phases there is really nothing wrong about such explanation but this cannot be generalised. It could have been argued that "a bright student might have thought of a heterogeneous equilibria" but as the phases of both the reactant and product were given such an argument is invalid.

3.3.10.4. SUGGESTIONS

Nitrogen dioxide/dinitrogen tetroxide equilibrium in a test tube provides a good opportunity for convenient individual experiments to overcome some of the misconceptions revealed by these questions. Pupils may not have understood that the static equilibrium learned in physics is different from chemical equilibrium. If teachers do not directly address this distinction, the pupils may tacitly and justifiably interpret the teachers explanation of chemical equilibrium in terms of what they already know about the static two-sided physical equilibrium.

Pupils need to be told explicitly that an arrow is used in an equation to distinguish between the reactants and products, but that in an actual reaction the reactants and products exist together. If this precaution is not taken then without the teacher being aware of it the pupils could interpret this explanation in terms of their own tacit assumptions.

While explaining enthalpy diagrams, teachers need to explicitly tell pupils that the reactants and products in a closed system exist together and the labels 'reactants' and 'products' between the changing potential energy graph is to make the energy change clear rather than to mislead them to a compartmentalised view of separated reactants and products.

Johnstone et al (1977) state that teachers sometimes use pupils as molecular models to explain equal rates of reaction, e.g. the number of students entering the classroom per second equals the number of pupils leaving the classroom per second). Such analogies, although employed in good faith could lead to a compartmentalised view of reactants and products unless teachers deliberately point out the problem to the pupils.

3.3.11. DISCUSSION OF GROUP 10 QUESTIONS

In questions 39 and 40 the emphasis was to test the ability to clearly distinguish between dynamic equilibrium and static equilibrium and between microscopic and macroscopic properties.

3.3.11.1. THEORY

At equilibrium although no visible changes are observable even when the temperature is constant, the forward and reverse reactions do not stop but continue at equal rates. Because these reactions are at the particle level, they are not visible.

At microscopic (particle level) it is the atoms or molecules that take part in a chemical reaction. Therefore an appreciation of the number of particles in one mole is quite necessary for the understanding of a reaction. It is the macroscopic and not the microscopic properties that are observable. Even when there are no observable changes, microscopic processes continue to take place.

3.3.11.2. DISCUSSION BY QUESTION

Question 39. (p = 35.0%; D = 0.37; Option C)

This question attempted to test the ability to recognise that the forward and reverse reactions do not stop at equilibrium but continue at equal rates. From Table 3.9:

* Option A - (3,6 : 15.0%) - suggests that about 15% held the misunderstanding that an equilibrium system has no observable and measurable properties.

* Option B - (2,8 : 16.7%) - suggests that about 15% held the misunderstanding that the system was static.

* Option C - (16,5 : 35.0%) - suggest that about 35% understood that although observable properties remain constant, both the forward and reverse reactions continue at microscopic level.

* Option D - (9,10 : 31.7%) - suggest that about 30% hold the misunderstanding that when observable properties remain constant, the reaction has ceased.

In terms of item difficulty and discrimination index this was a good item. Difficulty probably originates from the thinking that as long as no observable change took place, the reaction is at standstill.

Question 40. (p = 18.3%; D = 0.03; Option B)

Question 40 attempted to test the ability to distinguish between microscopic and macroscopic properties. From Table 3.9:

* Option A - (9,5 : 23.4%) - suggests that about 25% failed to recognise the magnitude of the number of particles in one mole.

* Option B - (6,5 : 18.3%) - suggests that only about 20% was able to relate the reaction in terms of interaction of the correct number of particles at microlevel.
* Option C - (3,7 : 16.7%) - suggests that about 15% did not understand the microscopic nature of molecules.
* Option D - (11,13 : 40.0%) - suggests that about 40% neither knew the difference between moles and molecules nor the microscopic nature of molecules.

Difficulty probably originates from mainly two factors:

(a) the inability to differentiate between moles and molecules. At the junior school level equations are interpreted in terms of molecules for simplicity but even when the interpretation in terms of moles and the distinction between micro and macro aspects are done, pupil continue to think in terms of molecules. Further, few pupils recognise that one mole contains 6.023×10^{23} particles;

(b) their lack of appreciation that molecules are too tiny to be counted by a school laboratory experiment.

3.3.11.3. CONCLUDING GROUP 10 QUESTIONS

These questions revealed that the sample had a poor understanding of dynamic equilibrium, moles and the distinction between microscopic and macroscopic properties.

3.3.11.4. SUGGESTIONS

A concept map during the introduction of chemical equilibrium could be helpful. It would also be necessary to explain that just because the observable properties are constant in a system one cannot conclude that the system is in equilibrium. The observable properties can remain constant also when one of the reactants has been used up. Therefore the concept of 'limiting reagent' must be explained simultaneously.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS.

4.1 SUMMARY OF INTERPRETATION OF RESULTS

4.2. RECOMMENDATIONS

4.1 SUMMARY OF INTERPRETATION OF RESULTS

At the very outset two points should be noted:

(a) although some of the pupils did not answer certain questions, one cannot infer with certainty that they have not learned anything related to the concept/principle on which the question was based. Wingfield (1979: 13) says, 'While correct performance implies learning, the absence of correct performance need not imply that no learning has occurred';

(b) all pupils who chose the correct answer for a particular question may not have arrived at that answer by a reasonably coherent argument. A study by Cook (1985: 38) found that although 44 out of 61 grade 12 chemistry pupils chose the correct option for a chemistry multiple choice question, only 21 succeeded in giving a 'reasonably coherent argument' for how they arrived at that answer. He concludes that if those pupils who chose incorrect options were also included, 66% were unable to produce a coherent reasoned response.

As stated in the introduction, the purpose of the study was to collect and collate information pertaining to common misconceptions of components of the concept of chemical equilibrium amongst a sample of Transkeian matriculants. The Chemical equilibrium questionnaire identified a number of misconceptions on chemical equilibrium within the sample of 112 Transkeian matriculants. The major misconceptions, misunderstandings and difficulties identified were:

(References to other researchers who identified or implied the existence of the same misconceptions, misunderstandings or difficulties amongst other samples are given in each case)

OPEN/CLOSED SYSTEMS, REVERSIBILITY AND DYNAMIC EQUILIBRIUM.

- absence of mass loss from the reaction system is not a basic criteria for a 'closed' system;
- a state of chemical equilibrium is possible only when reactions take place in physically closed containers/only physically closed systems are "closed";
- confusing the distinction between closed and open systems (Brand, 1988, 1990; Bradley et al, 1989 a and b);
- closed systems and reversibility are unrelated;
- in reversible reactions the products produce reactants but not vice-versa;
- presence of undissolved solute/reversibility are not necessary for maintaining the saturated nature of a saturated solution;
- chemical equilibrium does not occur in saturated solution;
- reversibility is unaffected by temperature changes.

AMOUNT/CONCENTRATION

- molecules and moles represent the same concept;
- mole is unrelated to the amount of substance;
- amount and concentration are synonyms/difficulty in distinguishing between mass and concentration/ confusing amount and number of moles with concentration (Wheeler and Kass, 1978; Brand, 1988, 1990; Bradley et al, 1989, a and b);
- concentration is mass per unit volume;
- concentration is number of moles per any volume;
- in a state of dynamic equilibrium, the concentration of reactants and products are equal;
- at equilibrium the masses of all chemical species do not remain constant;
- addition of a solid chemical increases its concentration in the equilibrium mixture; (Wheeler and Kass, 1978);

* pressure changes do not change the concentration of gaseous chemicals at equilibrium;

* changes in pressure or volume of gaseous equilibria are not related to concentration changes;

* reduction in the volume of a fixed amount of gas does not increase its concentration;

* gram and mole can be used interchangeably;

REACTION RATES

* The rate of forward reaction increases from the time of mixing of the reactants until equilibrium is established (Hackling and Garnett, 1985);

* there is no direct relationship between the rate of reaction and concentration;

* Even when the rates of forward and reverse reactions are unequal, the system is in equilibrium (Johnstone et al, 1977; Brand, 1988, 1990);

* different lengths of arrows are a measure of the comparative rates of forward and reverse reactions (Johnstone et al, 1977; Brand, 1988, 1990; Bradley et al, 1989 a and b, 1990);

* at equilibrium the product(s) does not react;

* addition of a chemical in any phase increases the rate of reaction (do not realise that addition of solid or liquid chemical does not increase the rate of reaction);

* when conditions affecting the equilibrium are changed, either the forward or reverse reaction ceases until equilibrium is re-established;

* At low temperature chemicals become inactive and reaction ceases;

* when the forward reaction is favoured the reverse reaction ceases;

* increased surface area of a solid does not affect the rate of a reaction;

LAW OF CONSERVATION OF MASS/ENERGY AND HEAT OF REACTION

- a reaction that is exothermic in one direction need not be endothermic in the opposite direction (Camacho and Good (1989);
- energy is not conserved in a chemical reaction;
- increase in concentration of a reactant increases that of a co-reactant;
- even before the reactants begin to react, some amount of product is present in the reaction mixture;
- as the reaction proceeds to equilibrium
  - (i) the concentration of reactants increases;
  - (ii) the concentration of products decreases;
  - (iii) the concentration of both the reactants and products increases;
- ΔH represents $\text{Energy}_{(\text{reactants})} - \text{Energy}_{(\text{products})}$
- heat of reaction represents
  - (i) only the energy liberated when bonds are formed;
  - (ii) the energy required to break bonds during a reaction; or
  - (iii) the energy supplied (implying absorption) to maintain the reaction;
  - (iv) bond energy.
- after an exothermic reaction the products have more energy than the reactants implying absorption of energy during the exothermic process;
- when the products are at a higher energy level than the reactants, the reaction is redox;
- In an exothermic reaction energy is absorbed and ΔH is positive;
- the magnitude of heat of reaction is independent of the number of moles of product;

DOUBLE SIDED VIEW

- it is possible to heat any one (or some) of the chemical species in the equilibrium mixture, i.e. considering equilibrium systems as consisting of two independent and separate compartments or sides rather than the one whole (Johnstone et al, 1977; Brand, 1988, 1990; Bradley et al, 1989 a and b, 1990; Gussarsky and Gorodetsky, 1990);

VARIABLES AFFECTING EQUILIBRIUM/EQUILIBRIUM CONSTANT

- change in temperature is the only variable that affects the concentration of chemicals at equilibrium;
- concentration of a reactant is the numerator in the formula to calculate K_c;
- concentration of the chemicals in the solid and liquid phases are also included in the calculation of K_c;
- pressure or volume changes affect all chemical equilibria;
- concentration changes affect only some chemical equilibria;
- Change in one of the conditions affecting an equilibrium system increases the rate of reaction in one direction but decreases that in the other direction (Hackling and Garnett, 1985)
- there is no distinction between stress (changing variable) and its effect (Brand,1988, 1990);

MACROSCOPIC/ MICROSCOPIC DISTINCTION

- atoms and molecules exhibit observable macroscopic properties/microscopic properties are observable (Brand, 1988, 1990, Bradley et al, 1989 a and b);
- When the macroscopic properties are stable, the microscopic properties are also static (Gussarsky and Gorodetsky, 1990);

CATALYSTS

- catalyst affects the rates of forward and reverse reactions differently;
- catalyst shifts the equilibrium in the forward direction;
- catalyst can be used to drive the equilibrium in the desired direction;
- catalysts affect only the rate of the forward reaction and so alter the proportion of products (Johnstone et al, 1977; Brand (1988), 1990, Bradley et al, 1989 a and b, 1990);

- catalyst, concentration and/or pressure affects the magnitude of equilibrium constant/variables other than temperature can change the value of equilibrium constant (Camacho and Good, 1989);

STATIC/DYNAMIC EQUILIBRIUM

- chemical equilibrium is similar to physical static equilibriums (Johnstone et al, 1977; Camacho and Good, 1989; Gussarsky and Gorodetsky, 1990)

Some of these were similar to those identified by other researchers in South Africa and other parts of the world and hence the purpose of the study was achieved. Their existence, frequency and consistency suggest that teaching strategies are designed simply to distribute knowledge and are not tuned to overcoming misconceptions. It is likely that this process is exacerbated by the dual problems of text book driven instruction in the hands of teachers who themselves either hold many misconceptions or are unaware of the subtleties of the concept of chemical equilibrium.

4.2 RECOMMENDATIONS

4.2.1. FOR TEACHING

Tamir (1983: 85) observes, 'Teachers are responsible for (pupils') learning.' Although there are variables other than the teacher that affect pupils' learning, teachers can play a vital role by avoiding the origins of misconceptions in their teaching; but this is possible only if they are conscious of the misconceptions themselves. It is also possible that pupils arrive in the classroom with entrenched misconceptions they have acquired elsewhere. In this case the teachers must

(a) identify the misconceptions to themselves;
(b) avoid seeding misconceptions;
(c) make pupils aware of the shortcomings of the misconceptions by showing that they lead to impossible conclusions; and
(d) attempt to convince pupils of the validity of the currently accepted view.

Whether one wishes to avoid the seeding of a misconception or to eradicate an existing misconception, some form of diagnostic test becomes essential (Johnstone et al, 1977; Bradley et al 1989 b). Thereafter the fine details of teaching style and lesson content require scrutiny. For instance, a suggestion from Hobden and Bradley (1984: 16) is relevant here:

> 'The holding of mistaken conceptions can often go unrecognised unless specific steps to reveal them are taken. The taking of such steps is very desirable because of the long-term handicap they otherwise will be to the pupil. Apart from taking such steps deliberately to reveal misconceptions, it would seem good policy to eradicate the use of misleading language and symbolism from one's own habits as far as possible. Thus one has to learn to replace such phrases as "the reaction (or equilibrium) moves to the left" by phrases such as "the concentrations of reactants increase at the expense of those of the products". It usually requires a few more words, but if it conveys the true meaning unambiguously, it is worth it!'

There are several possible sources of misconceptions. Some are cultural and others are from academic experiences. For example while explaining the effect of temperature, the teacher would say that the equilibrium moves to the left. Pupils making their own tacit assumptions about what the teacher has said, may conclude and assimilate that there are two **sides** to the reaction. The mental picture formed may be quite different from the 'more correct' version of interacting species randomly and homogeneously distributed. In this case it may not be the teacher teaching incorrectly so much as the pupils interpreting inappropriately what the teacher has implied. The teacher may remain unaware of the meaning the pupils have constructed.

> 'It is more probable that the presence of a misconception is the result of a tacit assumption made by the

> pupil with respect to what he, the pupil, thinks the teacher actually means, a tacit assumption about which the teacher is quite unaware.' (Johnstone et al, 1977: 170)

The use of analogies during teaching can serve as major sources of misconception. Johnstone et al (1977: 170) list a dozen analogies of chemical equilibrium used by teachers (Table 4.1) and suggests that analogies (a) to (g) 'perhaps create more problems than they solve'. This, they argue, is because 'these analogies are reasonably close to that which they purport to explain, and so are eminently capable of being confused in the pupils' minds with the real chemical equilibrium.'

Table 4.1.

List of Analogies used to teach chemical equilibrium

(a) water being transferred between two containers by different beakers;
(b) mice jumping back and forth between two containers;
(c) twin connected goldfish bowls;
(d) fan operated enthalpy box with adjustable "reactant" and "product" levels;
(e) a simple see-saw;
(f) a mechanical balance;
(g) a pupil walking up a down-escalator;
(h) water flowing into and out of sink at same rate;
(i) pupils simultaneously coming and going in one room;
(j) swimming against the current;
(k) school dance;
(l) "molecular" pupils.

In making a plea to teachers to avoid seeding misconceptions, they suggest:

> '... the teacher might restructure his approach so that misconceptions do not arise in the first place.

> This is particularly the case with the use of analogies. Analogies which are liable to misinterpretation should perhaps be avoided. ... safer analogies are either those which are far removed conceptually from the real equilibrium situation that there is no chance of confusion, or are those which are so close that there is no chance of conflict. There are, unfortunately, relatively few of these "safer" analogies.' (Johnstone et al, 1977: 170)

It follows that only when teachers are prepared to take deliberate steps either to prevent or eradicate misconceptions they become aware of pupil misconceptions and the ways they can be seeded.

It is hoped that the identification of the misconceptions will enable/assist physical science teachers
(a) to avoid seeding misconceptions;
(b) to unlearn their own misconceptions;
(c) to assist their pupils to unlearn misconceptions;
(c) to help their pupils learn the 'right concepts'.

Johnstone et al (1977: 170) observes:

> '... be aware of the kinds of assumptions which pupils are likely to make in a given teaching situation and actively dispel these as they arise. This might seem to require in the teacher a sixth sense in reading the minds of pupils, but it is not perhaps too difficult given an awareness on the part of the teacher of the kinds of assumptions which his pupils are liable to make.'

If science education for Africans is to succeed, their **cultural backgrounds** need to be considered (Gilbert and Watts, 1983: 66-67; Wittrock, 1985: 262-263; Osborne and Wittrock, 1985: 78-79).

Conceptions which one tribal/language group hold may be absent in other groups. Hewson (1984: 245) notes:

> 'There is no information available regarding the presence of caloric conceptions in non-Westerners. It is, however, well documented that there is a prevalent metaphor involving heat amongst many African people and, in particular, the Sotho people of Southern Africa. This metaphor or cultural belief is a dominant aspect of the intellectual environment of Sotho people, but is almost entirely absent from the intellectual environment of Westerners.'

The upbringing in some traditional cultures can be advantageous to the science teacher. Hewson (1984) notes:

> '... most Sotho students do not have to unlearn outdated scientific notions of caloric heat, which are deeply rooted in western thinking, before being able to acquire the contemporary kinetic view of heat. This is because features of their particular existing knowledge may be more easily reconciled with modern, formal scientific theories in specific subject areas.'

In contrast, Solomon (1987: 65) cites a paper by Hewson, P (1981) which argued that 'taught scientific ideas (can be) defeated by the children's own notions.' In other words there can be a conflict between the expectations based on the traditional culture and those based on the science culture. Pupils tend to reject science concepts that do not synchronise with their cultural expectations. This may be overcome by referring to pupils' everyday experiences, discussing the views from traditional culture and comparing it with the science culture. Urebvu (1984: 221-222) cites several studies concerned with African culture and science education.

(a) the greatest problem is how to bring African traditional thought into school science (Horton, 1971);

(b) 85% of African children grow up in a rural environment. This rural environment has impact on science learning (Coombs and Ahmed, 1974) ;

(c) pupils from a traditionally non-western society come to school aware of beliefs and explanations of the external world which are at variance with those that they meet in science. Not only do underlying assumptions differ but so do values and attitudes towards the world (Stone, 1965);

(d) the teaching of science should not be divorced from what the pupil already believes. It is important to ensure that the child's beliefs and natural knowledge are respected (Odhiambo, 1972);

(e) it is improper to use science to subvert the African thought system (Biesheuvel, 1972).

It is possible that when teachers try to teach science without direct references to and discussion of pupils everyday experiences and traditional culture there can develop not only a prejudice to science but also misunderstandings of science concepts. As soon as the pupils go out of the class room the social and semantic meanings become prominent. This could lead to either the pupils becoming confused or rejecting the scientific interpretation. Solomon (1987: 79) contends:

> '... social influences are pervasive and strong, ... they spring from a familiar uneradicable style of knowing which can discourage access to the realm of scientific thinking. But the problem cannot be avoided. Our pupils are strongly social beings for whom the teaching of a rigidly insulated science which makes no contact with the everyday context is simply not an option. Social influences of every kind permeate both the learning of science and its application.'

The broad view taken in this study is that concepts were assimilated by being positioned into cognitive networks. These networks existed prior to the teaching of new concepts and must therefore be illuminated:

> 'What our studies and the studies of others ...seem ... to be saying is that instructional efforts only directed at teaching the 'right' concepts will not be sufficient to modify in a positive way the conceptual framework of most students.' (Novak, 1988: 78).

Not only the pupils' previous knowledge but also the way and conditions under which it is taught influence concept acquisition. To insure the likelihood of meaningful concept attainment, it must be presented and used in different contexts. Concepts acquired earlier must be used to develop new concepts that come later. Concepts are most easily acquired when familiar and concrete perceptual materials are used **but** Johnstone et al (1977: 170) and Gussarsky and Gorodetsky (1990: 203) sound a warning against assimilation of scientific concepts into everyday common concepts neglecting the scientific meanings.

To enhance the understanding of the concept, it must be taught many times at different levels of abstraction with explicit references to related concepts. The test of learning is the extent to which pupils are able to use the same concept correctly and intercon-nectedly in a variety of contexts. The use of concept maps provide ample opportunity for such an approach. A concept map representing the key concepts in chemical equilibrium developed by Long (1988: 19) given in Appendix D may serve as an example.

Pupils' cultural backgrounds not only affect the understanding/misunderstanding of concepts and the process of science learning but also the social behaviour of pupils in the class room. It is uncommon in the Transkeian culture that younger members question adults or become critical of what adults say. In the class room also the pupils do not tend to therefore ask questions even when discrepancies between what the teacher says and what they already know cause 'inequilibrium'. Teachers must acknowledge that their description of a concept is initially only one of the alternatives for the pupils and learn to tolerate uncertainty in the pupils' minds while they compare and evaluate the teacher's description with their existing frameworks. Solomon (1987: 65) notes, '... the pupil (is) like a scientist moving between paradigms or research programmes'. Only by constantly encouraging pupils to ask questions and freely express personal views can the teacher assist his pupils to get rid of their misconceptions.

The author acknowledges that the Transkeian class rooms are overcrowded and this puts a heavy burden on those teachers who intend to expose pupil misconceptions. But in spite of this the teacher must be efficient and effective in the sense suggested by Cowan, J (1985) quoted by Bradley (1990 b: 24), 'Effectiveness means doing the right things; efficiency means doing things right.'

The author does not intend to give any prescriptions to teachers because each teacher, pupil and class room is different. However it is hoped that the discussion will enlighten teachers on some of the problems in teaching and learning chemical equilibrium and the suggestions will assist the critical selection of effective methods of teaching and learning. Hodson (1985: 41) says:

> 'How to teach science is not a scientific question and neither science nor philosophy of science can give us infallible guidance on how to proceed. Scientific theory does not contain within it a means of teaching and learning science, nor does scientific method represent a significant means of acquiring scientific knowledge.'

4.2.2. FOR FURTHER RESEARCH

While the main concern of educators has been why learners do not learn the way they are expected to, that of pupils, parents and societies has been the high failure rates of pupils and the accountability of teachers. The latter sometimes develop into socially explosive situations such as the one at Butterworth College of Education in 1989 (where the author was then a lecturer) when teacher trainees physically expelled four lecturers from the college. The students and some parents attempted to justify the action with the argument that physical eviction was the most effective way to protest against ineffective teaching that resulted in high failure rates in the subjects the concerned lecturers taught.

Few pupils and parents recognise that concepts themselves have an elusive quality in that they cannot be taught in the same way as facts can be. The teacher can only supply the necessary examples of a concept and create the external conditions conducive to meaningful concept attainment. The actual process of abstraction and generalisation comes almost entirely from within the learner and often without the learners' own awareness that it is taking place. Thus the best the teachers can do is to present the necessary examples in an ordered pattern with the necessary interconnections to facilitate acquisition of the correct meaning of the concept. However if teachers can understand the pattern of thinking the pupils make, it becomes easier for them to prevent the tendency of pupils to take wrong pathways of thinking.

One must look more closely at the response of each individual and groups of individuals on different questions based on the same or related concepts/principles and attempt to discover the paths of wrong thinking. It is possible that one bead in the string is followed by another. Videotaped interviews would be more useful for this purpose than audiotaped ones as facial expressions and gestures can also be made available to draw reliable conclusions.

It is the author's conviction that further research should focus on a 'second order analysis' in two parts:

(a) individual second order analysis:

This involves looking more closely at the same pupil's answers for a variety of questions that deal with closely related concepts and attempt to identify patterns in the choice of wrong answers;

(b) group second order analysis:
This involves grouping pupils who choose similar wrong answers for related concepts and attempt to verify or reject the conclusions from (a) above.

Conclusions that may be drawn from such comprehensive studies can arm teachers with effective and efficient strategies to deal with the paths of pupils' wrong thinking. Such an approach would not only promote pupils learning in the way they are expected to but also reduce the failure rate which in its turn enhance teachers' job satisfaction and accountability. Garnett and Tobin (1988: 10-11) observe that two forms of knowledge; "content" (topic/ subject) knowledge and "pedagogical" (content in a form that can be learned) knowledge are important in teaching and learning contexts. Knowledge of paths of pupils' wrong thinking will enrich teachers' pedagogical knowledge which Garnett and Tobin identify as an important 'rate determining step in the equation for effective chemistry teaching.'

With more pupil power (in Xhosa: **amandla**) and say in decision making on aspects that affect the teaching-learning context (in the Transkei in particular and South Africa in general), this type of research could become increasingly important in combatting high failure rates in the physical sciences. Pupils too must become aware that there is more to education than simply pupils learning what teachers teach. There are factors which intervene in the educational process which are not necessarily of the teachers' making. Conversely teachers, if made aware of their own misconceptions and alerted to the possible errors in their pupils' thinking, will be more effective. Research such as this can illuminate more than merely the problems in the teaching and learning of chemical equilibrium.

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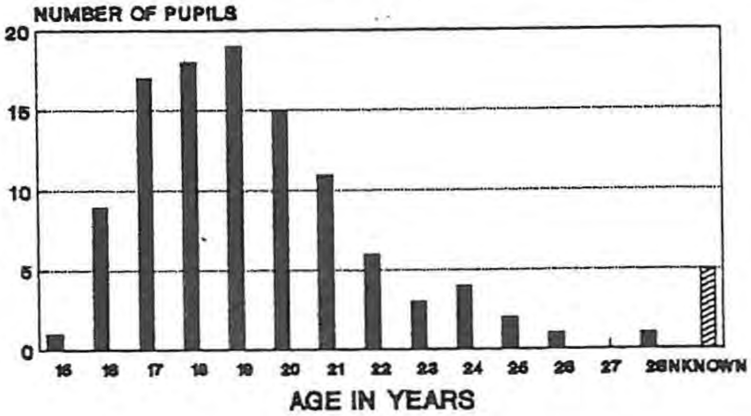
APPENDIX A

FIGURES A: 1.1 - 1.5

AGE DISTRIBUTION

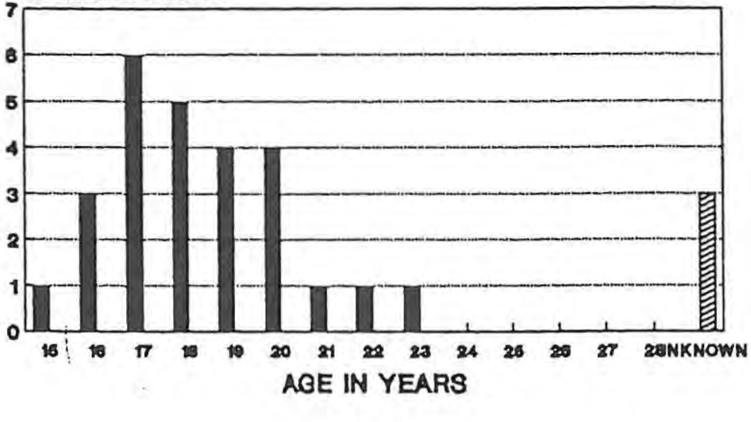
1.1 TOTAL SAMPLE

AVERAGE AGE=19.3 YRS
N=112(5 AGES UNKNOWN)

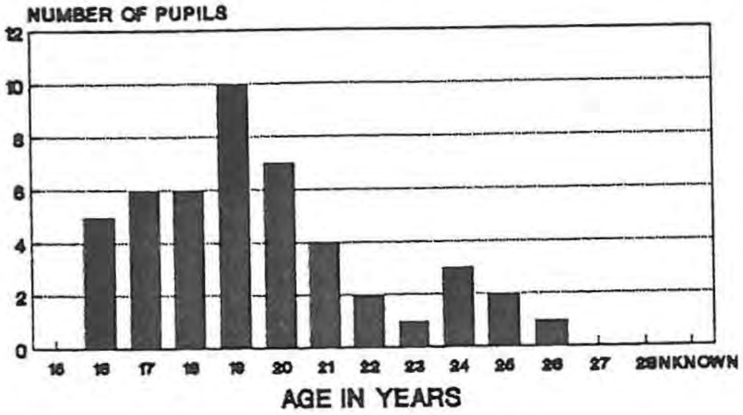


1.2 SCHOOL A

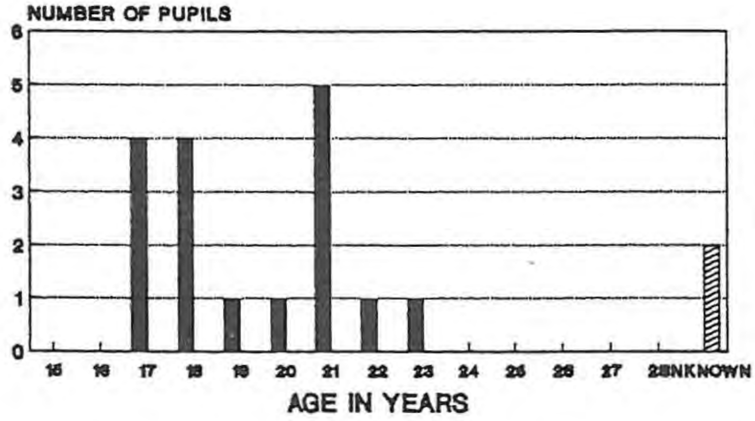
AVERAGE AGE=18.4 YRS
N=29(3 AGES UNKNOWN)



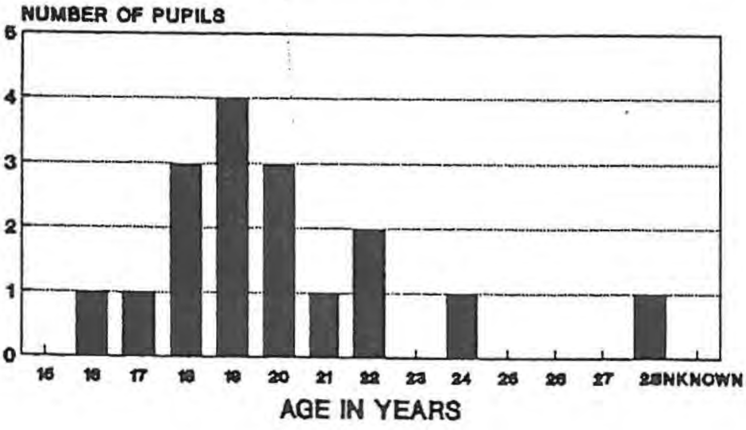
1.3 SCHOOL B
AVERAGE AGE=19.6 YRS
N=47



1.4 SCHOOL C
AVERAGE AGE=19.4 YRS
N=19(2 AGES UNKNOWN)



1.5 SCHOOL D
AVERAGE AGE=20.0 YRS
N = 17

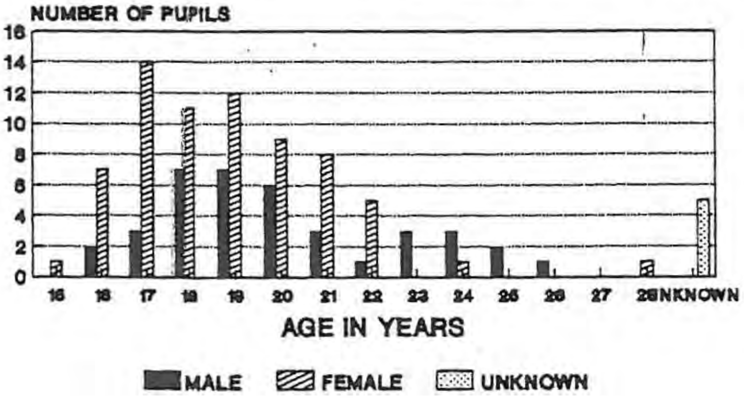


FIGURES A: 2.1 - 2.5

AGE-GENDER DISTRIBUTION

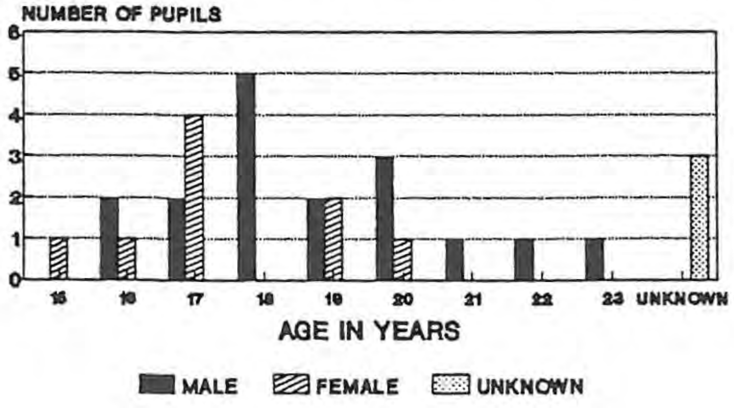
2.1 TOTAL SAMPLE

N=112 AVERAGE AGES:
MALE:20.1 YRS; FEMALE:18.9 YRS



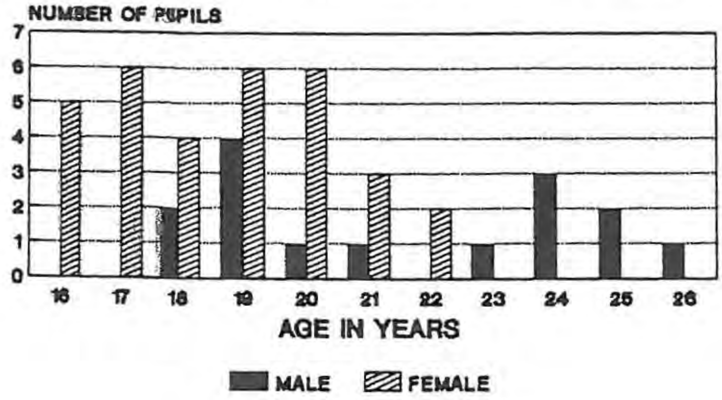
2.2 SCHOOL A

N=29 AVERAGE AGES:
MALE:18.8 YRS; FEMALE:17.4 YRS



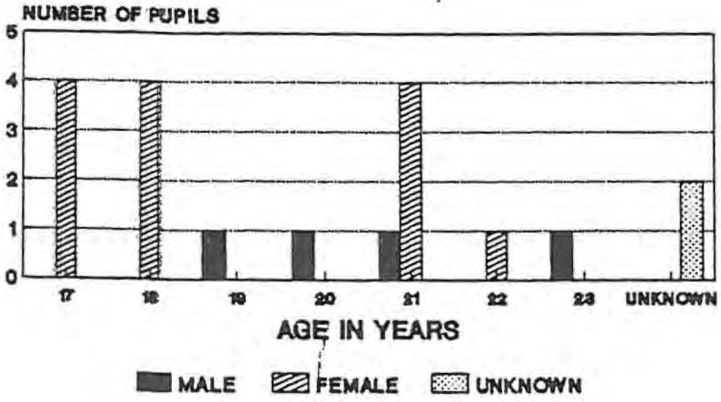
2.3 SCHOOL B

N=47 AVERAGE AGES:
MALE:21.6 YRS; FEMALE:18.6 YRS



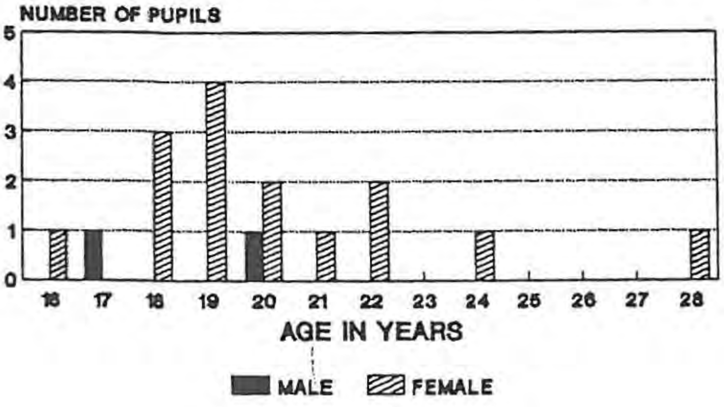
2.4 SCHOOL C

N=19 AVERAGE AGES:
MALE:20.8 YRS; FEMALE:18.9 YRS



2.5 SCHOOL D

N=17 AVERAGE AGES:
MALE:18.5 YRS; FEMALE: 20.2 YRS

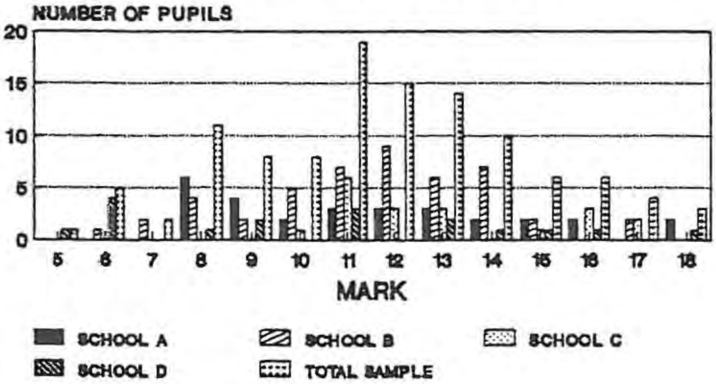


FIGURES A: 3.1 - 3.6

MARK DISTRIBUTION

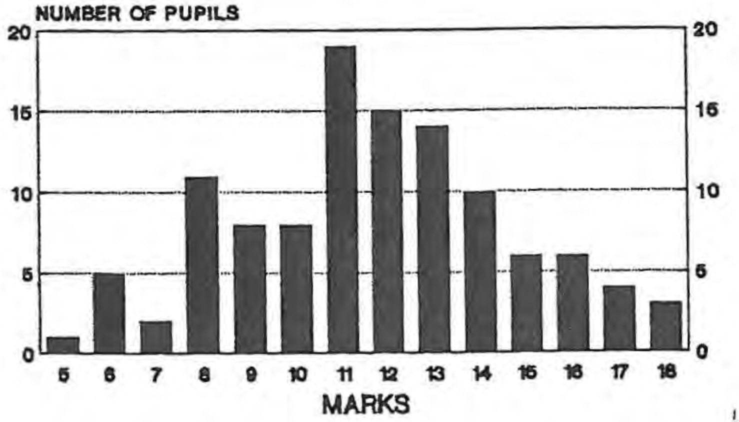
3.1 BY SCHOOL

AVERAGE MARK: SCHOOL
A=11.7;B=11.6;C=13.1;D=10.4;TOTAL=11.7



3.2 TOTAL SAMPLE

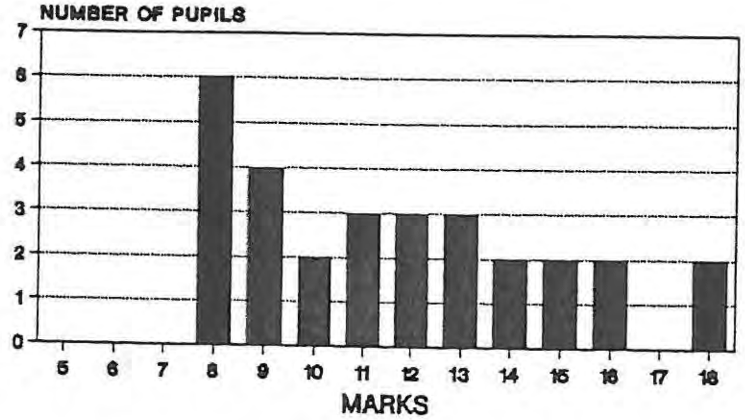
AV.MARK:11.7; AV.%:29.2
N=112



3.3 SCHOOL A

AV.MARK: 11.7; AV.% 29.2

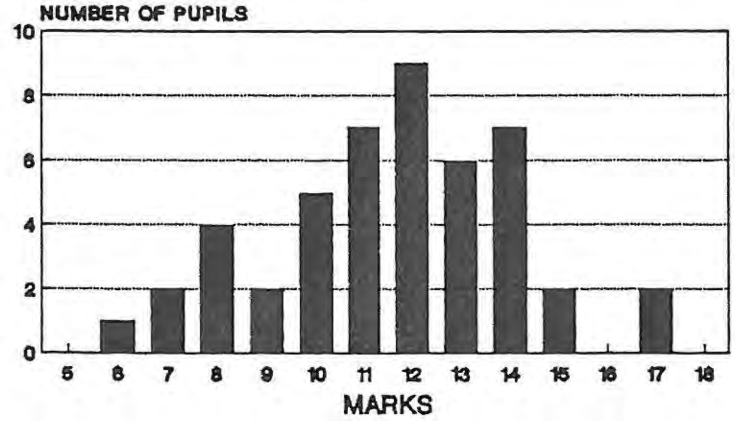
N=29



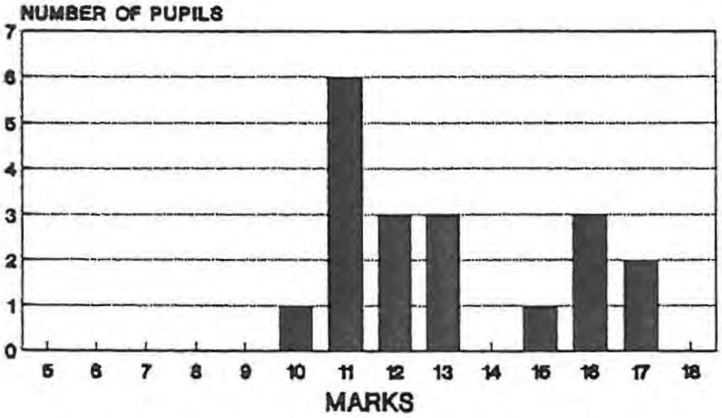
3.4 SCHOOL B

AV. MARK:11.6: AV.%: 29.0

N=47



3.5 SCHOOL C
AV.MARK:13.1; AV.%:32.6
N=19



3.6 SCHOOL D
AV.MARK:10.4; AV.%:26.0
N=17

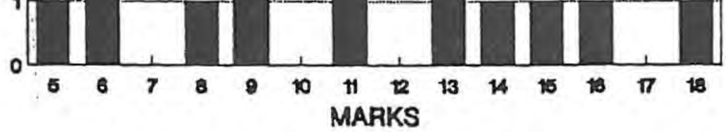
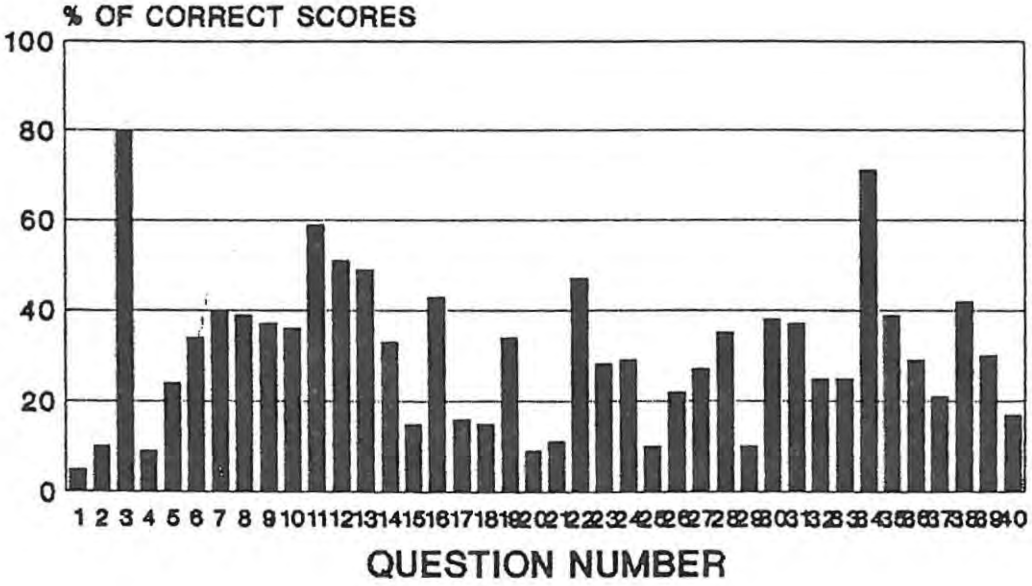


FIGURE A: 4

% OF CORRECT SCORES
PER QUESTION: QUESTIONS 1 - 40
TOTAL SAMPLE: N = 112



APPENDIX. B

CHEMICAL EQUILIBRIUM QUESTIONNAIRE

AIM

The aim of this questionnaire is to evaluate your knowledge of chemical equilibrium and related concepts. Your answers will provide valuable information and will help the understanding of the problems of teaching and learning chemical equilibrium.

THIS IS NOT A TEST OR EXAMINATION. YOUR ANSWERS WILL ONLY BE USED FOR RESEARCH PURPOSES.

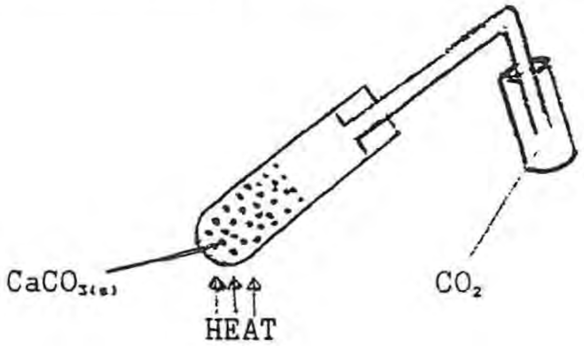
DIRECTIONS.

Write your **name, gender, age and the name of your school** at the top of the answer sheet. You have **three hours** to complete the questions although it is unlikely that you will need that much time.

The questionnaire consists of **40** multiple choice questions. These questions must be answered on the special answer sheet provided. Read each question carefully and place a **cross (X)** on the letter A, B, C or D corresponding to the BEST answer for that question.

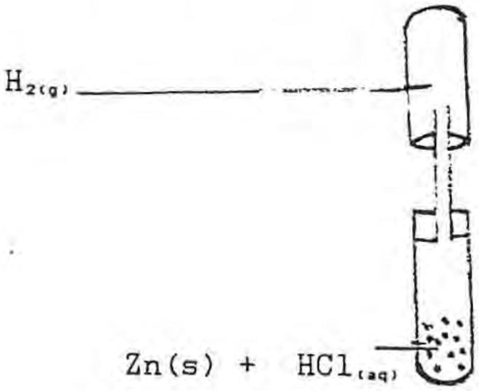
THIS QUESTIONNAIRE CONSISTS OF 20 PRINTED PAGES INCLUDING THIS COVER PAGE.

To answer questions 1 and 2, study the following four figures and the foot notes that accompany them.



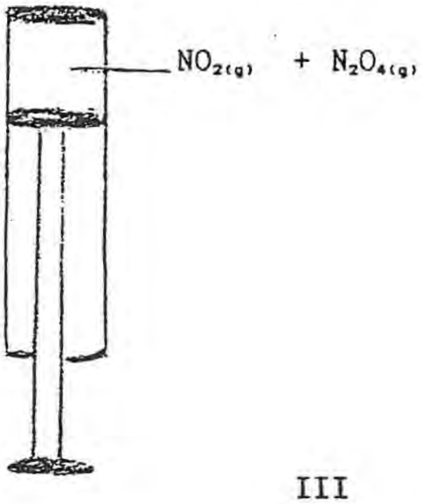
I

On heating solid sodium carbonate, $CaCO_{3(s)}$, produces solid calcium oxide, $CaO_{(s)}$ and Carbon dioxide, $CO_{2(g)}$.



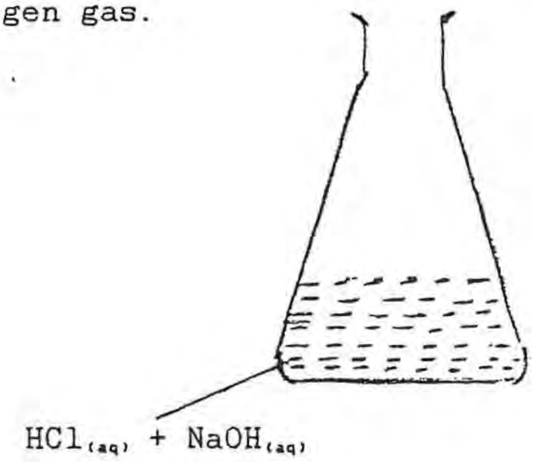
II

Zinc metal reacts with dilute hydrochloric acid to produce aqueous zinc chloride and hydrogen gas.



III

A reaction takes place in a sealed gas syringe between Nitrogen dioxide gas, $NO_{2(g)}$ and dinitrogen tetroxide gas, $N_2O_{4(g)}$.



IV

A neutralisation reaction takes place in an uncorked conical flask between dilute hydrochloric acid and aqueous sodium hydroxide to produce aqueous sodium chloride (salt), and water.

1. Which of the above four figures can be called "closed" systems?

A. I and II.
B. I, II and III.
C. III only.
D. III and IV.

2. In which system(s) is/are reversible reaction(s) occurring?.

A. I and II.
B. I,II and III.
C. III only.
D. III and IV.

3. Which of the following representations of a reversible reaction is/are acceptable?

I. $P + Q \rightrightarrows R.$

II. $P + Q \mathrel{\substack{\longrightarrow \\ \leftharpoondown}} R.$

III. $P + Q \mathrel{\substack{\rightharpoonup \\ \longleftharpoondown}} R.$

IV. $P + Q \longleftarrow R.$

A. I only.
B. I, II, and III.
C. II and III.
D. IV only.

4. Which of the following statement(s) is/are correct?

I. A saturated solution is a solution in which the solvent contains as much solute as it can dissolve at a particular temperature.

II. A saturated solution is a solution in which the undissolved solute is in equilibrium with the dissolved solute.

III. In a saturated solution, solid solute dissolves at the same rate as the dissolved solute precipitates.

IV. A saturated solution is a clear solution with no undissolved solute.

A. I only.
B. I, II and III only.
C. I and IV only.
D. II and III only.

5. Which of the following statement(s) describe(s) a dynamic chemical equilibrium?

I. A closed system and reversible reaction.

II. The rate at which reactants are used up equals the rate at which products are formed.

III. Concentration of reactant(s) equals the concentration of product(s).

IV. Rate of forward reaction equals the rate of reverse reaction.

V. Forward reation equals reverse reaction.

A. I, II and III only.
B. I, II and IV only.
C. I, II, III, IV and V.
D. III and V only.

6. $N_{2(g)} + 3\ H_{2(g)} \rightleftharpoons 2\ NH_{3(g)}$

At equilibrium, which of the following statements is FALSE?

A. Ammonia decomposes continuously.
B. Mass of all reactants and products remain constant.
C. Pressure changes will change the concentration of all reactants and products in the reaction vessel.
D. Reaction between N_2 and H_2 stops.

7. Which statement(s) is/are correct?

ALL dynamic chemical equilibria are influenced by:

I. Pressure or volume changes.
II Temperature and pressure changes.
III. Concentration and pressure changes.
IV. Concentration and temperature changes.

A. I only.
B. I, II and III.
C. I, II, III and IV.
D. IV only.

8. If a compound AB is at a higher energy than the sum of the energies of the reactants A and B, then the reaction

$A + B \longrightarrow AB$ is:

A. Endothermic.
B. Exothermic.
C. Spontaneous.
D. Redox.

9. Four equations are given below:

I. $P + Q \longrightarrow R$; $\Delta H < 0$
II. $P + Q \longrightarrow R$ + heat.
III. $P + Q \longrightarrow R$; $\Delta H > 0$
IV. $P + Q$ + heat $\longrightarrow R$.

Which of these equations represent an EXOTHERMIC reaction?

A. I and II.
B. I and IV.
C. II and III.
D. III and IV.

10. Consider the equation:
$P + Q$ + heat $\longrightarrow R$.
This equation can be re-written to represent the direction of the exothermic reaction as follows:

A. $P + Q \longrightarrow R$; $\Delta H > 0$.
B. $R \longrightarrow P + Q$; $\Delta H > 0$.
C. $R \longrightarrow P + Q$; $\Delta H < 0$.
D. $P + Q \longrightarrow R$ + heat.

11. Heat of reaction, (ΔH) can be equated with:

A. $\text{Energy}_{(\text{products})} - \text{Energy}_{(\text{reactants})}$.
B. $\text{Energy}_{(\text{exothermic})} - \text{Energy}_{(\text{endothermic})}$.
C. $\text{Energy}_{(\text{endothermic})} - \text{Energy}_{(\text{exothermic})}$.
D. $\text{Energy}_{(\text{reactants})} - \text{Energy}_{(\text{products})}$.

12. The heat of reaction, ΔH is:

A. the net energy liberated or absorbed during a reaction.
B. the energy liberated when bonds are formed during a reaction.
C. the energy supplied to the reaction mixture to keep the reaction going.
D. the energy required to break bonds during a reaction.

13. When one mole of hydrogen gas reacts with one mole of fluorine gas, two moles of hydrogen fluoride gas, 2 HF are produced. During this reaction, 536 kJ of heat are lost from the system.

Which of the following statements is/ are TRUE?

I. $H_{2(g)} + F_{2(g)} \longrightarrow 2\ HF_{(g)}$; $\Delta H = +\ 268$ kJ/mol.
II. $H_{2(g)} + F_{2(g)} \longrightarrow 2\ HF_{(g)}$; $\Delta H = +\ 536$ kJ.
III. $H_{2(g)} + F_{2(g)} \longrightarrow 2\ HF_{(g)}$; $\Delta H = -\ 536$ kJ.
IV. $H_{2(g)} + F_{2(g)} \longrightarrow 2\ HF_{(g)}$; $\Delta H = -\ 268$ kJ/mol.

A. I and II.
B. I and III.
C. II and IV.
D. III and IV.

14. When one mole of solid carbon reacts with one mole of oxygen gas, one mole of carbon dioxide gas are produced. During this reaction, 393.5 kJ of heat are lost from the system.

Which of the following statement(s) is/are true?

I. $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$; $\Delta H = +393.5$ kJ/mol
II. $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$; $\Delta H = +393.5$ kJ
III. $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$; $\Delta H = -393.5$ kJ
IV. $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$; $\Delta H = -393.5$ kJ/mol

A. I only.
B. I, II, III and IV.
C. III only.
D. III and IV.

15. $P + Q \overset{\longleftarrow}{\xrightarrow{\hspace{3em}}} R$ at 25°C can be interpreted as meaning that when equilibrium is reached at 25°C

A. the concentration of P and Q equals the concentration of R.
B. there is a greater concentration of R than P and Q.
C. P and Q are more ionised than R.
D. P and Q react faster than R.

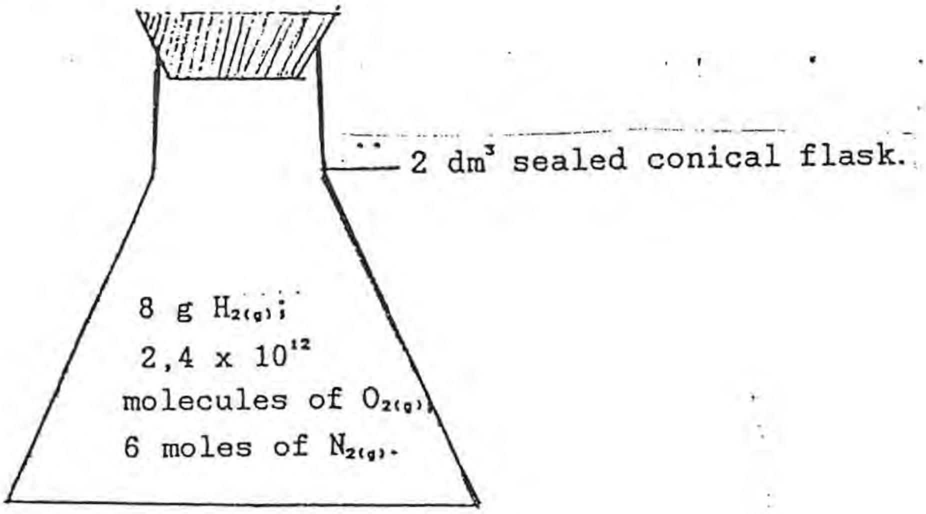
16. For the reaction $P + Q \underset{\longleftarrow}{\xrightarrow{\hspace{3em}}} R$, the equilibrium constant

$$K_c = \frac{[\text{PRODUCTS}]}{[\text{REACTANTS}]}$$

The magnitude of the equilibrium constant K_c would most probably be approximately:

A. 0.
B. 10.
C. 10^{-14}.
D. 1.

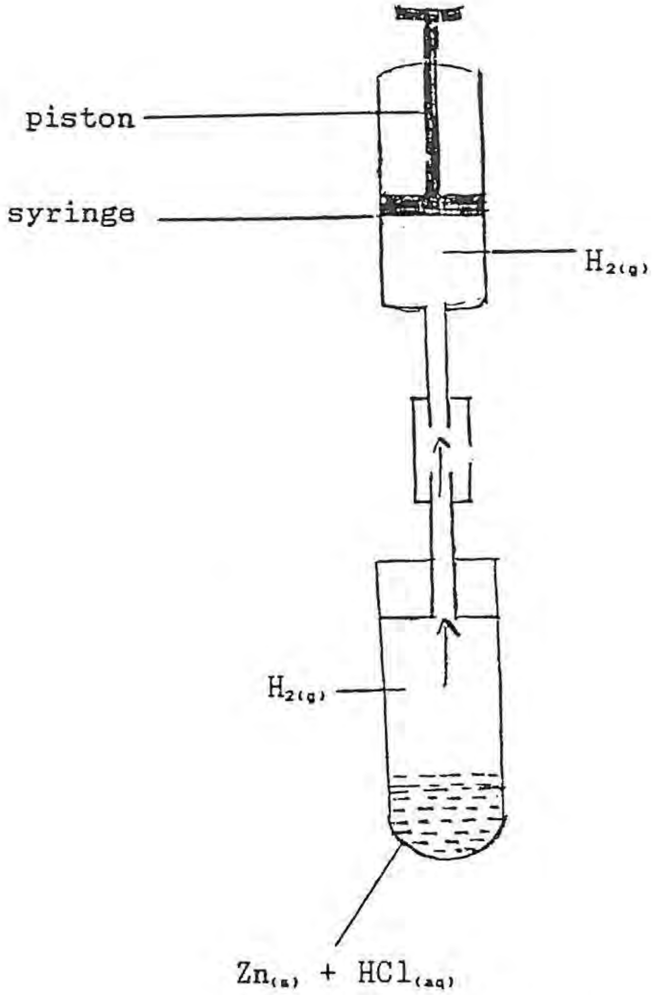
17.



The concentration of hydrogen gas, oxygen gas and nitrogen gas are most correctly given by:

	Hydrogen gas	Oxygen gas	Nitrogen gas.
A.	8 g / 2 dm^3.	2.4×10^{2} mol / 2 dm^3	3 mol / 2dm^3
B.	4 mol / 2 dm^3	4×10^{-12} mol / 2 dm^3	6 mol /2dm^3
C.	2 mol / dm^3	2×10^{-12} mol / dm^3	3 mol / dm^3
D.	8 mol / dm^3	4×10^{-12} mol / dm^3	6 mol / dm^3

18.



The hydrogen generated is collected in the syringe as sho in the above figure. As the hydrogen gas enters the syring its piston is progressively pushed out. Which of the followi factors will NOT increase the rate at which the piston is pushed out?

A. An increase in the concentration of the hydrochloric acid.

B. Replacing the zinc pellets in the test tube with the same quantity of zinc powder.

C. Addition of more zinc pellets.

D. No suitable choice is given.

19. To investigate the "common ion effect", two students each prepare a saturated solution of sodium chloride. They then filter their solutions. Student A adds concentrated hydrochloric acid to his portion while student B adds dilute hydrochloric acid to his. Salt crystals precipitate out in portion A while portion B exhibits no visible change.

Consider the following statements:

I. Both students, A and B increased the amount of Cl^- ions in their respective portions of the saturated solutions.

II. Student A increased the concentration of Cl^- ion while student B decreased the concentration of Cl^- in their respective portions of saturated solutions.

III. Student A and student B increased the concentration of Cl^- ions in their respective portions of saturated solutions. But it was because student B was slower than student A in adding the acid, there was no visible change in portion B.

IV. In both portions, precipitation of NaCl should have taken place.

Which of the above statements are CORRECT?

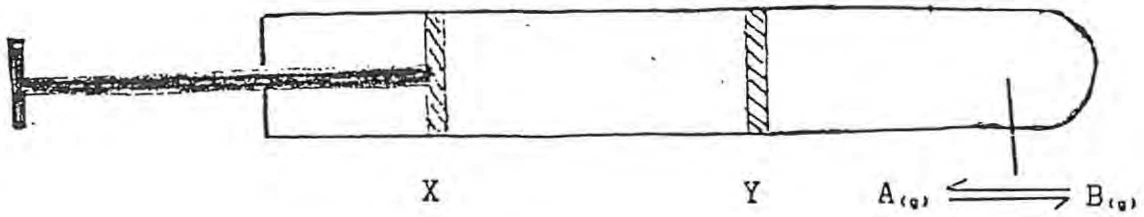
A. I and II.
B. I, III and IV.
C. II, III and IV.
D. III and IV.

20. $2\,R_{(g)} \rightleftharpoons P_{(g)} + Q_{(g)}$

1 mol of R is heated in a 2 dm³ container to 600°C. At equilibrium it was found that 50 % of $R_{(g)}$ remain un-reacted. The concentration of $P_{(g)}$ and $Q_{(g)}$ present in the mixture are:

A. P : 0,125 mol / dm³; Q : 0,125 mol / dm³.
B. P : 0,5 mol / dm³; Q : 0,5 mol / dm³.
C. P : 0,25 mol / dm³; Q : 0,25 mol / dm³.
D. P : 0,125 mol; Q : 0,125 mol.

21.



A chemical equilibrium exists between gases A and B in a sealed syringe and the piston is at position X. The piston of the syringe is then pushed in so that it goes to position Y. Which of the following statement(s) is/are CORRECT when equilibrium is re-established at constant temperature?

A. Concentration of $A_{(g)}$ increases and $B_{(g)}$ decreases.

B. Concentration of $A_{(g)}$ and $B_{(g)}$ remain constant because the number on moles on either side of the arrow is the same.

C. Concentration of $A_{(g)}$ and $B_{(g)}$ increases.

D. Concentration of $A_{(g)}$ decreases and $B_{(g)}$ increases.

Read the description below carefully to answer questions 22, 23 and 24.

P and Q react in a closed container to produce R at laboratory temperature. The reaction is started by enclosing 1 mol of $P_{(g)}$ and 1 mol of $Q_{(g)}$. Equilibrium is reached after 5s. The equation for the reaction is:

$$P_{(g)} + Q_{(g)} \rightleftharpoons R_{(g)}$$

22. Which of the following statements are correct at the time of mixing $P_{(g)}$ and $Q_{(g)}$ i.e. when t = 0?

A. $[P] > [Q]$

B. $[P] = [Q] > [R]$

C. $[P] = [Q] < [R]$

D. $[P] < [Q]$

23. As the time lapses from 0s to 5s, the change in the concentration of the reactants and products can best be described as:

A. The concentration of the reactants P and Q increase.
B. The concentration of the product R decreases.
C. The concentration of reactants decrease and the concentration of product increases.
D. The concentration of both the reactants and the product increases.

24. Consider the following statements :

I. [P] and [Q] high and [R] = 0 when t = 0.

II. [P] = [Q] = [R] always at equilibrium.

III. [P] = [Q] but always not equal to [R] at equilibrium.

IV. To hold [P], [Q], and [R] constant at equilibrium, only temperature needs to be held constant.
Which of the above statement(s) is/ are CORRECT?.

A. I and III.
B. I, II, III and IV.
C. I, III and IV.
D. I and IV.

<u>Consider the following closed system and the explanations given to answer Questions 25 and 26.</u>

$$P_{(g)} + Q_{(g)} \rightleftharpoons R_{(g)}$$

The average rate of a reaction can be represented by $\bar{v}$. The average rate of forward reaction can be represented by $\vec{v}$ and the average rate of reverse reaction by $\overleftarrow{v}$.

25. Which of the following equations can be used to calculate the average rate $(\overrightarrow{v})$ for the forward reaction?.

I. $\overrightarrow{v}$ = Number of moles of P used up / Reaction time (seconds).

II. $\overrightarrow{v}$ = Number of moles of Q used up / Reaction time (seconds).

III. $\overrightarrow{v}$ = Number of moles of R produced / Reaction time (seconds).

IV. $\overrightarrow{v}$ = Amount of P or Q used up / Reaction time (seconds).

A. I, II and III.
B. I and III.
C. I, II, III and IV.
D. IV.

26. The rate of the forward and reverse reactions progressively change as time `t´ lapses from the start of the reaction as follows:

I. $\overrightarrow{v} > \overleftarrow{v}$ when $t = 0$.

II. $\overrightarrow{v}$ is highest when `t´ just begin to lapse and when $\overleftarrow{v} = 0$.

III. $\overrightarrow{v}$ decreases progressively and $\overleftarrow{v}$ increases progressively until equilibrium is attained.

IV. $\overrightarrow{v}$ increases progressively until equilibrium is attained.

The CORRECT statement(s) is/are:

A. I.
B. I, II and III.
C. I, II, III and IV.
D. IV.

27. The rate of forward reaction **in the case** of ALL reversible reactions can be increased by:

I. Adding a suitable catalyst.
II. Increasing the concentration of the reactant(s).
III. Adding more reactants.
IV. Heating.

The CORRECT statements are:

A. I.
B. I, II, III and IV.
C. II.
D. II and III.

28. $2\ NO_{2(g)} \rightleftharpoons N_2O_4(g)$

reddish brown (favoured at laboratory temperature).	colourless (favoured at low temperature).

The above system is in equilibrium. When the test tube is immersed in ice water, the reddish brown colour disappears.

A pupil explains this observation as follows:

I. The reverse reaction does not cease.
II. The forward reaction is faster than the reverse reaction.
III. At the temperature of ice-cold water, no reaction can take place.

Which of the statement(s) is/are FALSE?.

A. I.
B. I, II and III.
C. II.
D. III.

Consider the following reaction for questions 29 to 31.

$P_{(g)} + Q_{(g)} \rightleftharpoons R_{(g)}$.

In this reaction, heat is released from the system to the surroundings.

The rate of the forward reaction $\overrightarrow{v} = k_1 [P][Q]$.

The rate of the reverse reaction $\overleftarrow{v} = k_2 [R]$.

k_1 and k_2 represents rate constants.

$K_c = k_1 / k_2 = [R] / [P][Q]$.

29. If the system is heated:

A. k_1 and k_2 will remain equal.
B. k_1 and k_2 will remain constant.
C. k_1 will increase and k_2 will decrease.
D. k_1 will decrease and k_2 will increase.

30. Which of the following affects the equilibrium constant in the above reversible reaction?

I. Addition of a catalyst.
II. Change in concentration of the reactant.
III. Change in total pressure.
IV. Change in temperature.

A. I only.
B. I, II and III.
C. I, II, III and IV.
D. IV only.

31. Addition of Q(g) will

A. Reduce [P] and the value of K_c.

B. Reduce [P] but the value of K_c will remain unchanged.

C. Increase [P] as well as the value of K_c.

D. Reduce [P] but increase the value of K_c.

32. When the reaction $2\,NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$ reached equilibrium, the concentration of NO_2 was found to be 0,5 mol/dm^3. If the equilibrium constant is 8, the equilibrium concentration of $N_2O_{4\,(g)}$ will then in mol / dm^3 be:

A. 8 x 0,5.

B. 0,5 / 8.

C. $(0,5)^2$ x 8.

D. $(0,5)^2$ / 8.

33. For the reaction $P_{(s)} + Q_{(g)} \rightleftharpoons R_{(l)} + S_{(g)}$, the equilibrium constant can be simply written as:

A. K_c = [R] x [S] / [P] x [Q].

B. K_c = [S] / [P] x [Q].

C. K_c = [S] / [Q].

D. K_c = [R] x [S] / [Q].

Consider the following equilibrium equation for questions 34 and 35.

$$P_{(g)} + Q_{(g)} \rightleftharpoons R_{(g)} + \text{heat.}$$

34. Removal of R(g) would:

I. Decrease [P] and [Q].

II. Decrease [P] but increase [Q].

III. Increase [P] but decrease [Q].

IV. Decrease the yield of R in the reaction.

The correct statement(s) is/are:

A. I only.
B. I and II.
C. I, II and III.
D. I, II, III and IV.

35. If the pressure on the system is increased:

I. More $R_{(g)}$ would be produced.
II. The reverse reaction would be accelerated.
III. Temperature of the mixture would decrease.
IV. More $P_{(g)}$ and $Q_{(g)}$ would be produced.

The CORRECT statement(s) is/are :

A. I only.
B. I, II, III and IV.
C. II only.
D. III only.

36. Consider the following statements about a positive catalyst (i.e. a catalyst that increases the rate of a reaction.):

A positive catalyst:

I. Does not affect the equilibrium position or heat of reaction, ΔH, in a reversible reaction but simply enables the system to reach the state of equilibrium faster.

II. Affects both the rate of forward and reverse reactions equally in a closed system.

III. Has no effect on the value of the equilibrium constant K_c

IV. Lowers the activation energy of a given reaction and so th rate of exothermic reaction would decrease.

Which of the above statement(s) is/are FALSE?.

A. I, II, III and IV.
B. I, II and III.
C. II.
D. IV.

37. Iron oxide or aluminium oxide is used as a catalyst in t Haber Process employed for the industrial manufacture of ammonia.

$N_{2(g)} + 3\ H_{2(g)} \rightleftharpoons 2\ NH_{3(g)}$; $\Delta H < 0$.

Which of the following statement(s) is/are FALSE?.

I. Catalysts have no effect on the reverse rate.

II. Catalysts increase the rate of the forward reaction and decrease the rate of the reverse reaction.

III. Catalysts help to produce a higher percentage of ammonia the equilibrium mixture.

IV. Catalysts can be used to drive the equilibrium in the forward direction.

A. I and II.
B. I, II, III and IV.
C. II and IV.
D. III and IV.

38. Consider the equilibrium $2\ NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$. $H = < 0$

reddish brown colourless or light brown.

Mr. X asks the following question:
If a shift in the equilibrium to the right is indicated by a lightening of the gas colour and a shift to the left is indicated by a darkening of the gas colour, what colour change will you observe if ONLY the $N_2O_{4(g)}$ is heated ?.
Which is the BEST response to Mr. X´s question?.

A. It is impossible to predict any colour change due to heating.
B. The colour will change to colourless or light brown.
C. There will be no colour change.
D. The question cannot be answered since it is impossible to heat only the $N_2O4(g)$.

39. Consider the equilibrium $2\ NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$.

$2\ NO_{2(g)}$	$N_2O_{4(g)}$
reddish brown.	colourless.
(favoured at room temperature).	(favoured at low temperature).

When the container enclosing the gases is lowered into ice-cold water, the reddish colour disappears and equilibrium is re-established.

Consider the following statements:

I. The equilibrium is characterised by observable and measurable properties.
II. Opposing processes (formation of $N_2O_{4(g)}$ and dissociation of $N_2O_{4(g)}$) continue at the same rate at particle level.
III. As long as the flask is in iced water, the concentration of $NO_{2(g)}$ and $N_2O_{4(g)}$ and the colour remain constant meaning that the reaction remain ceased.

Which of the statement(s) is/are FALSE?

A. I.
B. II.
C. III.
D. NONE.

40. $N_{2(g)} + 3\ H_{2(g)} \rightleftharpoons 2\ NH_{3(g)}$.

Consider the following statements regarding the above system in equilibrium:

I. When one mole of nitrogen gas reacts with three molecules of hydrogen gas, two molecules of ammonia gas are produced.

II. One mole of nitrogen molecules reacts with three moles of hydrogen molecules to produce two moles of ammonia gas.

III. The best way to confirm if the system has reached equilibrium is to test by experiment if there are two molecules of ammonia in the system.

Which of these statement(s) is/are CORRECT?

A. I.
B. II.
C. III.
D. ALL.

APPENDIX. C

SOME XHOSA WORDS RELATING TO CHEMICAL TERMINOLOGY

English		Xhosa
absorb	=	funxa
balance	=	uninzo/zinza
catayse	=	thelekisa
catalyst	=	umthelekisi
close	=	vala
closed system	=	evalekileyo
cold	=	banda/ebandayo
concentrate	=	qwalasela
concentration	=	ubungakanani
conservation	=	ulundolozo/ugcino/ukhuselo
conserve	=	londoloza/gcina/khusela
dynamic	=	enamandla
energy (power)	=	amandla
equilibrium	=	ulingano
greater	=	enkulu
hot (drunken)	=	shushu
in	=	phakathi
lesser	=	encinane
lump	=	iqhubu
open	=	vula
out	=	phandle
powder	=	umgubo
power (energy)	=	amandla
product	=	imveliso
release (unite)	=	khulula
reverse	=	tshintsha
reversible	=	etshintshekayo
saturated (full)	=	ndonele/ndonelesikile
shift	=	ukushenxisa
soluble	=	enyibilikayo
solution	=	umxube
temperature	=	iqondo lobushushu

APPENDIX. D

Long's (1988) concept map on chemical equilibrium

A CONCEPT MAP REPRESENTING THE KEY CONCEPTS IN CHEMICAL EQUILIBRIUM