IDENTIFYING STUDENTS' MISCONCEPTS AND LEARNING BARRIERS IN CHEMISTRY AND DESIGNING AND EVALUATING APPROPRIATE REMEDIAL MEASURES

Ph. D. Thesis

SAVITA LADAGE

Homi Bhabha Centre for Science Education
Tata Institute of Fundamental Research
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IDENTIFYING STUDENTS' MISCONCEPTS AND LEARNING BARRIERS IN CHEMISTRY AND DESIGNING AND EVALUATING APPROPRIATE REMEDIAL MEASURES

A Thesis Submitted to the
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Savita Ladage
Homi Bhabha Centre for Science Education
Tata Institute of Fundamental Research
BOMBAY

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CERTIFICATE

Certified that the work incorporated in the thesis "Identifying students' misconcepts and learning barriers in chemistry and designing and evaluating appropriate remedial measures" submitted by Mrs. Savita Ladage was carried out by the candidate under my supervision. Such material as has been obtained from other sources has been duly acknowledged in the thesis.

V.G. Kulkarni

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Supervisor

(V.G. Kulkarni)

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SYNOPSIS

Background :

The Homi Bhabha Centre for Science Education (HBCSE) at the Tata Institute of Fundamental Research (TIFR), Bombay, is conducting action research projects to identify various factors responsible for low scholastic achievements of students in science and mathematics, especially in rural areas and of first generation learners in general. These projects also make attempts to design and test remedial measures to overcome these factors. In the studies conducted so far, efforts were made at:

i) To develop operational objectives for use by science teachers in classrooms and to study the implementation and effectiveness of these in terms of pupil-teacher behaviour.

ii) To study factors hampering the performance of underprivileged students, that is, students coming from low socio-economic strata of society and to develop and test appropriate remedial measures to overcome these identified factors.

iii) To study socio-cultural factors responsible for career choices of socially deprived sections of society such as SC/ST students, with special emphasis on the females in this group.

The work described in this thesis is an attempt to study students' conceptual understanding of various fundamental concepts in chemistry. Attempts are also made to develop remedial measures for teaching some of these concepts and to test their effectiveness. The preliminary work in the thesis was done in the Dahanu project (1987-1990), conducted by HBCSE in collaboration with the Government of Maharashtra, for all the secondary schools of Dahanu Taluka in Thane district of Maharashtra. Later, a large part of the work was conducted in various schools of Bombay. Lastly, some work was also conducted in Solapur, where an extension of the Dahanu project was conducted for secondary schools (1990-1993).

The motivation for undertaking the work described in the thesis as well as the details of the thesis are presented below.

Motivation :

In Maharashtra, science and mathematics are compulsory subjects up to the secondary level, that is, up to class X. In today's world, which is dominated by science and technology this compulsory teaching of science and mathematics provides opportunities to all students, including the first generation learners to get exposed to basic scientific concepts and principles. Such an exposure is expected to create interest and curiosity among the students, and motivate them to study these subjects further. At the same time, it is expected to help the bulk of the students who drop out at class X to acquire adequate knowledge of science and mathematics to enable them to function in the modern world. To fulfil these purposes, efforts are being made to update and modernize the syllabi and to improve instructional methods. All these attempts inevitably need to be based on research and development in the fields of science/mathematics education.

Chemistry, as a distinct branch of science, is introduced to students, at class VIII and is taught up to class X on a compulsory basis. The chemistry which is taught in the schools today, has three basic facets (Johnstone, 1993) - i) macro (visible and tangible), ii) micro or sub-micro (atomic and molecular) and iii) representational (symbols, formulae and equations). For learning most of the fundamental concepts in chemistry, students have to deal with all these aspects simultaneously. Further, understanding of macro and representational aspects in terms of the sub-micro aspect is crucial in understanding of chemistry. This makes most of the fundamental concepts in chemistry abstract in nature, besides causing problems for students, who often perceive chemistry as a difficult subject (Ben-Zvi and others, 1988; Nakhleh, 1992).

This thesis attempts to study students' understanding of the facets mentioned above. In particular, it concentrates on concepts related to chemical symbols, formulae, equations and periodic table. Attempts have also been made at developing some remedial measures to assist teaching and learning of these concepts.

Such a study has a relevance to the task of improving the teaching learning process. It is now well established that students coming to formal schooling are not blank slates (Driver & Easley, 1978; Osborne and Gilbert, 1983; Pines and West,1986). All individuals, young and old, whether exposed to formal teaching or not, do have descriptive and explanatory frameworks for phenomena they see, which are compared with formal instruction obtained at school (Driver & Easley,1983). Several misconcepts arise out of a mismatch between these two. If teaching takes into account the misconcepts then it will help in better learning of the subject (Driver & Erickson, 1983).

Objectives of the thesis are:

1) To study students' concepts, misconcepts and learning barriers with reference to different chemical concepts related to chemical symbols, formulae, equations and the periodic table.

2) To develop remedial measures.

3) To evaluate the effectiveness of the remedial measures developed.

Organisation of Thesis :

The thesis is divided into six chapters. The first chapter, describes the background of the problem, the motivation and relevance of the work. The scope and limitations of the problem and details regarding the current chemistry curricula are also presented in this chapter.

Chapter two, presents a review of literature on the topic describing essentially the terminology used in this field and the different philosophical viewpoints for the same. Work done in different areas with special emphasis on chemical equations and periodic table is also described in the chapter.

The third chapter, describes the methodology used in the study. It gives an account of the data collection tools used, such as diagnostic tests and clinical interviews. Details regarding the experimental research design and the statistical tools used in analysis are given in the chapter. The chapter also describes the development of a model of the periodic table as a pedagogic aid.

Chapter four, describes the analysis of the work done on chemical formulae and equations. This includes the analysis of various diagnostic tests and clinical interviews conducted. Initially, it describes various concepts required for meaningful learning of chemical equations and their relations to each other. The analysis reveals:

1) That students harbour several misconcepts regarding the symbolic language of chemistry and about concepts related to it.

2) These misconcepts persist, even after two to three years of exposure to chemistry.

3) The misconcepts are not revealed through routine tests. Students who performed well on routine tests were found to exhibit several misconcepts.

4) The analysis of tests, on balancing equations and stoichiometric interpretations of the equations, indicated that misconcepts regarding the relevant chemical concepts, rather than a lack of understanding of required mathematical knowledge, is an important factor which hinders the meaningful learning of equations.

Chapter five, describes the analysis of the work done with respect to the periodic table, using it in a model form as a remedial measure. The analysis showed that

1) Students regard the periodic table as a complex body of information and the current class-room practices do not present it as a powerful tool for understanding chemistry.

2) Students (specially the average and low achievers in chemistry) have difficulties in understanding the interconnections between the properties and atomic structure and trends of these properties in the periodic table. Students also interpret words related to the periodic table (such as period, periodicity, periodic event) differently. The introduction of the topic of periodic table, in isolation, at class X (the topics of atomic structure, valency and chemical equations are introduced at class IX) is the probable cause for not understanding of the interconnections between the properties of substances and atomic structure. Moreover, the low weightage given to this topic results the superficial coverage of this topic.

3) The use of remedial measures has helped the students in better understanding of the topic of the periodic table and concepts related to it.

The last chapter summarises the major findings of this study. Limitations of the study and recommendations based on it are also presented in this chapter.

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Statements required by the University

1) Statement regarding discovery of new facts.

This thesis presents students' misconceptions and learning barriers with respect to various fundamental concepts in chemistry and tests the effectiveness of the remedial measures developed for better understanding of some of these concepts. The topics selected for the study were chemical equations and formulae and the periodic table. The study was conducted at class IX, X and XI. At school level, students from Municipal schools as well as non-Municipal schools participated in the study. The intervention studies using the remedial measures (that is, the periodic table model developed by the researcher) were conducted for students from class X in a Bombay Municipal school and also for students of class IX in a reputed girls' school at Solapur. The aim of these experimental studies was to test the usefulness of the developed model in the regular school system.

The following aspects of the thesis are new to the best to our knowledge:

i) The tools developed for data collection, that is, the diagnostic tests used and the clinical interviews conducted in the study. Both these tools included various concepts related to the two topics mentioned above (for example, understanding of the symbolic language, valency, concepts of elements, compounds and mixture, concept of atoms and molecules and the periodic table).

ii) The periodic table model developed as a part of remedial measures.

iii) The findings of the study which are related to:

a) the errors committed by students on various tests on chemical equations revealed that students have misconceptions regarding particulate nature of matter, valency, elements, compounds and mixtures and their symbolic representations. Lack of chemical knowledge rather than the required mathematical knowledge, hampered the performance on stoichiometric interpretations of equations.

b) The pictorial representations drawn by students revealed that students' perceptions of symbolic language differ from the scientifically accepted ones.

c) Students failed to understand the significance of the periodic table in study of chemistry. Students confused the technical terms used and also tended to interpret the words related to the periodic table differently (especially in Marathi).

d) The experimental studies at class X indicated that the use of the periodic table model did help students in better understanding of the topic and related concepts. At class IX, the sequential discussions of various concepts helped students to perform significantly better on the post-tests, but the model did not prove to be significantly better as compared to the chart.

2) Statements including the sources of information, etc.:

The work described in the thesis was conducted under the guidance of Prof. V.G. Kulkarni. The Dahanu project which was conducted by HBCSE in collaboration with Government of Maharashtra aimed at improvement of science education in Dahanu taluka of Thane district (1987 - 1990) was useful to me, as the project gave exposure to me to the educational field and also to students' and teachers' difficulties regarding chemistry.

The entire work of this thesis including planning, developing tools for data collection, the development of the periodic table model and the qualitative and quantitative analysis of the data was done independently by me. For the data collections, I was helped by Shri R.M. Bhagwat and Ms. Katti (Solapur). Regarding the data entry, I was assisted by Ms. Sneha Narvekar. The experimental studies at class X were conducted by me whereas that at class IX was conducted by Ms. Katti (Solapur).

a) References are stated at appropriate places in the thesis whenever works of other people have been used. The rest of the thesis may be claimed to be original.

b) I, hereby declare that for the thesis which I am submitting no degree, diploma or distinction has been awarded to me by this or any other University.

CHAPTER I

INTRODUCTION

1.1 Background

The Homi Bhabha Centre for Science Education (HBCSE) at the Tata Institute of Fundamental Research (TIFR), Bombay, has been undertaking action research projects to identify various factors responsible for low scholastic achievements of students and to design and test remedial measures to overcome them. The projects concentrate on attempts to improve science and mathematics education. The rationale behind all these projects is that low scholastic performances of students, specially the first generation learners, is due to pedagogic, linguistic and the conceptual difficulties faced by them.

The first action research project of the Centre (1975-78) was conducted in schools at Khiroda, a rural region in the Jalgaon district of Maharashtra. In this project attempts were made to identify socio-economical, pedagogic and linguistic factors that hamper the progress of first generation learners at school and to design specific remedial measures for overcoming the same. Another important objective of the project was to generate field-tested pedagogy based on the remedial measures devolved. Besides these two aims, the project was also aimed at sensitizing teachers to the difficulties faced by the first generation learners and stimulating them to adopt the developed pedagogy. This project was conducted for standards I to VII (Ramdas, 1981).

Another project, the Talent Search and Nurture among the Underprivileged (TNP) focused on studying the learning difficulties experienced by scheduled caste students studying at the high-school level, that is, students from class VII, IX and X was started in 1980-81. An important goal of the project was to devise remedial measures to overcome the identified barriers. The effectiveness of the remedial measures, in terms of the scholastic performance of the students, was also studied in the project (Agarkar, 1987). This work was conducted at HBCSE's old premises located in the Nana Chowk Municipal Secondary School, Grant Road, Bombay.

Both the above mentioned projects were fairly successful. In the case of the Khiroda project, it was observed that teachers accepted the new pedagogy and paid particular attention to the first generation learners in their classes, which reflected in considerable improvement in the teacher-pupil interaction. Outcomes of the TNP project revealed that the scholastic performance of SC/ST students could be improved substantially. The project also revealed that the remedial measures designed to overcome the hurdles were relatively simple and could be implemented without much difficulties. These results were acknowledged by the Government of Maharashtra which lead to the collaborative projects between the government of Maharashtra and HBCSE. The first collaborative project was implemented for all eighteen secondary schools in the Dahanu Taluka of Thane district (1987-90). Dahanu has a substantial population of scheduled tribes. The Dahanu project provided an opportunity to HBCSE scientists to see whether the remedial measures developed on a small scale and under controlled experimental conditions could be incorporated in the normal teaching of typical teachers. Another important aim was to see whether such an assimilation has positive effects on the science and mathematics performance of students. The details of the project can be found elsewhere (Agarkar et al., 1990). An extension of this work was conducted in Solapur (1990-93). In this project which covered twenty secondary schools in Solapur city of Maharashtra, an attempt was made at developing resource persons who could conduct orientation courses for the teachers in their area (Agarkar, 1994).

Apart from these projects, many other important projects have been conducted at HBCSE. One such project was the Non-formal education project. The project was commenced by the Indian Institute of Education (IIE), Pune which invited HBCSE to collaborate and to contribute to the project by devolving a science curriculum in terms of pictorial folders and an experimental kit to be used in project areas from the Pune district of Maharashtra. Accordingly, HBCSE had intensive interactions with the teachers from two areas, that is, Katewadi and Pabal (1983 - 1985). The evaluation of the developed material was done as a part of the project. One of the major aims of evaluation of the project was to study the process of acquisition of basic learning tools like literacy, numeracy, language behaviour and some aspects of method of science in an integrated manner (Kulkarni et al., 1991).

In yet another study, effect of language simplification of the science textbooks on students' performance was studied. The work was conducted at classes V, VI and VII and included 29 Bombay Municipal schools (1980 - 83). It was observed that simplifying the books linguistically, keeping all other factors unchanged, enhanced the teacher-pupil interaction and also lead to improved performance of students (Gambhir, 1984). The results of the study were once again noticed by the Government of Maharashtra and now HBCSE scientists are regularly involved in preparation of science textbooks to be used in the system.

Besides the studies mentioned above, it will be useful to mention two more studies. One of these studies concentrated on the use of mathematical modelling for modelling the growth of 'Literacy' and 'Informational science literacy' in a developing society. The study illustrated a number of quantitative results with interesting social implications (Deshpande, 1991). The other study looked at social aspects of the educational field, namely, the process of career decision-making and the factors affecting career choices. The study was conducted for both SC/ST students and non-SC/ST students. Three factors, namely, awareness of occupations, prestige of occupations and sex-role stereotyping of occupations were studied in detail (Chunawala, 1992). The pilot work for this study was conducted with students from the TNP project and later the work was conducted with students in the Dahanu area.

Most of the projects mentioned above revealed that the scholastic performance of the first generation learners could be improved by identifying various difficulties of these students and by designing appropriate remedial measures. These projects also showed that it was possible to sensitise teachers about difficulties faced by these students through teachers' orientation courses. Such an awareness of students' difficulties influenced teacher-pupil interaction positively. These projects revealed further that appropriate suggestions based on research can be accepted in writing of the text-books. All these results were very encouraging for the researcher. Further, the participation in teachers' orientation courses and school visits conducted in the Dahanu project sensitised the researcher regarding the difficulties faced by teachers as well as students, especially in teaching and learning of the subject chemistry. The researcher (who had a Masters Degree in chemistry), therefore, decided to undertake the work of understanding of students' difficulties about chemistry.

The work described in this thesis is an attempt to study students' conceptual understanding of various fundamental concepts in chemistry which is a component of science taught compulsorily at the high school level. The preliminary work of the thesis was done in the Dahanu project. Later, the major part of the work was conducted in various schools of Bombay. Some work was also done in Solapur. At the preliminary stage of the study, the researcher spent considerable time developing the model of the periodic table and writing the book 'The Fascinating Story of the Periodic Table'.

The objectives of the thesis are:

1) To study students' conceptions, misconceptions and learning barriers with reference to different chemical concepts related to chemical formulae, equations and the periodic table.

2) To develop remedial measures for better understanding of some of the chemical concepts under study.

3) To evaluate the effectiveness of the remedial measures developed.

1.2 Significance of the problem

In the state of Maharashtra, science and mathematics are compulsory subjects up to the secondary level, that is, up to class X. In today's world, which is dominated by science and technology this compulsory teaching of science and mathematics provides opportunities to all students, including first generation learners, to get exposed to basic scientific concepts and principles. Such an exposure is expected to create interest and curiosity among the students (as stated in introduction of school science text-book of class X, 1991), and to motivate them to study these subjects further. At the same time, it is expected to help the bulk of the students who drop out at class X to acquire adequate knowledge of science and mathematics which will enable them to function in the modern world. To fulfil these purposes, efforts are being made to update and modernize the syllabi and to improve instructional methods. All these attempts inevitably need to be based on research and development in the fields of science/mathematics education.

Until recently (that is, approximately up to 1960's), it was thought that students coming to formal schooling possess little or no knowledge regarding scientific concepts. The teacher was the person responsible for transmitting scientific knowledge to the students through teaching. The concept of Tabula Rasa and Teacher Dominance (see Gilbert et al., 1982) were two concepts which dominated the field of science education. The first concept which existed science the ancient Greeks (Plato) viewed students as blank slates. The concept of Teacher Dominance had some awareness about students' conceptions. However, this conceptual knowledge was not considered to be significant for learning. It was assumed that these concepts could be replaced directly and easily through appropriate formal schooling.

Thus, most of the curricula and curricular reforms (specially up to 1960) concentrated on pedagogical instructions and ignored the learner. However, research done in the last two to three decades regarding students' understanding of various scientific concepts, prior to, during or after formal schooling, has proved conclusively that students are neither blank slates nor are they passive receptors of knowledge (see Pines & West, 1985). Students coming to formal schooling do possess knowledge regarding the world and natural phenomena even before their formal schooling begins. This knowledge is acquired through sensory experiences, interactions with peers, parents and other individuals and through exposure to mass media. Language and culture are two important factors which influence this knowledge (Driver, 1983; Pines and West 1985). Research on conceptual understanding has shown that what is learned through formal schooling is greatly influenced by the knowledge possessed by the students (Driver & Eslay, 1983; Pines and West 1985). Thus, the study of students' understanding of scientific concepts is an important research area today. Several such studies are going on for various concepts in physical sciences including chemistry.

The subject chemistry is introduced to the students at secondary level, that is, at class VIII and is taught up to class X as an integral part of science syllabi in many states of India, specially in the state of Maharashtra. In other words, students at secondary school level study chemistry from class VIII onwards.

The school chemistry syllabus which is taught in the schools today, has three basic facets (Johnstone, 1993) - i) macro (visible and tangible), ii) micro or sub-micro (atomic and molecular) and iii) representational (symbols, formulae and equations). To learn the fundamental concepts in chemistry, students have to deal with all these aspects simultaneously. Further, understanding of macro and representational aspects in terms of the sub-micro aspect is crucial in learning chemistry. This makes most of the fundamental concepts in chemistry abstract in nature, besides causing problems for students, who often perceive chemistry as a difficult subject (Ben-Zvi et al, 1988; Nakhleh, 1992).

The present thesis attempts to study students' conceptual understanding of different fundamental concepts in chemistry, especially the concepts related to chemical formulae, equations and periodic table. Attempts have also been made at developing some remedial measures to enhance teaching and learning of these concepts. Such a study has implications for teaching and learning of chemistry at school level. The reasons for selecting the above mentioned topics are presented below.

1.2.1 Rationale for selection of topics

Description and explanation of chemical changes is the primary concern of chemistry. The representational aspect of chemistry, that is, the symbolic language of formulae and equations, is an important means to describe all the necessary information about reactions in a compact manner. Information such as, the composition of reactants and products, the state and proportion of reactants and products and the energy changes in the reaction, are represented by an equation. It is, therefore, necessary for students of chemistry to be well- acquainted with this symbolic language in order to understand the described chemical change. Thus, understanding the representational aspect is fundamental to the study of chemistry. Due to these reasons the topic of chemical equations and formulae was selected for study. A survey conducted by the researcher revealed that this topic was perceived as one of the most difficult topics at the school level, both by students and teachers which was yet another reason for selecting this topic.

Like the symbolic language, the topic of periodic table is of considerable importance for students of chemistry. The chemistry syllabus at school level begins with the macro aspect of chemistry, where students primarily study the properties of various elements and compounds. Such a study is of considerable importance, since uses of various materials are linked to their properties. It is more important, however, that students of chemistry should be exposed to the relation between chemical properties of elements and the atomic/ molecular structure of materials. In other words, such an exposure helps students to understand why a particular element or a compound has to have certain characteristic properties. The Periodic Table of elements forms the very basis for this understanding. The periodic table not only displays the interconnections between properties and the atomic structure, but also reveals how the periodicity in the electronic shell structure leads to the periodicity of properties of elements. Thus, an understanding of the topic of the periodic table is essential and crucial to the study of chemistry, and hence was selected for the research.

It may seem that the two topics, chemical equations and the periodic table, mentioned above, are not related to each other. However, this is not true. Both these topics help to link the same important concepts in chemistry such as elements and compounds or atoms and molecules or valency. Thus, the study of students' understanding of these two topics gives opportunities to study the understanding of some important fundamental concepts of chemistry.

1.3 Chemistry syllabus at the secondary level

Before going into the details of the syllabus, it is important to note that from 1994, the school science (and mathematics) syllabi at class IX and X has undergone some major changes. These changes are already implemented for class IX from July 1994 and will be implemented for class X from July 1995. According to the new syllabus of science, students are expected to learn science in an integrated way. An integrated science textbook including topics from physics, chemistry and biology will be used at class IX and X. The text-book whenever possible attempts to present the interconnections between the various branches of science. Since the study reported in the thesis was conducted during 1989 - 1993, the syllabus up to 1993 is discussed first (table 1.01, for the content of the table prescribed chemistry text-books at class VIII, IX and X till 1993 are used) followed by new chemistry syllabus.

At class VIII, chemistry is centred around the macro aspects or what can also be referred as descriptive chemistry. At this stage, students study topics such as air, water, oxygen, hydrogen and characteristics of acids, alkalies and properties of some other common elements and compounds and some physical methods of purification of substances (all these form 9 topics out of 13). There are two topics which discuss important concepts in chemistry such as concepts of elements, compounds, mixtures and chemical and physical change. These topics would fall under conceptual chemistry rather than descriptive chemistry or the macro-aspect. However, in practice, in the class VIII the topics have been presented in macro aspect, that is, by dealing with descriptive aspects of the concepts. The micro aspects of these concepts are introduced in another topic, that is, the topic 'atoms and molecules' where students also get introduced to the representational aspects of chemistry, that is, symbols of elements.

At class IX, there is a major shift from descriptive chemistry to micro and representational aspects of chemistry. In other words, there is more of conceptual chemistry (which includes mainly the micro aspect) than the descriptive chemistry. At this stage, students study atomic structure, valency, ionic and covalent bonds and chemical formulae and equations in detail. All these topics deal with the micro and representational aspects of chemistry. Even for understanding of other topics such as oxides, oxidation, reduction and gaseous phase an understanding of the micro aspect is crucial. Thus, the topics which can be included under conceptual chemistry constitute 6 chapters out of the total 12 chapters. The other six topics, which are a part of macro aspect or descriptive chemistry, increase in complexity as these topics present considerable details about occurrence, methods of preparations, properties and uses of different substances studied (as compared to class VIII). All this information involves many chemical reactions which are represented by the symbolic language of chemical equations (that is, the representational aspect). Thus at class IX, students start dealing with all the three aspects of chemistry, namely, macro, representational and micro aspects, almost simultaneously. Understanding of all these facets, simultaneously is not easy for students and this is more true when the concepts discussed are abstract in nature.

At class X, the complexity of the syllabus increases even more as many advanced concepts are introduced. The syllabus includes concepts such as solutions and ionization, radioactivity and rates of chemical reactions. The topic of the periodic table is also introduced at class X. All these concepts are discussed in four different chapters of the textbook (out of 12 chapters). Under macro or descriptive chemistry, students study some metals and non-metals in detail as in class IX. Apart from this study, under industrial chemistry, students study glass, matchsticks, soaps and detergents (all these from a descriptive point of view). Thus, descriptive chemistry constitutes seven of the twelve chapters. The remaining chapters introduce students to a different branch of chemistry, that is, organic chemistry. Once again, this topic is complex as students study different hydrocarbons in considerable detail and also study different functional groups. The syllabus discussed so far is presented in table 1.01.

Table 1.01 : School Chemistry Syllabus
(At the time of the study)

Ch.No.	Class VIII	Class IX	Class X
1	Chemistry in everyday life (g)	Nitrogen (d/c/r)	Periodic table (c)
2	Classification of substances (d)	Ammonia (d/c/r)	Solutions & ionization (c)
3	Air (d)	Halogens (d/c/r)	Rates of chemical reactions (c)
4	Changes in matter (d/c)	Structure of atoms (c)	Radioactivity (c)
5	Characteristics of some elements (d)	Valency (c)	Metals & their compounds (d/c/r)
6	Characteristics of some chemicals (d)	Chemical equations & formulae (r)	Phosphorus (d/c/r)
7	Methods of purification (d)	Oxides, oxidation & reduction (d/c/r)	Sulphur (d/c/r)
8	Water (d)	Gaseous state (c)	Sulphur di & tri oxide & sulphuric acid (d/c/r)
9	Atoms & molecules (c)	Combustion & fuels (d/c)	Carbon (d/c/r)
10	Oxygen (d)	Metals & metallurgy I (d/c/r)	Chemistry of carbon compound (d/c/r)
11	Hydrogen (d)	Metals & metallurgy II (d/c/r)	Industrial chemistry I (d)
12	Characteristics of acids & alkalies (d)	Study of some compounds (d/c/r)	Industrial chemistry II (d)
13	Acid, bases & salts (d)	-	-

d = descriptive; c = conceptual; r = representational

In the proposed changes at class IX, there are six topics which are part of chemistry. This chemistry syllabus is much more homogeneous as compared to the prior chemistry syllabus. To begin with, students are exposed to different states of matter and concepts of elements, compounds and mixtures. After an introduction to these concepts, as in the earlier syllabus , the atomic structure is discussed in detail. All these constitute three of the six chapters. The contents of these topics are more or less the same as was before. However, unlike the previous syllabus, the concept of mole is discussed in considerable details.

The other three chapters concentrate on the formation of compounds (that is, ionic and covalent bonding), chemical reactions and products, and types of chemical reactions. From the names of the topics, it is clear that these topics deal mainly with chemical reactions and thus, there is a continuity among various concepts discussed. The chapter on chemical reactions initially discusses physical and chemical changes and then introduces the symbolic language of chemistry, that is, chemical symbols, formulae and equations. Balancing and interpreting of the equations are also discussed in the chapter, but there is no discussion of the nomenclature of chemical compounds (as was done in the earlier chemistry textbook). The topic, however, introduces the concept of internal energy and also discusses exothermic and endothermic reactions (in the earlier chemistry syllabus, exothermic and endothermic reactions were discussed in class X). The reactions which are discussed as examples of exothermic and endothermic reactions are fairly complex biochemical reactions such as the photosynthesis reaction and reactions of glucose in aerobic and anaerobic conditions. The chapter on chemical reactions discusses various different types of reactions and factors affecting the chemical reactions (this chapter was taught at class X in the earlier syllabus). Apart from these topics, the chapter on heat discusses concepts such as melting point, boiling point and effect of pressure and of dissolving salts on these, the concept of latent heat of fusion and heat of vaporization, and some other concepts.

For the new syllabus of class X, the new textbook is not yet available. From the contents presented in the book of syllabus by the Board of Secondary and Higher Secondary Education, Maharashtra (1993), it appears that the periodic table will be taught at class X as before. There will be at least two topics on electrolysis and electrolytic cell which would discuss electrolytes and non-electrolytes and, electrolysis (covered in the previous syllabus). Unlike the earlier syllabus, Faraday's first law of electrolysis and electroplating is also covered. The chapters on energy would cover fuels as well as nuclear fission and fusion. One of the chapter on energy will introduce some concepts from thermodynamics (that is, heat engine).

From the syllabi changes for class IX and X, it is clear that for both these classes, the macro or descriptive chemistry is almost eliminated from the syllabus. In other words, the new syllabus for chemistry is loaded towards micro aspect of chemistry. In fact, complexity of concepts as compared to the earlier syllabus has increased (for example, introduction of concept of mole or different exothermic and endothermic reactions or concept of heat engine). Table 1.02 summarises the new syllabus of chemistry.

Table 1.02 : New Chemistry syllabus at class IX & X

Class IX	Class X (proposed)
Properties of matter (d/c)	Periodic table (c)
Structure of Atom (c)	Electrolysis & electrolytic cell (c)
Mass of Atom (c)	Fuels (d/c)
Formation of compounds (c)	Mechanical work & energy (c)
Chemical reactions & products (d/c/r)	-
Types of chemical reactions (c)	-

d = descriptive; c = conceptual; r = representational

1.3.1 Perceptions about chemistry syllabus

As stated before, a questionnaire was administered to students and teachers to understand their perceptions regarding the topics of chemistry in the syllabus. This survey was conducted for the syllabus of class IX and X because the topics of chemical equations and periodic table are included in the syllabus of class IX and X respectively.

1.3.1.1 Methodology

i) Sample

For class IX, the questionnaire was administered to the students from two schools in Bombay and two schools in Dahanu. Out of the two schools at Dahanu, one was well reputed and consisted of students who were average and above average in their scholastic performance. The other school was not very reputed and consisted of students with average or below average scholastic performance. The two schools selected at Bombay, one school was well-reputed and like the Dahanu school, it consisted of students with an average and above average scholastic performance. The other school was a Municipal Corporation school and this school consisted of students with average and below average scholastic performance in general (all these statements are based on the information obtained through informal discussions with school teachers). The data obtained from the students (N = 54) in the Municipal Corporation school was used to test the reliability of the questionnaire and not for any further analysis. Thus, the total sample for the questionnaire consisted of 88 students, (which did not include the sample of students used for reliability testing of the questionnaire).

Similar questionnaires were administered to teachers at Dahanu and Bombay. The sample of teachers consisted of ten teachers from different schools of Dahanu and twenty-nine teachers from different schools of Bombay. The educational background of most of these teachers was B.Sc. B.Ed. The exact distribution of the total sample of students and teachers is displayed in the table 1.03.

Table 1.03 : Total sample for questionnaire of class IX

Place	Students	Teachers
Bombay	35	29
Dahanu	57	10
Bombay (for reliability)	54	-

A similar procedure was also conducted at class X. As compared to class IX, the sample of students of class X was limited. The questionnaire was administered to one class, (32 students) from a Municipal Corporation school. In other words, this sample was a biased sample. In general, it was difficult to conduct work at class X, especially towards the end of the academic year due to various reasons. In all the schools, at class X, it is expected that the portion should be finished by the end of December and the preliminary examinations should be conducted by the mid or end of January. Often schools conduct study camps to enable students to student solve/revise the portion and solve different question-papers. Students are also busy with private tuition classes. Thus, getting a sample of students at class X, specially at the end of the academic year, is extremely difficult.

For teachers, the questionnaire at class X was administered to teachers involved in the Solapur project. This sample of teachers was accessible to the researcher easily and it also included science teachers from fourteen different schools in Solapur city. The general educational qualification of teachers was B.Sc. B.Ed. and most of the teachers involved had considerable teaching experiences. For these reasons, this sample of teachers was preferred. The distribution of total sample of students and teachers (for class X) is represented in the table 1.04.

Table 1.04 : Total sample for questionnaire at class X

Place	Students	Teachers
Bombay	32	-
Solapur	-	22

ii) Questionnaire and its reliability

The questionnaires administered to students and teachers are given in appendices 1.01 to 1.04 (1.01 & 1.03 - for students, 1.02 & 1.04 - for teachers). In the questionnaires for students, students were expected to rate the various different topics on a five point scale (from very difficult to very easy). For each point, the option was stated. For the purpose of analysis, the options were assigned numbers 1 to 5 (where 1 stood for very difficult and number 5 stood for very easy). In the questionnaires which were administered to the teachers, the teachers were asked to fill them from a typical student's point of view. In other words, teachers' opinion about a students' view of the syllabus was asked.

The test-retest procedure was used for testing the reliability of the questionnaire which was administered to the students at class IX. The reliability of the questionnaire administered to the teachers (both for class IX and X) and for the questionnaire administered to students at class X was not tested due to various reasons (mainly because these samples were not easily available).

The reliability of a measuring instrument (in this case, the questionnaire) is defined as the ability of the instrument to measure consistently the phenomenon it is designed to measure (Black & Champion, 1976). It, thus, refers to test consistency. One of the most common procedure used to measure reliability is test-retest method. In this method, a test is administered to the sample and after a suitable time interval the same test is administered to the same sample. The two sets of results are correlated and the correlation coefficient is taken as the measure of reliability. This method has certain drawbacks. One important criticism against the method is that individuals are often able to recall their first responses and thus, they tend to give the same responses on retests. To minimise this effect suitable time interval should be selected between test and retest (2 to 4 weeks, see Black & Champion, 1976).

At class IX, the questionnaire was administered to 54 students of one class in a Municipal Corporation school at Bombay. The same test was administered after a gap of 15 days. The Pearson correlation coefficient was calculated for each chapter. The results are displayed in table 1.05.

Table 1.05 : Correlation coefficients for test - retest (N = 54)

Chap. No.	1	2	3	4	5	6	7	8	9	10
Corr. Coe.	0.62 **	0.57 **	0.62 **	0.54 **	0.56 **	0.57 **	0.50 **	0.46 **	0.43 **	0.37 *

** - Significant at 0.001
* - Significant at 0.01

From the above table, it is clear that for all the chapters, the correlation coefficients were significant. The coefficient generally varied between 0.45 to 0.60. It is important to remember that for calculation of correlation coefficient, the data is treated as interval even though it is ordinal level (Kerlinger, 1981).

1.3.1.2 Analysis and Discussion of the data

From the data obtained, the chapters were then ranked depending on the overall average ratings of the chapters. Ranking was the secondary procedure carried out by the researcher to arrange various topics on a hierarchial scale. This was done for the data obtained from teachers and students separately. For ranking of the chapters, first a mean rating for each chapter was calculated in following manner. The sum of the weighted ratings given by all students (or teachers) to that chapter was divided by total number of students (or teachers) rating that chapter. Thus, when no rating was given by the student (or teacher), the mean was calculated by deleting the cases. The chapter receiving lowest rating was ranked as 1, the chapter with next lowest rating was ranked as 2 and so on, till all the chapters were ranked. If there were ties in the ratings, that is, more than one chapter receiving the same rating, then the chapters were ranked by adding all the concerned ranks and dividing by the number of ties, for example, when chapters 4 and 12 in table 1.06A received the same rating 3.08, instead of ranking both as 4 or 5, 4 + 5 was divided by the number of ties, that is, 2 and the rank 4.5 was assigned to both the chapters. Table 1.06A presents this data while table 1.06B presents the results of t-test analysis.

Table 1.06A : Mean rating and ranking of various chapters at class IX

Chap. No.	Students		Teachers	
	Mean Rating	Ranking	Mean Rating	Ranking
1	3.96	11	3.82	12
2	3.63	9.5	3.74	10
3	3.43	7	3.13	9
4	3.08	4.5	2.63	6
5	3.09	6	2.28	2
6**	2.28	1	2.23	1
7	3.51	8	3.08	8
8	3.63	9.5	2.56	4
9	4.04	12	3.77	11
10	3.07	3	2.62	5
11	3.00	2	2.51	3
12	3.08	4.5	2.85	7

Table 1.06B : t-test results for chapters at class IX

Chap. No.	Mean Rating of Students	Mean Rating of Teachers	t-values with one tailed probability
1	3.96	3.82	-1.08 (p=0.14)
2	3.63	3.74	0.82 (p=0.21)
3	3.43	3.13	-2.23 (p=0.01)*
4	3.08	2.63	-1.98 (p=0.03)*
5	3.09	2.28	-4.98 (p=0.00)*
6**	2.28	2.23	-0.26 (p=0.40)
7	3.51	3.08	-2.42 (p=0.01)*
8	3.63	2.56	-5.50 (p=0.00)*
9	4.04	3.77	-1.08 (p=0.04)*
10	3.07	2.62	-3.19 (p=0.00)*
11	3.00	2.51	-3.68 (p=0.00)*
12	3.08	2.85	-1.02 (p=0.15)

* = significant difference

Table 1.06A reveals that the topic of the chemical equation, that is, chapter 6, received the lowest rank 1 and thus, this chapter is perceived as the most difficult chapter by students and the same is also true for teachers.

Students' t-test was conducted to see whether there are significant differences between the mean rating given by teachers and by students for a particular chapter. The t-tests can be conducted for data which are ordinal in nature (as above) by treating the data as interval (Kerlinger, 1981). The null hypothesis (H_0) that there was no difference between the mean ratings given by students and teachers was tested against the one-tailed alternative hypothesis (H_1), that the mean rating given by teachers was lower than the mean rating of students. The results displayed in the table show that out of 12 chapters, for seven chapters the alternative hypothesis was accepted. In other words, for all these topics the mean ratings given by teachers were lower as compared to the mean ratings of students. This difference in rating implies that teachers perceive the chemistry syllabus to be more difficult for students than the students do themselves.

A similar analysis was conducted for the test given at class X. The results are shown in the following tables (table 1.07A presents the mean ratings by students and teachers whereas table 1.07B presents the t-test results).

Table 1.07A : Mean rating and ranking of chapters at class X

Chap. No.	Students		Teachers	
	Mean Rating	Ranking	Mean Rating	Ranking
1	3.75	12	3.40	8
2	2.97	3	2.50	1
3	3.25	5	2.64	3
4	3.00	4	3.36	7
5	3.34	6	3.18	5.5
6	3.41	9	2.55	2
7	3.50	11	3.50	9
8	2.75	1	3.18	5.5
9	3.47	10	3.64	10.5
10	2.81	2	2.86	4
11	3.38	7.5	3.82	12
12	3.38	7.5	3.64	10.5

Table 1.07B : t-test results for chapters at class X

Chap. No.	Mean Rating of Students	Mean Rating of Teachers	t-values with one tailed probability
1	3.75	3.40	- 1.82 (p=0.04)*
2	2.97	2.50	- 1.87 (p=0.03)*
3	3.25	2.64	- 2.78 (p=0.00)*
4	3.00	3.36	1.21 (p=0.12)
5	3.34	3.18	- 0.62 (p=0.27)
6	3.41	2.55	- 3.28 (p=0.00)*
7	3.50	3.50	0.00 (p=1.00)
8	2.75	3.18	1.56 (p=0.06)
9	3.47	3.64	0.74 (p=0.23)
10	2.81	2.86	0.18 (p=0.42)
11	3.38	3.82	1.59 (p=0.06)
12	3.38	3.64	0.96 (p=0.17)

* = significant Difference

Table 1.07A indicates that the most difficult topics from students' point of view are sulphur compounds, chemistry of carbon compounds, solutions and ionization, and radioactivity. The teachers' perception is that, students find the topics of solution and ionization, phosphorus, rates of chemical reactions and chemistry of carbon compounds as difficult topics. The topic of the periodic table is perceived as easy by teachers for the students whereas students themselves perceive the topic as the easiest one. Even though the sample of student was limited and biased, the t-test was carried out to get a feel about the mean ratings given by teachers and mean ratings given by students. The t-test analysis in table 1.07B indicates that for eight topics the null hypothesis was valid and for the other four topics, the alternative hypothesis, that the mean rating of the teachers was lower than the mean rating of the students, was valid. Once again, all these topics including the topic of periodic table (all these topics are mainly conceptual in nature), are perceived by teachers as more difficult for students than by the students themselves.

1.4 Scope and limitation of the study

The study concentrated on two topics from school chemistry, that is, chemical formulae and equations and periodic table. It included students from class IX, X and also from XI (especially for the work on chemical equations). The work was conducted at various schools of Bombay, Solapur and Dahanu. The students participating in the study in general were average or low scholastic chemistry/ science performances.

With regard to the work done, diagnostic tests and clinical interviews were used as data collection tools. The interviews were conducted before or after the diagnostic tests or in the absence of tests. The data, regarding the wrong answers given by the students were analyzed qualitatively.

The remedial measure was a periodic table model prepared and used in teaching. Three experiments were conducted for testing the effectiveness of the remedial measures. The first two experimental studies were conducted at class X whereas the third experiment was conducted for class IX. The experimental study used, a control group and an experimental group. Intervention using the model was conducted for the experimental group whereas the control group either had no intervention (as in the first experimental study at class X) or had intervention using the textbooks or the periodic table wall chart (as in other the two experiments). The intervention was the independent variable and performance of the students on the tests administered to them before (that is, pretests) and after the intervention (that is, post-tests) were treated as the dependent variable. The mean marks received by the control group and by the experimental group on the pre-tests were compared using t-tests.

The main limitations of the study is sample selection. As stated before, the study was restricted to the students belonging to class IX, X and XI. The total sample consisted of students from two or more classes (that is, from class IX and X or from IX, X and XI). However, the number of students of a particular class in a sample was generally small (from 20 - 30 students). This is especially true for the interviews conducted (sample varied between 10 to 30). As the study is qualitative in nature, the extent of generalisation of the results is limited. In this study, it was also not possible to do lesson observations for various teachers involved. This is a limitation of the study as teachers can influence students' conceptions. However, in a doctoral thesis, it is not possible to cover all aspects of an issue and so some specific aspects were selected for study.

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CHAPTER II

REVIEW OF LITERATURE

2.1 Introduction

This chapter presents a review of literature regarding students' understanding of various scientific concepts. Initially, it discusses different terms used to describe students' conceptions and the philosophical background needed to understand these terms. The next section concentrates on the definitions for the three most widely used terms, namely, misconceptions, alternative conceptions and alternative frameworks. Such a discussion is essential as the present thesis attempts to study students' conceptions and uses the terms misconcepts and learning barriers. Lastly, the work done in the field of chemistry, with special emphasis on chemical equations and the periodic table of elements is reviewed in the chapter.

2.2 The terms and the philosophical background

A survey of various research papers on students' conceptions, reveals usage of different terms. Some of the terms used are ***'Preconceptions'*** (Driver & Easley, 1978) ***'Children's science'*** (Gilbert et al., 1982), ***'Alternative frameworks'*** (Driver & Easley, 1978), ***'Alternative conceptions'*** (Gilbert & Watts, 1983), ***'Misconceptions'*** (Lawson & Thompson, 1988; Pines & West, 1986), ***'Naive conceptions'*** (Eylon & Linn, 1988), and ***'Intuitive conceptions'*** (Eylon & Linn, 1988). This raises an obvious questions, 'why are so many terms used?' 'Do these terms differ in their meanings or are they synonymous?'

To understand the above mentioned terms, it is necessary to know two philosophical perspectives, namely, the ***empiricist philosophy*** and the ***new philosophy of science*** (Driver & Easley, 1978; Abimbola, 1988). While going through the discussion about these philosophies, it is important to remember that these perspectives are two different viewpoints and both of these exist, in current research. There are different groups of researchers who share the tenets of both these philosophies.

The empiricist view of science, assumes that knowledge exists in an absolute sense and true discoveries can be made by suitably trained observers (Gilbert & Watts, 1983). This is also called ***realism***. The steps involved are: an Investigator (scientist or student) first observes the facts objectively and formulates singular or particular statements leading to hypotheses and theories by the process of induction (Gilbert & Watts, 1983). A new theory is seen as an improvement over the old one because it accounts for more observations (Abimbola, 1988). Thus, scientific knowledge increases by accretion. As against this philosophy, the 'new philosophy of science' (by Popper, Kuhn, Lakatos) believes in the provisional status of knowledge (that is, ***relativism***). It suggests that hypotheses and theories are not related in a logical manner to the so-called objective data, but they are products of human imagination (Driver & Easley, 1978; Abimbola, 1988). With the impact of new concepts, there is a reorganisation of existing concepts in such a manner that a new view of the world is obtained. Progress in science results from such reorganisations. The progress is not cumulative, as conceptual change involves changes in meaning (Abimbola, 1988). The important events in the history of science are revolutions and they result from dissatisfaction with the prevailing concepts. Both observational data and theories undergo changes during scientific revolutions.

Apart from these philosophies, Gilbert and Watts (1983) discuss the relevant notions from the field of psychology and sociology which are important to understand the terminology and the meaning of the word 'concept' itself. They point out that the field of science education cuts across the disciplines of science and education. Thus, research in this field is influenced both by the philosophies of science and by the relevant notions from psychology and sociology. In psychology, the authors discuss behaviourism (which dominated psychology almost up to 1960), phenomenological movements (by Kelly) and cognitive psychology (of Piaget, Ausubel and others). Behaviourism as it professed then (almost up to 1950) emphasised the passivity of mind, whereas the latter two were concerned with the individual, her/his mind and how an individual perceives and interprets a given situation. Regarding sociology, the same authors point out, that in the case of social enquiries, there was a shift from empirical-inductivism to the interpretative traditions which were more concerned about an individual and her/his perceptions of the world. This shift in the field of psychology and sociology (and even the in philosophy of science) is important and has considerably affected the field of science education.

2.2.1 The term concept

The term ***concept*** is viewed differently by the two perspectives discussed above. In the classical view of concept (based on empirical-inductivism), all instances of concepts share common properties which are necessary and sufficient to define the concepts (Gilbert and Watts, 1983). In other words, a particular concept can be described in terms of the critical attributes that define the concept. The underlying assumption here is that knowledge is decomposable into elementary steps arranged in a hierarchical manner. Further, acquisition of knowledge depends on the complete mastery of the prior steps. Thus, concepts are viewed as units of cognition present in a static, logical, organised, cognitive system (Gilbert and Watts, 1983).

As against this, there is the actional view of a concept based on the new philosophy (Gilbert and Watts, 1983). It looks at concepts as ways of organising our experiences. Conceptualising is 'a kind of doing'. The new experiences do not leave existing concepts intact and there is always some reorganisation of the existing concepts. Thus, conceptual development is an active, continuous, and creative process (Gilbert and Watts, 1983).

Science education researchers with views nearer to the classical view of concepts are more likely to assign superior status to formal science knowledge than to the knowledge possessed by students (Gilbert & Watts, 1983). They see students' conceptions as wrong ideas or as flaws which originate from illogical thoughts or incorrect observations (Driver & Easley, 1978). Thus, the terms used by such researchers are generally obvious connotations of wrong ideas. The term ***misconception***, (or ***misunderstanding*** or ***erroneous concepts)*** fall under this category. These terms indicate the inferior status of students' conceptions, and suggest that these are flaws which can be rectified with appropriate instructional methods. The terms ***preconceptions*** (used by Ausubel) and ***naive conceptions*** also fall in this category. Even though both these terms do not have direct negative connotations, they still indicate something ingenuous, immature or less developed than a concept (Driver & Easley, 1978).

Contrary to this view, researchers in science education who accept the actional view of concepts, are more likely to grant relative or alternative status to formal school knowledge and students' conceptions (Gilbert & Watts, 1983). The terms ***alternative frameworks***, ***alternative conceptions*** and ***children's science*** fall under this category.

While discussing the latter terms, Abimbola (1988) argues that even though alternative or relative status is assigned to formal science and students' conceptions, it does not necessarily mean that the assigned status is equal. He describes two different groups of researchers who share the actional viewpoint but differ in the terminology they use for students' conceptions. The first group of researchers, though using a revolutionary perspective, still view students' conceptions as potential barriers to new learning. Such researchers prefer to use terms with negative connotation such as misconceptions or erroneous ideas to describe students' conceptions. Abimbola thus points out that even though terms with negative connotations are used by researchers sharing the traditional view of concept, these are also used by researchers sharing the actional viewpoint. Probably, these researchers fall at the interface of two perspectives and are to some extent closer to the empirical viewpoint. Thus, the classification discussed so far is not rigid and compartmentalised, but is flexible.

2.2.2 Misconceptions, alternative frameworks and alternative conceptions

Definitions of the terms, 'alternative frameworks', 'alternative conceptions' and 'misconceptions' by various researchers are presented below.

The term 'alternative framework' is defined by Driver and Erickson (1983) as "the mental organisation imposed by an individual on sensory inputs as indicated by regularities in an individual's responses to particular problem settings". However, Gilbert and Watts (1983) view frameworks in a different manner. They state that alternative frameworks are "short summary descriptions that attempt to capture both the explicit responses made by students and the constructed intentions behind them". They perceive frameworks as generalised non-individual descriptions. Thus, a framework is sometimes defined as an <u>individual construct</u> and at some other times as a composite picture based upon ideas shared by a <u>number of pupils</u>.

As the above discussion indicates, frameworks include the explicit responses as well as the constructed intentions behind them. According to Abimbola (1988), a framework refers more to organisation of ideas than the ideas themselves. He, therefore, argues that although ideas reflect frameworks and vice versa, it does not necessarily mean that both are the same. Frameworks are inferred from data and hence, there is a chance that the drawn inferences are fallible. According to him, this term is useful when it is possible to group students' conceptions under a particular system of laws and theories (for example, Newtonian physics or Lamarckian evolution or Phlogiston theory). However, it may not always be possible to group students' responses in such a manner. His viewpoint is true especially for concepts in chemistry (for example, representational chemistry) and biology (for example, circulatory system or digestive systems). Abimbola also comments on the perceived parallels between students' misconceptions and history of science. He is not positive about such comparisons and feels that such a comparison may be compelling the use of the term 'alternative frameworks'. He further argues that the term 'alternative conception' is more appropriate than 'alternative framework'. According to Gilbert and Watts (1983), conceptions focus on personalised theories and hypotheses of an individual. It is, thus, a more general and inclusive term as compared to frameworks. It also eliminates the need to prove historical correlates of students' conceptions. However, the term 'conceptions' assumes that internal subgroups are possible for use in organising and explaining student's ideas (Abimbola, 1988).

Lawson and Thompson (1988) define misconceptions as "knowledge spontaneously derived from extensive personal experience that is incompatible with established scientific theory". They further state that - "misconceptions are not viewed as simple minor misunderstandings or trivial gaps in knowledge that students may have forgotten. Rather they are allegedly embedded in highly robust alternative conceptual frameworks". Posner and others (1982) define misconceptions in a similar manner. Pines and West (1986) state that the prefix 'mis' is used when students' private conceptions are compared with some publicly accepted meanings. These misconceptions result from the attempts to make sense of various inputs of public knowledge. Nakhleh (1992) states that the term misconceptions means "any concept that differs from the commonly accepted scientific understanding of the term". In other words, the prefix 'mis' is used to indicate a mismatch between students' conceptions and scientific conception. All these points have been summarised by Fisher (1985), who states the following characteristics for misconceptions -

i) They are at variance with scientific conceptions.

ii) Many misconceptions are highly resistant to change, at least by traditional teaching methods.

iii) A single misconception, or a small number of misconceptions, tend to be pervasive.

iv) They sometime involve alternative belief system comprised of linked sets of propositions that are used by students in systematic way.

v) Some misconceptions have historical precedence.

It is clear from these definitions that even though the term misconceptions has its origins in the traditional viewpoint, it is being used with new meanings. As Driver and Easley (1978) point out, the term has been generally used in studies where students are exposed to formal theories and have assimilated them wrongly.

In this thesis, the term misconcepts and misconceptions will be used synonymously. The term misconcepts/ misconceptions is used in the thesis in following sense -

a) This term is preferred to the other terms as this thesis attempts to study different interrelated concepts required for an understanding of the chemical equations and the periodic table. In other words, this work attempts to study these topics as a whole.

b) This term is used since the work in this thesis attempts to study students who are exposed to formal theories. It describes any conception which differs from scientifically accepted understanding of the term. The misconcepts/misconceptions described in this thesis need not arise out of natural observations. This is especially true for representational chemistry which is studied in the present work.

The term learning barriers is also used along with misconcepts. This term refers to any other barrier (say, linguistic or mathematical) which hampers the understanding of the chemical concepts which are being studied.

2.3 Students' conceptions and formal knowledge

This section illustrates how students acquire various conceptions and some of the interactions between the formal knowledge and knowledge possessed by students.

Students acquire knowledge about the world and natural phenomena, in their attempts to make sense of various inputs from their surroundings. This knowledge is also acquired through interactions with peers, parents, other individuals and through exposure to the mass media (Pines & West, 1986). Language and culture are also influential in affecting and directing this knowledge (Pines & West, 1986). While discussing the origin of conceptual frameworks, Driver and Erickson (1983) discuss the importance of perceptual experiences, metaphors and analogies in concept formations by students. They point out that the ideas which are constructed from perceptual experiences are held strongly and are resistant to change (for example, dropping, lifting, throwing, sensation of 'hot' and 'cold'). They further argue that the frameworks derived from such perceptual basis may be universal as most of the students will construct their experiences in similar manner. In some new situations, the available metaphor in language may be a source of ideas used to assimilate a new experience into a familiar one. In fact, often the sense experiences and everyday language reinforce, and thus, strengthen the certainty with which certain ideas are held. Analogies are important in situations where there are no clear beliefs or sets of expectations. In such cases, individuals may think in terms of verbal and physical analogies in order to understand the new situation. Such ideas are likely to be more flexible and personal as compared to the ideas derived from sensory experiences and metaphorical use of language (Analogies are important especially in chemistry. In teaching and learning of fundamental concepts in chemistry, the concepts of atoms and molecules plays a central role. This makes these concepts abstract in nature. Analogies and analogical relations used to explain this aspect of chemistry are important and will play a crucial role in understanding of these concepts).

The formal knowledge which is presented in schools is someone else's interpretation of the world, some one else's reality (Pines & West, 1986). This knowledge, which is considered to be "correct", is presented in the textbook and taught by teachers. Students are expected to acquire this knowledge within a certain time period and to demonstrate their competence through tests conducted in the schools.

What happens when students' conceptions and formal knowledge meet each other? Pines and West (1986) describe different possible interactions between these two types of knowledge by using a 'vine metaphor'. They use an upward-growing vine to represent the students' conceptions (which they refer to as "spontaneous knowledge") and a downward-growing vine to represent formal knowledge. Interactions between the two types of knowledge are referred to as prototypes. Pines and West (1986) point out that this is a simplistic picture, but, it helps in understanding some of the interactions between these two types of knowledge. As the authors suggest the identified interactions are neither exhaustive nor are they mutually exclusive.

It is possible that in a particular learning situation, more than one prototype has to be considered. The figure by Pine and West (1986) showing the four prototypes is presented below :

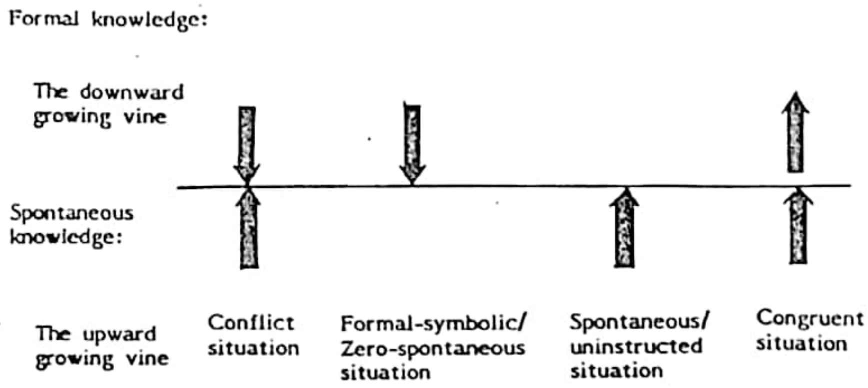

FIGURE 2A : Figure by Pines & West (1986) showing the four prototypes

Prototype 1 is referred to as a conflict situation. In this prototype, both the vines are well established and they conflict with each other. According to the authors, most of the research in alternative frameworks falls in this category. Mature learning in such situations will involve transfer from one set of beliefs to another, which is completely incompatible with the old set. In other words, one has to abandon one's ideas which are acquired over a long period. Such a conceptual change is referred to as accommodation (Posner et al., 1982) or conceptual exchange (Pines and West, 1986). There is bound to be reluctance on the part of students to do so and the reluctance will be maximum when the ideas are formed on a perceptual basis. This is true especially for concepts from physics (such as force, velocity, heat and light). If there is no awareness about the conflict situation (as in the case of traditional instructional methods), then students will maintain their old conceptions and learn the formal content by rote. In other words, what can be best achieved in such situations is compartmentalization of knowledge. Students in the above situation do not really believe the knowledge which is imposed on them. The conflict situation is a challenging situation for science educationist.

Prototype 2 is the congruent situation. As the name suggests, the two vines do not conflict with each other. In such cases, students' reality can be integrated with formal knowledge without any need to abandon the old deeply held commitments. As Pines and West (1986) point out, this is often true in the biological sciences. What is important to remember here is that this prototype does not mean that there are no misconceptions. However, there are no clashing or conflicting belief systems. The problem is one of integration of the old belief system with new knowledge (such conceptual change is referred to as assimilation; Posner et al., 1982). One has to adopt different strategies to enhance such a conceptual change as compared to conflict situations. These two prototypes indicate extreme situations.

The third prototype is termed as formal-symbolic or zero-spontaneous situation. As the label indicates, in this situation, there is little spontaneous knowledge to interact with formal knowledge, which is complex, and well structured. As an example of this, Pines and West discuss learning of the substitution reaction in organic chemistry. This situation can be true for other concepts in chemistry also (especially representational aspects and probably the micro aspect). Once again, one should remember that this prototype does not imply absolute zero spontaneous knowledge but it means that the spontaneous knowledge is much less as compared to other situations. In such cases, it is possible that students will use analogies, verbal or physical, to interpret the formal knowledge.

Prototype four is a spontaneous/uninstructed situation. In this situation, there is no formal school knowledge. However,, students possess extensive spontaneous knowledge which is derived from culture and mythology.

2.4 Review of studies conducted in chemistry

This section is devoted to the work done in field of chemistry. The third edition of bibliography on students' alternative frameworks and science education by Pfundt and Duit (1991) indicates that the work done in the field of chemistry is fairly recent as compared to the work done in physics and biology. The work in chemistry began around 1980's and as Nakhleh (1992) suggests it is still a fertile field. Table 2, produced from the bibliography, gives details regarding the various topics covered so far in different subject areas and the total number of articles produced up to 1990. This figure also reveals the topics covered so far in the field of chemistry.

Mechanics	281	Force and motion/work,power,energy/speed, acceleration/gravity/pressure/density/ floating,sinking
Electricity	146	Simple,branched circuits/topological and geometrical structure/models of current flow/current,voltage,resistance/electro-statics/electromagnetism/danger of electricity
Heat	68	Heat and temperature/heat transfer/expansion by heating/change of state,boiling, freezing/explanation of heat phenomena in the particle model
Optics	69	Light/light propagation/vision/ color
Particles	60	Structure of matter/explanation of phenomena(e.g.heat,states of matter)/conceptions of the atom/radioactivity
Energy	69	Energy transformation/ energy conservation/ energy degradation
Astronomy	36	Shape of the earth/characteristics of gravitational attraction/satellites
"Modern" Physics	11	Quantum physics/special relativity
Chemistry	132	Combustion,oxidation/chemical reactions/ transformation of substances/chemical equilibrium/symbols,formula/mole concept
Biology	208	Plant nutrition/photosynthesis/osmosis/ life/origin of life/evolution/human circulatory system/genetics/health/growth

Table 2: Studies on Students' Conceptions in Different Areas (the figures give the number of articles contained in the present edition of the bibliography in a certain area)

Before going into details of the work done in chemistry, it will be useful to understand the characteristics of chemistry as a subject. As mentioned in chapter I, chemistry which is taught in schools today, has three basic facets (Johnstone, 1993) -

i) **Macro chemistry** - tangible and visible,

ii) **Micro or Sub-micro chemistry** - atomic, molecular and kinetic,

iii) **Representational chemistry** - symbols, formulae, equations, stoichiometry and mathematics.

As discussed in chapter I, the chemistry curriculum in schools begins at macro-level and soon sub-micro and representational aspects are introduced to students. All these aspects and their interconnections are important in order to understand different fundamental concepts in chemistry. Thus, in learning various chemical concepts students have to deal with all these facets, simultaneously. Further, the concept of atoms and molecules, that is, the micro aspect plays a central role in learning these concepts. In fact, understanding of fundamental concepts such as elements, compounds, mixtures, chemical reactions and bonding is incomplete without the micro aspect. This makes most of the chemical concepts abstract in nature. Moreover, if students' experiences are considered, then most of these experiences are going to be related to tangible objects and thus, will be concentrated at the macro level (Johnstone, 1993). Comparatively, the experiences at the other two levels, specially at the micro level are limited. All these reasons cause problems for students in learning chemistry, especially when several concepts are introduced rapidly in a short period of time (that is, in 2 to 3 semesters).

2.4.1 Studies on particulate nature of matter

As stated above, the concept of particulate nature of matter is important in understanding chemistry. Various studies have been conducted so far to study students' conceptions about particulate nature and concepts related to it.

One of the classic studies in this field was conducted by Novick and Nussbaum (1981). This cross-age study attempts to understand students' conceptions of particulate nature of matter with respect to the gaseous phase. (N = 576 students, from elementary schools to university level). Some of the misconceptions observed were-

i) Almost 30% of junior high school students and 10% of students at senior and university level, did not apply the idea of particle motion to arrive at uniform distribution of particles in gaseous phase. They possessed a static particle picture of gaseous phase.

ii) Far fewer students (15-25%) explained cooling, that is, decrease in temperature in terms of decreased particle motion.

iii) Almost 70% of students from junior high school onwards depicted liquification of gas, as gas particles coming together at the bottom or along the walls of containers. Almost 10% of students at every level, drew a continuous picture for liquid.

iv) Almost 60% of subjects beyond junior high school did not picture empty space in a gaseous medium.

Gabel et al.(1987) have tried to study prospective elementary teachers' views of particulate nature of matter. The test administered was pictorial in nature. Students were expected to draw pictures after a physical or chemical change took place. The total sample consisted of 90 students. Some of the misconceptions observed were -

i) Enlargement of atoms during phase change, that is, from liquid to gases, rather than increasing the distance between the particles.

ii) Picturing an orderly arrangement of particles of a gas.

iii) Addition of lines to show levels of liquids.

Vos and Verdonk have published a number of articles which discuss teaching of different concepts in chemistry. In one of these articles (Vos and Verdonk, 1987), they stated the different misconceptions which they observed while working with students of age 14-15 years. Some of the misconceptions were as follows -

i) After the experiment on heat conduction by metal, a student explained the phenomenon by stating that each molecule is a good heat conductor.

ii) Number of students ascribed expansion of substance to expansion of an individual molecule.

iii) Several students agreed to the statement that in living creatures each molecule is alive.

iv) The transparency of glass, water and air was explained by students in terms of the transparency of each individual molecule of these substances.

In the study conducted by Ben-Zvi et al. (1986) on class X students, they observed that even after studying chemistry for almost half a year students assigned macroscopic properties, such as, electric conductance, colour and malleability to one single atom. In other words, they perceive an atom to be the smallest part of a substance having all the properties of the substance. This indicates that students have difficulties in abandoning the continuous model of matter.

Haider and Abraham (1991) have conducted a study on high school students (N = 183) in order to understand their applied and theoretical knowledge of selected concepts based on particulate nature of matter. The concepts tested were dissolution, diffusion, effusion and states of matter. The 'application form' of the test used everyday language while the 'theoretical form' used scientific language. On an average, nearly 40% of students displayed alternative conceptions on both types of form. Dissolution was the most difficult concept of all. It was also observed that students used macroscopic reasoning at microscopic level, for example, in condensation of water, decrease in volume of water was ascribed to decrease in the size of each particle. Similarly in colouring of water by food colour, students thought that the food- colour stains the individual water molecules. It was also observed that students misinterpreted the formal knowledge or applied it too literally, for example, in case of diffusions, students stated that the food-colour combines with water molecules to form a new substance. In this example, colour change which is used by chemists as an indicator for formations of a new substance, is used by the students for describing physical change.

All these studies indicate that students have difficulties in accepting the particulate model of substances. Students hold a continuous model of matter which is revealed in their responses to various questions. As a result of this, they tend to use macroscopic properties at microscopic levels.

2.4.2 Studies on conceptions of matter

Stavy (1990) has conducted a study of students' conceptions of changes in the state of matter (N = 120; grade 4 to 9). Students were interviewed on two tasks, namely, evaporation of acetone and sublimation of iodine. Four different aspects, that is, conservation of matter, conservation of properties of matter, conservation of weight and reversibility of process were studied. She observed the following different conceptions of matter among these students -

i) Matter as a concrete solid object- In sublimation of iodine, students from grade 4 and 5 thought that matter disappeared when the crystal of iodine was heated.

ii) Matter as made up of material core and non-material properties such as smell or colour. On the acetone task, students stated that after evaporation, acetone disappeared but the smell remained.

iii) Matter exists only when there is evidence of its existence. According to some students, the acetone vapours were not matter, whereas coloured iodine gas was matter.

iv) Weight was not seen as an intrinsic property of matter, for example, students believed that gas has no weight and that gases are lighter than the same material in liquid or in solid state.

Some of the other findings were, that students were unable to recognize weight conservation on the acetone task, but were able to do so on the iodine task. This indicates the importance of the perceptual element in understanding weight conservation during the phase changes (specially from liquid to gases). Students who were able to recognize weight conservation were not aware of the reversibility of the process.

Further in her study, Stavy used these two tasks to teach conservation aspects during evaporation. The work was conducted on students from class V and VII. The students were divided into two groups. One group initially studied sublimation of iodine (where gaseous iodine was visible) and then conducted a similar task with acetone. The other group completed the two tasks in the reverse order. Stavy observed that performance on the acetone task was better when it was preceded by the iodine task. The study confirms the importance of the perceptual element, which helped students understand the two tasks by analogy. The study also draws attention to the experiments which have to be selected and their sequencing which would be useful while teaching such aspects.

In yet another study, Stavy (1991) tried to understand how students define matter, and in what way they classify given substances and other phenomena as matter or non-matter (N = 80; 20 each from grade 1,3,5

& 7). Students were asked to explain the word 'matter' and asked to judge whether they thought of a given series (matter or non-matter) as matter or not. The series included iron piece, ice cube, milk, air and other substances along with examples of non-matter (such as fire, light, smell) and some phenomena associated with matter (such as wind, electricity, heat and shadow). Students described matter -

i) by using examples (common among young students),

ii) by some function (for example, use),

iii) by structure (that is, made up of),

iv) by properties.

However, only 10% of 7th grade students assigned weight and/or volume as a property to matter. While classifying different materials, almost 50% of students did not classify liquids and biological materials as matter. Air was classified as matter by 24% of the students whereas the phenomena related to matter was classified as matter by 29% of students.

These studies indicate that students have different conceptions regarding matter. It appears that for many students matter means something which they can see and grasp. It is preferably solid and inanimate. They also have difficulty in differentiating between matter and the phenomena associated with it. This study also exemplifies that while teaching the concept of matter, it is essential to discuss different types of examples.

2.4.3 Studies on representational aspects of chemistry

Several studies have been conducted in order to understand how students interpret the symbolic language of chemistry. Ben-Zvi et al. (1988), studied students from class X (N = 275) regarding their understanding of different chemical symbols such as $Cu_{(s)}$ (for copper), $H_2O_{(l)}$ (for water) and $Cl_{2(g)}$ (for chlorine). In case of $Cu_{(s)}$, only 45% of students used some sort of a model to describe this symbol. Other students described it by using some property. For $H_2O_{(l)}$ and $Cl_{2(g)}$), 90% of the students presented models, however, 64.5% used single particle model. The study indicated clearly that students did not use multi-atomic model for description of the symbols which are used to indicate substance in liquid or gaseous state. From the descriptions given for the symbol $H_2O_{(l)}$, it was observed that nearly 13% of students had an additive view of the compound, that is, H_2O molecule equals H_2 + O. Similar findings were observed once again, in another study conducted by the same researchers, for students from class XI.

In another study by Ben-Zvi et al. (1987) on students' visualisations of reactions, 994 students from class X were tested on equations related to electrolysis reactions. Students were asked to explain the meaning of given equations through drawings. The responses of students were classified using four categories -

i) Lack of understanding - meaningless drawings

ii) Macroscopic understanding - Drawings in this category did not involve any use of models.

iv) Static microscopic representation - Student drew models representing the constituents of equation without giving the indication of something happening during the process. Some of the drawings once again revealed the use of single unit (one particle was drawn).

v) Dynamic microscopic representation - these responses either represented different stages of a reaction or they showed movements of ions to the electrodes. The number of students in this category were few.

These researchers prepared a remedial chemistry book which took into account the different misconceptions possessed by the students (discussed above). An experiment was conducted for evaluation of the text and the introductory course based on this text. The sample consisted of 1078 students from 32 different schools (538 students - control groups and 540 students - experimental group). The paper presents the analysis of sub-sample of 328 students (142 - control and 186 - experimental group). The evaluation of students' understanding of subject matter was conducted with the help of the routine achievements tests and some conceptual tests. Testing was conducted thrice during the academic year. The conceptual tests covered two topics, namely, structure of matter and chemical reactions (dynamic and interactive aspects).

The analysis of the experiment indicated that overall there was a significant difference among the control and the experimental group on the post tests. Regarding the topic 'structure of matter', it was observed that the experimental group performed significantly better as compared to the control group. Regarding the topic of chemical reaction, the performance of students in the experimental group on dynamic aspect of reaction was significantly better as compared to students belonging to the control group. However, only about half of the high ability students in the experimental group solved questions about the dynamic aspect of reaction correctly. The study indicated that the new program based on analysis of students' misconceptions did help the students in acquiring better conceptual knowledge about chemistry.

Yet another study regarding understanding of chemical equations was conducted by Yarroch (1985). He interviewed fourteen high school chemistry students on how they balance, interpret and represent simple equations pictorially. All the fourteen students balanced the given equations correctly, but half of the students were unable to draw correct molecular diagrams of the balanced equations. Students were unable to interpret the information provided by the subscripts and coefficients in the given formulae.

The above studies indicate that students generally use a single unit model (that is, a single atom or a single molecule) for symbols which stands for substances in solid, liquid or gaseous state. Even though they are able to balance the reactions, their pictorial representations are different from the scientifically accepted ones. They do not understand the dynamic aspects of chemical reactions and also have simple additive views of compounds.

2.4.4 Studies on understanding chemical reactions

Anderson (1986) has studied students in the age group 12-15 for their understanding of chemical reactions. He found that the answers of students fall under five different categories. The first four categories show misconceptions-

i) It is just that way.

ii) Displacement - New substance can appear at a given place simply because they have been displaced, for example, coating on a hot water pipe comes from the air or from hot water inside the pipe.

iii) Modification - The new substance is actually the same original substance in a modified form, for example, copper pipes turn dark due to heat, or particles in solid state become soapy in the liquid and veil-like or cloud-like in gaseous state.

iv) Transmutation - A given substance is transmuted completely into a new substance, for example, a substance in steel wool was transformed and became heavier when it was heated, or steel wool on burning was converted into carbon.

v) Chemical interaction - Acceptable explanations, for example, Oxygen reacts with copper and forms copper oxide.

BouJaoude (1991) has studied students from class VIII regarding their understanding of burning (N = 20). Some of the misconceptions observed were -

i) Substances undergo no chemical change during burning.

ii) Phrases such as physical change and chemical change can be used interchangeably.

iii) In case of burning of an alcohol, the terms evaporation and burning are equivalent to one another.

iv) Students thought that wax, alcohol and oxygen are not actively involved in burning.

Hesses and Anderson (1992) have studied students' conceptions regarding chemical change (N = 11). The analysis of interviews revealed that students commonly experienced difficulties at three different levels -

i) Chemical knowledge - Most students failed to invoke atoms and molecules as the explanatory constructs.

ii) Conservation reasoning - Students could not predict or explain mass changes in the chemical reaction. The common problem was to treat chemical change as physical change and a failure to understand the role of invisible reactants or products, such as, colourless gas in the reactions.

iii) Explanatory ideals - there was a preference for explanations based on superficial analogies with everyday events, over explanations based on chemical theories, for example, rusting was compared to decay.

2.4.5 Studies on chemical equilibrium

Chemical equilibrium is an important concept which is associated with chemical reactions. Gusssarsky and Gorodetsky (1990) have used a word association technique to understand conceptions of students about chemical equilibrium (N = 309, grade 12). They observed that students did not perceive chemical equation under equilibrium as a single entity and that they manipulated each side of a chemical equation independently. The student also failed to understand the dynamic nature of chemical equilibrium, by assuming that once the chemical reaction reaches an equilibrium, no further reaction takes place. In fact, these misconceptions were deeply rooted and resistant to change. The authors noted that students confused everyday experiences of a physical equilibrium with chemical equilibrium. In every-day usage, generally the equilibrium state is characterised as a static balanced state. The responses of students revealed that to them equilibrium referred to physical and mental aspects of everyday balance such as walking, riding or weighing.

Banerjee (1991) has conducted a study on students' and teachers' understanding of chemical equilibrium (N = 162 students; 69 teachers). Almost 35% of the students and 49% of the teachers believed that for an exothermic reaction when the temperature is decreased, the rate of the forward reaction will decrease. They also believed that the large value of equilibrium constant means a very fast chemical reaction. A large number of students and teachers thought that there were no hydrogen ions in an aqueous solution of sodium hydroxide or in distilled water.

Bergquist and Heikkinen (1990) observed the following misconceptions about chemical equilibrium in interviews of students taking a general college chemistry course -

i) In equilibrium, the forward reaction goes to completion before the reverse reaction starts.

ii) Equilibrium is attained when one or both of the original substances are consumed.

iii) Students failed to differentiate between concentration and amount of a substance.

2.4.6 Studies on phase changes of water

Osborne and Cosgrove (1983) conducted a study on children's conceptions about familiar phenomena associated with water, such as evaporation, condensation and boiling of water. Some of the misconceptions observed were -

i) With respect to bubbles in boiling H_2O, almost 35% of students believed that they are made up of H_2 or O_2. Almost 20% thought that they are made up of air.

ii) In the case of evaporation of H_2O, nearly 25% of students thought that hydrogen and oxygen from water are separated.

iii) Regarding condensation of H_2O on a cold surface, once again almost 35% of students thought that H_2 and O_2 from air are combined and deposited on the cold surface.

Bodner (1991) observed similar misconceptions for chemistry graduate students on question regarding bubbles in the boiling of water

(N = 132). Almost 25% of the students thought that bubbles were made up of air or oxygen or hydrogen.

2.4.7 Miscellaneous

Abraham et al. (1992) have studied students from class VIII for their understanding of five different concepts, namely, chemical change, dissolution, conservation of atoms, periodicity and phase change (N = 247). In the case of chemical change, almost 15% of the students possessed some misconceptions. The general misconception on a question regarding burning of a candle was that burning was a physical change (Like change of shape or form). Some of the students stated that burning is not a chemical change as no chemicals were involved in burning. Students suggested oxygen, carbon dioxide and air as the sources responsible for formation of the black soot on the glass rod held in the flame. In the case of dissolution, none of the students used the concepts of atoms and molecules in their answers. Some of the students thought that a chemical reaction was taking place in dissolution. Regarding the question on the conservation of atoms in a chemical reaction, almost 77% of students did not show any understanding. Some students changed the formula of the compound to conserve atoms. The answers for the question of stoichiometry indicated that students generally use the proportion of atoms which is initially present in the given unbalanced equation. In the case of periodicity , they observed that most of the responses revealed lack of understanding of the topic.

Abraham et al. (1994) have recently repeated the study with some modifications of questions on a cross-age sample (1994). This study included 100 students from a junior high school, a high school and an introductory college. In this study, they observed that exposure to the subject does lead to significant differences in the understanding of concepts of chemical change, dissolution of solids, conservation of atoms and periodicity. However, only a few students from college level exhibit sound understanding of periodicity, chemical change and phase change. The study brought out yet another instance of students considering the burning of a candle as a physical change, or a phase change, or essentially remaining the same substance. Some students stated that the change was chemical as the reactants were getting converted into gases. Students' reasoning for considering burning as a physical change were -

i) No chemicals are involved.

ii) You can see it physically.

iii) It gives heat and light.

In case of conservation of atoms, 32% of students thought that the coefficient is used to balance valence charge. In case of periodicity, most of the responses showed no understanding.

2.4.8 Studies on periodic table

The studies discussed in the above sections indicate that even after considerable exposure to chemistry, students do have problems in understanding the periodic table. Lehman et al. (1984) have conducted a study with students from class X, XI and XII. The nature of this study is different from those discussed so far because the study does not discuss students' conceptions. One of the aspect which was investigated in the study was the effects of structural modifications of periodic table on learning of the periodic table. Students (N = 106) from class X, XI and XII were included in this study. The study revealed that the modified table with colour, shading and visual representation of atoms included on it, was more effective for the students who had less prior experience with the periodic table. They also noted that lower ability students used the traditional periodic tables more effectively whereas higher ability students used the modified tables better.

2.4.9 Studies on problem solving and concept learning

Several studies have been conducted on problem solving and concept learning. These studies are different from the studies mentioned earlier as they do not give details of misconceptions. However, it is essential to know of these studies as they address an important point. It is often assumed that problem-solving is the application of understood knowledge. In other words, students understand different concepts in chemistry and then solve the problems. However, the studies on problem solving and concept learning have shown that this assumption need not be true. Students solve the given problems correctly without understanding the chemistry which is involved in the problem. In other words, students solve problem as algorithmic exercises.

Nurrenbern and Pickering (1987) have conducted research on students enrolled in general chemistry at the university level. Two types of tests, one traditional (using algorithmic strategies) and another on conceptual understanding (pictorial in nature) were administered to students. The questions concerned, gas laws and stoichiometry. There was a significant difference between the percentages of students responding to these two questionnaires. The percentage of students who solved conceptual questions was half as compared to those who solved the traditional questions.

An extension of the above mentioned work was conducted by Pickering (1990). The aim behind this study was to see whether the difference between the two groups of students, that is, the students successful on traditional problems and the students successful on conceptual problem is due to differences in ability to do the problem or due to gaps in knowledge. The study indicated that the difficulty with conceptual problems was due to lack of some specific knowledge rather than due to ability differences.

This study was repeated by Sawrey (1990) on a more homogenous group. The effects were also studied for the top 27% and bottom 27% students of the class. Similar findings were observed, both for the top and the bottom levels of students.

The study conducted by Nakhleh (1993) on almost 1000 students from different courses at university level once again revealed that nearly 31% of students lay in the high algorithmic and low conceptual category.

Lythcott (1990) tried to study the effect of two different instructional methods regarding problem-solving, namely, algorithmic and conceptual problem-solving on high school students. The problems involved were simple mass-mass problems. Analysis of the interviews of students (N = 13), revealed that the conceptual problem-solving approach yielded in successful gains, both understanding chemical concepts and on problem-solving performance as compared to the algorithmic approach.

2.5 Conclusion

All the studies discussed above indicate that students possess different conceptions and misconceptions regarding various concepts of chemistry. They have difficulties in accepting the particulate nature of matter. Often, students use macroscopic properties at the microscopic level. Their conception of matter varies from the scientifically accepted one. Students are unable to differentiate between chemical and physical changes and also have difficulties in interpreting the symbolic language of chemistry. The pictorial representations of the equations indicate that though students are able to balance the equations, they are unable to give correct molecular representations. Students also do not understand the dynamic aspect of chemical equations. The studies on problem solving, indicate that students possess little understanding about the chemical concepts involved in the problems. However, if instructional materials takes misconceptions into account, it does help students understand the concepts better. It is important to teach problem solving from the point of view of conceptual understanding.

The selections of correct experiments and their proper sequencing helps students in learning of chemistry.

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Chapter III

Methodology of the study

3.1 Introduction

This chapter describes the methodology of the study. Characteristics of qualitative and quantitative research methodologies are presented in section 3.2 as both these methodologies are used in the work described in the present thesis. The next sections are devoted to the participant profile of the study, the research designs used and the tools for data collection, namely, diagnostic testing and clinical interviews. The statistical procedures used for analysis of the data and the model of the periodic table developed as a part of the remedial measures are also discussed in this chapter.

3.2 Qualitative and Quantitative Research Methodologies

The terms qualitative and quantitative are used to describe different approaches to research. Both types of studies are conducted in the field of science education. In general, there is a lot of discussion about these two approaches and in what ways these two approaches differ from each other. Leedy in his book 'Practical research' (1993), has presented contrasts between the two mentioned traditions, such as,

Table 3.01 : Characteristics of Quantitative and Qualitative research

Quantitative	Qualitative
Outsider perspective-detached,objective view of understanding of facts	Insider perspective - focus on individuals and their interpretation of situations
Reality is stable - gathered facts do not change and so focuses on accumulations of facts	Reality is dynamic - and is always changing
Verification orientation - highly structure procedures used with minimum flexibility. Controlled conditions used for data collection	Discovery orientation - exploratory procedures with flexibility. Naturalistic conditions used for data collection.
Objective data - data free from feelings & thoughts of individuals and expressed through numbers	Subjective data - data exists in the minds of individuals and expressed through language
Concentrates more on reliability of results - ability to replicate the results	Concentrates more on validity of results - data that are representative of true and full picture

According to Nurrenbern and Robinson (1994), quantitative research in the field of science education generally involves designing and completing systematic, unbiased investigation of the relationship between some intellectual, psychological and instructional variable and science proficiency. This type of research involves manipulating variables in order to control natural phenomena and concentrates essentially on what can be observed (Phelps, 1994). Constructing and testing hypothesis against the facts of reality is an important aspect of such type of research. It presents statistical results using numbers. Traditionally, experimental research and survey research fall under quantitative research methodologies.

As against this, the qualitative research is concerned with individual human beings and her/his understanding. Research of this type is interactive, with extensive time spent in the field to observe, interview and record processes. The facts are presented in words. Often non-observables such as meaning, thinking and attitudes are studied using qualitative research methodologies (Phelps, 1994). The research done on students' conceptions in the field of science education falls in the qualitative traditions as this research attempts to understand individual student's ideas and his/her understanding of scientific concepts.

The work described in this thesis has two objectives: to understand students' conceptions and misconceptions and to develop and test the remedial measures developed. For the study of students' conceptions, the focus of the study was on knowing what meaning an individual student assigns to a given concept. Each word of the answers (written or oral) of an individual is important as it reveals her/his understanding. In other words, such a study emphasises the characteristics of a student's learning rather than establishing trends for the student group under study. For this purpose, qualitative methods are better suited. However, for testing of the remedial measures, a quantitative methodology has been used. This study used two groups. One group was intervened using the remedial measures and the other group was intervened without the remedial measures. The performance of the two groups was tested before and after the interventions and conclusions about the effectiveness of remedial measures were drawn by making appropriate hypotheses and by accepting or rejecting them based on statistical tests. It is clear that such a study involves controlling the other possible variables which may affect the performances of the students in the two groups. For such a study, the quantitative methodology is better suited. Hence, for testing the remedial measures quantitative methodology was used.

It is essential to remember that both these methodologies have their role in educational research. They have different foci, and have their own advantages and disadvantages. Choice of the appropriate methodology depends on the objectives of the study to be conducted. It is also important to note that qualitative studies often use quantitative data or present data in a quantitative manner. The quantitative study may also present some of its data in qualitative manner. The demarkation between the two methodologies is neither rigid nor well defined.

3.3 The Sample of the Study

The term sample is used when a group of individuals is selected from a larger group. The sample is a part of a population. The term population refers to the group of observations about which the investigator wishes to draw conclusions (Minium and Clarke, 1982).

The sample of students who participated in the study varied as the data collection was done over a period of five years (1989 - 1993). The data was collected from different schools situated in Bombay (four schools), Solapur (one school) and Dahanu (two schools). For class XI, the data was collected from two colleges one from Dahanu and one from Bombay. It was possible to conduct work at different places as the prescribed textbook and syllabus for chemistry is the same in all these places. The schools at Bombay included Municipal Corporation schools and some other schools. Out of the four schools at Bombay, three schools catered to students from low socio-economic background, and the parents of these students had low educational qualifications in general. In the case of the remaining school, students came from educated middle class families. Of the two schools at Dahanu, one school was well reputed and students from this school belonged to educated middle class families whereas the other school catered to tribal students coming from low income groups (and had parents with low or no educational qualifications). All these schools were co-educational schools. The school at Solapur had a high reputation for performance and was a girls' school. Once again in this school, most of the students belonged to middle class educated families. Regarding colleges, both the colleges had students with average academic performance and came from typical middle class educated families. It is important to note that all the above statements are based on the information obtained from the school authorities or students in informal discussions. The educational qualifications of the science teachers teaching in all these schools was B.Sc., B.Ed. (for colleges the information was not available to the researcher).

The data was collected from the students of classes IX, X and XI. Thus, for the work described in this thesis, the term population will refer to all secondary school students of Bombay, Solapur and Dahanu and the higher secondary students from colleges of Bombay and Dahanu. The general age range of the students was 13 - 18 years. The samples used for different tests or interviews differed in number, the exact details of which will be given in chapters IV and V which present analysis of the data. However, a particular test was administered across the classes, that is, either to class IX and X or class IX, X and XI. Thus, the sample for a particular test included students across the different classes. The sample at class IX and X varied between 20 to 70 students whereas at class XI, the sample varied between 50 to 70. In case of interviews, the sample generally varied between 10 to 30 students (no interviews were conducted at class XI). The students involved in the study were average or below average in their school chemistry or science performance.

3.4 The Procedure

This section will discuss the research design used for evaluation of remedial measures (that is, quantitative methodology used in the study), the data collection tools and statistical techniques used for analysis of this data.

3.4.1 The research design

In section 3.2, it is stated that conventionally, experimental designs fall under quantitative research methodology. As Wiersma (1986) points out, the term experimental research design broadly refers to a preconceived plan for conducting an experiment. In other words, in the experimental research design, the researcher tries to have some control over what will happen to the participants by systematically imposing or withholding specified conditions (McMillan and Schumacher, 1989). The basic purpose behind such designs is to investigate a cause-and-effect relationship between the manipulated condition (referred to, the independent variable) and the measured outcome (that is, the dependent variable).

MacMillan and Schumacher (1989) describe and discuss six general characteristics of experimental research. According to them for the study to be experimental, it should have -

i) the presence of two groups or two conditions,

ii) statistical equivalence of the students in different groups (this is important),

iii) control of extraneous variables,

iv) manipulation of independent variables,

v) measurement and quantification of dependent variable,

vi) use of inferential statistics.

Along with these characteristics of experimental designs, the term <u>experimental validity</u> is also an important characteristic. This term is used to refer to the degree to which an experiment answers the questions asked or the degree to which the conclusions follow logically from the study (Manson and Bramble, 1989). There are two types of experimental validities, namely, **internal validity** and **external validity**, which are important in understanding the strengths and weaknesses of experimental research designs. The term <u>internal validity</u> refers to the extent to which the extraneous variables can be controlled. It answers the question, "Did the experimental treatment make a difference in this specific experimental instance " ? (Manson and Bramble, 1989). The term external validity refers to the generalization of the experimental findings. It tries to answer the question "Can the results of the experiment be generalized to other samples at other times and settings from the population being studied?" (Manson and Bramble, 1989). If the field of education is considered then there are many extraneous variables present in any given situation. It is not possible to control all such variables even if a restrictive and artificial setting is created. Such a situation is not desirable specially in the field of education because even if such a situation is created, the responses of students in artificial situations would differ from the responses in normal settings. Therefore, such an experiment will severely hamper the generalizability of the results. Thus, balancing between internal and external validity is an important factor in any experimental design (MacMillan & Schumacher, 1989).

In general, experimental designs are classified into
a) **Pre-experimental** b) **True experimental** c) **Quasi-experimental**.

The Pre-experimental designs in general lack in two or more characteristics out of the six characteristics which are described at the beginning of this section (MacMillan & Schumacher, 1989). These designs are the simplest of all experimental designs. They use either a single experimental group or use non-equivalent experimental and control groups and thus these designs are weak in internal validity.

True experimental designs have a greater assurance of both external and internal validity. The most important characteristic of true experimental design is that they involve random assignment of subjects (MacMillan & Schumacher,1989).

In practical situations, it is not always possible to assign subjects randomly. Often, intact classes which are already organized for instructional purposes are used in experimental research. Such designs are referred to as quasi-experimental designs (MacMillan & Schumacher,1989). The designs used in this study are of this type.

The quasi-experimental design for experiment 1 used pre-tests, post-tests, experimental and control group. The design was as follows -

Table 3.02 : Quasi-experimental design for experiment 1

Group	Pre-tests	Intervention	Post-tests
Experimental	Yes	Intervention with model	Yes
Control	Yes	No intervention	Yes

An intact class of standard X students from a Municipal school at Bombay was selected for the study. The students, as described by their teachers, were average or below average in their school chemistry performances. Initially, the aim of the experiment was explained to the students in detail and two tests regarding the periodic table were administered to the students as pre-tests. These papers were then numbered as 1,2,3,4,...... The students with paper numbers 5 or multiples of 5, or close to 5 were assigned to experimental group. In other words, the students with paper number 4, 5 or 6 and multiple of these numbers were assigned to experimental group and the students with paper number 1, 2 and 3 and multiple of these numbers were assigned to the control group. However, it was observed that the two groups were non-equivalent with respects to distribution of girls and so a few students were shuffled. During the experiment, 8 students from experimental group and 4 students from control group dropped out. The mean scores of the two groups on pre-tests were tested for differences if any, by using t-test for differences. It was observed that the two groups did not differ significantly on the pre-tests. Thus, the two groups were assumed to be equivalent for the purpose of this study even though the groups were not matched on all the possible variables.

The above design used the control group for comparison and also used pre-tests which gave a feel about students' understanding of the topic before intervention. However, in this type of design, one major problem is that of selection of students which is a threat to the internal validity of the experiment. Procedure adopted for assigning students to control and experimental group is discussed above along with the reasons why the groups were considered equivalent. As both the groups were pre-tested the effect of pretests will be present for both groups. Because of pre-testing, the results could be generalised only to those groups of students who are pre-tested using these tests. Effect of diffusion of treatment can not also be denied as the subjects belonged to the same class-rooms. Lastly, one must remember that, in the field of education, it is not ethical to give treatment to one group (which will be beneficial) while denying it to the control group.

Due to the complexity of the educational field, often it so happens that weak research designs are used or have to be used in practise. Therefore, it is important that the researcher should be aware of the strengths and weaknesses of the design which is used and if possible, try to modify the design to overcome the weaknesses. The above mentioned design was modified for later study. The modified design was as follows -

Table 3.03 : Modified research design

Group	Pre-tests	Intervention	Post-test
Experimental	Yes	Intervention using models	Yes
Control	Yes	Intervention using textbook	Yes

This design was used for the second experimental work conducted at Bombay. Once again an intact class was selected for the study. The entire class was given pre-tests. The students were divided into experimental and control group using the following procedure -

The chemistry marks of students on the previous year's final examination were available to the researcher. The students were matched for their performance, based on the available data. However, the matching was not pair-wise. If four students had marks are above 25, then two students were placed per group. If there were 5 students between marks 20 to 25, then three were put in one group and the remaining two were put into another groups. Some other precautions were also taken. One precaution was that both the groups had equal distributions of girls and other precaution was that equal number of students from the two groups were interviewed. After such a distribution, the two groups were tested for significant differences between the mean marks received on the school chemistry test and on the pre-tests. It was observed that the two groups did not differ significantly in their mean performances. Thus, the two groups were assumed to be equivalent even though the groups were not matched on all possible variables. The experimental group was taught, using the model for 3 days (one session of 90 minutes per day) and then the control group was taught for the same amount of time, using the prescribed text-book. Teaching was done by the researcher. Two days after the treatments post-tests (equivalent to the pre-tests) were administered to both the groups.

In the above design, attempts were made to match the groups using the marks obtained in school chemistry test. As against the first design, this time intervention was conducted for the experimental as well as the control group and then the performance of students in the two groups was compared. An equivalent tests (the test which consisted of similar types of questions as in pre-tests) were used as post-tests. All other limitations of this research design are similar to the research design used for experiment 1. Please note that in both these studies, the intervention was conducted by the researcher.

For the experiment conducted at Solapur (experiment 3), the research design was the same as above. However, this time the experiment was conducted by the science teacher of the school. This was done to avoid any biases of the researcher. For this experiment, two classes of standard IX were selected from a girls school at Solapur. (Both these, classes were otherwise also taught by the same science teacher.) Once again, the marks of all these students on routine chemistry examination were available to the researcher. The matching of the two groups was done as discussed before. In this process, some of the students from the two classes were shuffled. As usual the purpose of the experiment was explained to the students in detail. The two groups were tested for their mean performance on regular chemistry test and also for their performance on the pre-tests which were administered to them. In both the cases it was observed that the performance of two groups did not differ significantly. The two groups were, thus, assumed to be equivalent even though the groups were not matched on all possible variables. The weaknesses of this design have been discussed earlier.

3.4.2 Tools of data collection

Diagnostic tests and clinical interviews were used as the tools for data collection. Most of the diagnostic tests were generally administrated by the researcher alone. On a few occasions, the researcher was assisted by her colleagues or school personnel. The clinical interviews were conducted by the researcher alone. The present section discusses in detail these two tools of data collection.

A) Diagnostic tests

Most of the tests which were developed and administered as a part of the work were diagnostic in nature. In general, diagnostic tests are used in diagnostic assessment. In order to understand diagnostic tests, it will be useful to understand the characteristic of diagnostic assessment along with the other two important assessments which are generally used in the field of education, namely, formative and summative.

In this study the words assessment and evaluation are used synonymously. The terms assessment/ evaluation refers to the process of drawing conclusion from a study using data gathered as a result of measurement (Armstrong and Savage, 1990). It requires interpretation and it is judgemental. It differs from measurements, which is simply the process of gathering information (Armstrong and Savage, 1990). In other words, measurement is the process of assigning numbers to individuals or to their characteristics according to specific rules (Ebel and Frisbie,1986). Tests represent one particular measurement technique . A test is a set of questions which examinees usually answer orally or in writing. In other words, tests are a subset of measurements which in turn are a subset of assessment/evaluation (Ebel and Frisbie,1986).

As stated before, there are three different types of assessments: i) **Summative** ii) **Formative** iii) **Diagnostic**

The first two terms were introduced by Scriven (Ebel and Frisbie,1986) to describe the role of evaluation in curriculum and instruction.

i) **Summative assessment** : is generally conducted at the end of an instructional segment. The main aim of such an evaluation is to know whether the learning is sufficiently complete so that the subsequent instructional segment can be started for the learner (Ebel and Frisbie,1986). Such an evaluation determines the status of achievement at the end of instructional segment. Unit tests and final examinations are examples of summative evaluation. The summative information collected is generally less detailed but it is broader with respect to the content or skill assessed .

ii) **Formative assessment** : is generally conducted while teaching is going on, in order to discover what students are learning (Carin, 1993). The main use of such an assessment is in the form of feedback to the teacher and to students about how things are going on. The feedback to the teacher helps in modifying lesson plans and teaching methods (Carin, 1993). Such an evaluation requires frequent data gathering over time. Generally, short tests, assignments, classroom questioning, teacher observations are used as tools in such types of evaluation.

iii) **Diagnostic assessment** : The main aim of such an assessment is to discover what students know and do not know prior to the teaching. Such data provides inputs about students' strength, weakness and interests (Carin, 1993). Generally, informal questioning or paper-pencil devices are used as tools for data collection. Diagnostic tests are useful before the teachers begin teaching. They generally provide a variety of exercises and problems graded in difficulty in a somewhat restricted range of instructional objectives (Mehrens & Lehmann, 1984). Errors on such tests are analyzed to indicate potential deficiency. A good diagnostic test permits the user to obtain an accurate picture of students' conceptions and misconceptions that results in students' errors (Mehrens & Lehmann, 1984). Such diagnostic testing is important as it will help the teacher to build her/his teaching around the knowledge possessed by students. It will also help the teacher to determine what specific experience will help in better learning of science.

Several diagnostic tests were developed as a part of this study. Each test concentrated on a particular concept. The tests which were formulated and administered in the study were -

1) Test on balancing chemical equations - Students were asked to balance various equations given to them (appendix 4.01).

2) Test on identifying and correcting the given errors and then balancing the equations - In this test, some errors were deliberately introduced in equations. Students were asked to locate and correct the errors and then balance the equations. Corrections of errors required an understanding of symbolic representations of atoms, molecules, valencies of elements and radicals (appendix 4.02).

3) Test on interpretation of a given equation - In this test, students were given a fairly simple chemical equation and were asked to answer questions about the reactants and the products and the number of molecules of the substances involved, the reversible sign and the meaning of subscripts and coefficients with respect to element and compound (appendices 4.03 & 4.04).

4) Tests on stoichiometry - This test was administered to see students' understanding of quantitative aspects of chemical reactions. Once again, a simple chemical equation describing the formation of NH_3 was given and the students were asked to state the number of molecules of reactants, when the number of molecules of product are given and vice versa. One more mathematical test (similar to the chemistry test) was administered along with this test. This test was administered to learn whether students were lacking in understanding of proportions involved in the equations or the chemical concepts and their symbolic representation (appendices 4.05, 4.06, 4.07 & 4.08).

5) Test on chemical symbols - Various chemical symbols were presented in the test and students were asked to give their pictorial representations and meaning in words (appendix 4.09). Another test on symbols included questions regarding symbols of different elements (appendix 5.12).

6) Test on atomic structure and electronic configuration - Both these tests were used in the experimental work conducted at Solapur using the periodic table model. The questions concentrated on atomic number, charge on nucleus and atom, stating electronic configuration from total number of electrons and changes in electronic configuration in ion formation (appendices 5.08, 5.08A, 5.09 & 5.09A).

7) Test on valency - This test consisted of questions on defining valency, calculation of valency, valency and chemical properties and valency

and reactivity. This test was administered in the experimental work conducted at Solapur using the periodic table model (appendices 5.10 & 5.10A).

9) Test on writing chemical formulae - The questions in this test were two types, i) writing the formula of a given compound using the valencies and ii) writing formulae of similar compounds from given information. Once again, this test was used at Solapur (appendices 5.11 & 5.11A).

10) Tests on the periodic table - These tests were used in the experimental work regarding the periodic table. One test concentrated more on the factual information regarding the periodic table and the other test concentrated on the variations of different properties in the periodic table (appendices 5.01 to 5.04). Another test on the periodic table was used at Solapur. This test was a multiple - choice type and had questions similar to those from tests discussed above (appendix 5.13).

Generally, the questions in the diagnostic tests were open-ended. The number of question per test often varied between 5 to 10. No time limit was set for the completion of the tests. However, the time taken for completing different tests varied between 5 minutes to 40 minutes.

B) Clinical Interviews

Besides diagnostic tests, clinical interview which is an important data collection technique used for understanding students' conceptions and misconceptions was used in the thesis.

Clinical interviewing is in general is directed towards the information gathering function (Posner and Gertzog, 1982). Its important aim is to ascertain the nature and the extent of an individual's knowledge in a particular domain by identifying the relevant conceptions held and the perceived relationships among these conceptions (Posner and Gertzog, 1982).

The major credit for developing the clinical interview approach, which is suitable for the field of science education, goes to Jean Piaget who in 1920's developed the clinical method for investigating the nature and extent of children's knowledge (Posner and Gertzog, 1982). He preferred this method over testing and observation (Ginsburg and Opper, 1979) because in tests, a series of questions are asked to all students in a similar manner and they are administered to a large sample (Ginsburg and Opper, 1979). However, tests have a disadvantage, that is, they are inflexible. The meaning of inflexibility is that if a student gives an interesting response, it is not possible to pursue it or if a question is misunderstood by the student, it is not possible to clarify it. It is also possible that the answers on tests need not reveal the content of students' spontaneous thought.

According to Ginsburg and Opper, another useful method for investigating students' spontaneous thinking is observation. It is an ideal method, specially suited for young children. However, a lot of time has to be spent on observation and it can not be used as the chief instrument of research (Ginsberg and Opper,1979). Piaget thought that the clinical method avoided the drawbacks both of testing and the observational method. The basic aim behind this method is to follow a child's (or students') thought without deforming it by suggestion or imposing the adult view. Such an interview is deforming it by suggestion or imposing the adult view. Such an interview is guided by students' responses. It is clear that such an interview will depend a lot on verbalization and it is possible to misinterpret these responses. Piaget himself realised these drawbacks and modified his procedures. In the new modified method, that is, revised clinical interview, he used concrete objects or events (Ginsberg and Opper, 1979). In this, he tried to provide ample opportunities to a child so that answers could be obtained by manipulating these objects. He also suggested use of counter-arguments or counter suggestions. These involved presenting a point of view which was contradictory to what the child was saying and asking the child to comment on it. This helps in determining the stability of child's thinking. Once again, the questioning is flexible and no standardised procedures are followed.

The interview techniques used today are modified versions of revised clinical interviews. However, the principles behind all these techniques are similar to those discussed above. Two of the important modified techniques are -

i) Interview - about - Instances (Osborne and Gilbert, 1980).

ii) Interview - about - events (Gilbert et al., 1982).

All interviews conducted in this study were conducted by the researcher alone who kept exhaustive notes of all the interviews. These interviews depended largely on verbal responses of the participants. However, in some of the interviews, pictorial diagrams were shown to the students along with other questions or in some other interviews, students were expected to draw diagrams. Interviews on the periodic table used the periodic table from the textbook. The interviews conducted were about -

1) Chemical equations - In this interview students were asked to balance four different reactions. Then they were interviewed regarding the subscripts and coefficients, atoms and molecules, valency and pictorial representations of equations (see appendix 4-I).

2) Elements, compounds and mixtures - The interview concentrated on how students define these concepts, what examples they present along with reasoning and understanding of these concepts in terms of atoms and molecules (see appendix 5-I.2).

3) The periodic table - These interviews concentrated on understanding of the structural aspects of the periodic table (that is, group, period, information presented in the periodic table, basis for classification), the prerequisites (that is, properties of elements, atomic number, atomic weight, valency) and the new words related to the periodic table that is, period, periodicity, periodic event and periodic function (see appendix 5-I.1).

In all these interviews, the general outline of an interview was decided, however, the questions varied depending on students' responses. Any particular interview involved a single student at a time. Before the interview, the aim of the interview was explained to the student in detail (see appendix 4-I). A typical interview lasted for about 40 - 50 minutes. Different where the analysis of interviews is presented.

Interviews were conducted for students belonging to different schools in Bombay and Solapur. The students interviewed were above average, average or below average in their routine chemistry/science performance. The interviews were conducted either with, or without a preceding diagnostic test.

3.4.3 Analysis of quantitative data

The data on evaluation of remedial measures, which used a quasi-experimental designs, were analyzed using statistical techniques (the t-test). The analysis was done on a PC at HBCSE, using the statistical package for social sciences (SPSS/PC+, version 2.0) (Norusis, 1988).

A statistical hypothesis is a statement about one or more population distributions, and specifically about one or more parameters of such population distributions (Hays, 1988). It is a statement which is always made about the population and not about the sample. Statistical hypotheses are tested using appropriate statistical tests. Generally, the hypothesis which is tested is known as the null hypothesis and is denoted by the symbol 'H_o'. The null hypothesis asserts that there is no difference (say, between the population means). This is the hypothesis against which the researcher often hopes to gather evidence. The alternative hypothesis denoted by H_a or H_1, specifies those values that the researcher believes would hold true. This hypothesis is assumed to be true when the null hypothesis is false. It is the hypothesis for which the researcher wishes to gather supporting evidence. Both these hypotheses are mutually exclusive and must be stated clearly before any statistical test of significance was carried out.

After setting up the hypotheses, the next step is to test the validity of H_0 against H_a. The confidence with which the researcher accepts or rejects a null hypothesis depends upon the levels of significance set up. The levels of significance which are generally used in educational research are the 0.05 and 0.01 (Blalock, 1972). The level of significance indicates the probability of rejecting the null hypothesis. The decision of rejecting or accepting a hypothesis depends upon whether the sample result falls in region of rejection or in the region of acceptance. If the sample results fall in the region of rejection, it means that the sample observations are not consistent with the null hypothesis and so the null hypothesis is rejected (Gupta). In other words, it means that the observed differences are significant and that the difference are not due to chance.

The alternative hypothesis can be of two types- i) **Non - directional (or two tailed)** ii) **Directional (or one tailed)**. The non - directional hypothesis, does not specify the departure from H_0 in a particular direction. In such cases, the null hypothesis will be rejected if the sample value falls in an extreme position on either side of sampling distribution. The directional hypothesis is the one in which the alternative hypothesis is directional and included in symbols " < " or " >". It specifies the tail of sampling distribution.

3.4.3.1 Test of differences in means (t-test)

The Student's t-test can be used to test whether there are any differences between the means of two populations (Blalock, 1960). In this study, t-tests were used to see whether the differences in the mean performance of the experimental and the control group before and after the intervention (that is, between group analysis) were significant. The assumption made in order to use the t-distribution are (Blalock, 1960) -

i) the two samples are random

ii) the two populations are normal

iii) the two populations have the same variance

The t-value is calculated as follows -

$$t = \frac{(\overline{X_1} - \overline{X_2}) - (\mu_1 - \mu_2)}{\sqrt{S_p^2(\frac{1}{n_1} + \frac{1}{n_2})}}$$

$$S^2_p = (n_1\text{-}1)\ S_1^2 + (n_2\text{-}1)\ S^2_2 / n_1 + n_2 - 2.$$

	Sample 1		Sample 2
n_1 =	sample size	n_2 =	sample size
X_1 =	sample mean	X_2 =	sample mean
S_1^2 =	Variance of sample 1	S_2^2 =	Variance of sample 2

Sample 1 drawn from population with mean = μ_1 and standard deviation σ_1 and sample 2 is drawn from population mean = μ_2 and standard deviation σ_2. Since under the null hypothesis it is assumed that $\mu_1 = \mu_2$, the term $(\mu_1 - \mu_2)$ in the above formula is zero. Thus, the above formula reduces to

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{s_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

The variance of two populations are assumed to be equal and therefore, then the pooled variance S_p^2 is used which is the weighted average of the separate sample variances (S_1^2 and S_2^2). This formula can be used only if the assumption about variance (that is, assumption iii) is true. Thus, this assumption should be checked before using the pooled variance. The F value which is the ratio of the larger sample variance to that of the smaller one, is used to test this assumption. If the significance of the F value is low then the hypothesis that the population variances are same is rejected and separate variance t-test is used rather than pooled variance t-test. The separate variance test calculates t value as follows -

$$t = \frac{(\overline{X}_1 - \overline{X}_2)}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

The t - test was also used for the questionnaire for ranking of various topics from the chemistry syllabus based on students' and teachers' rating of the topics. This was done to learn whether the two set of rankings of the same topics differ significantly or not. The t- test was used even though the data are of the ordinal type. The ordinal data can be treated as interval and the t-test can be used for such data (Kerlinger, 1983).

Another form of t - test is used for paired data, that is, when the same individuals are tested twice. This t-test is called as paired t-test (Norusis. 1988). This t - value is calculated as

$$t = \frac{\overline{D} \times \sqrt{N}}{S_D}$$

D = the observed difference between the two means

S_D = the standard deviation of the paired observations

N = number of pairs

This formula of the t-test was also used in this study to see the differences in the mean performance of a particular group on the pre-tests and the post-tests (that is, within group analysis). In other words, this test was used when same individuals from a particular group were tested twice (that is, on the pre-tests and the post-tests).

3.4.4 Analysis of the qualitative data

The data of diagnostic tests and clinical interviews were analyzed qualitatively. In case of the tests, the errors or the wrong answers were analyzed in detail and similar types of errors were grouped together. For example, for the test on balancing equations, the errors were categorised as : i) wrong numerical balancing ii) balancing by changing subscripts iii) balancing by adding new product iv) balancing of only one or two elements and v) blank/no responses. The categorisation varied from test to test and sometimes it was not possible to categorise all the answers. The details of the analysis are presented in chapters IV and V where the analysis of various tests and interviews is presented.

For interviews, often the answers were grouped as i) correct answers, ii) other answers or incorrect answers, iii) meaningless answers and iv) no answers. The other answers were analyzed in detail as these are important for studying misconceptions, and then the misconceptions and probable reasons of such misconceptions are discussed. The details of such analysis are presented in chapter IV and V where the analysis of interviews is presented in detail. However, one point should be noted that in all these studies, there was no control for teachers (as it was not possible to observe lessons of the different science teachers).

3.4.5 The periodic table model

As a part of remedial measures, a three dimensional periodic table model was developed. The objective in preparing the model was that it should give opportunities to the students to fill necessary information whenever required and thus, construct the periodic table. In other words, it should help in interactive teaching of the periodic table.

The model was prepared using transparent cube-shaped plastic boxes. Different types of information about an element were displayed on the four different faces of the box. For example, face one showed the name, symbol and the atomic weight of an element. The second face showed the symbol along with the atomic number, and other information such as whether the element is solid, liquid or gas at room temperature and whether it is a metal, a nonmetal or a metalloid. The third face displayed the electronic configuration whereas the fourth face showed some properties of the element (See figure 1). The displayed information could be changed any time just by removing the inserted cards from the boxes. For example, in case of the elements predicted by Mendeleev, one of the surfaces could purposely be kept blank. The students could then be asked to guess the properties of these missing elements from the properties of other elements belonging to the same group. This activity would help students to understand the importance of Mendeleev's work.

Such boxes were prepared for every element. Holes were made in the boxes through which steel rods were passed and the boxes were arranged in groups. A simple aluminium frame was used to support the columns of the boxes. The distance between the two columns was adjusted in such a manner that each box could rotate freely around the vertical axis. Small rubber pieces were inserted between two successive boxes to reduce friction. In case of the lanthanides and the actinides, two bunches of 14 cards each were prepared and were tied at their appropriate places in the model (See figure 2). Each card included the name, symbol, the atomic weight and the atomic number of the corresponding element.

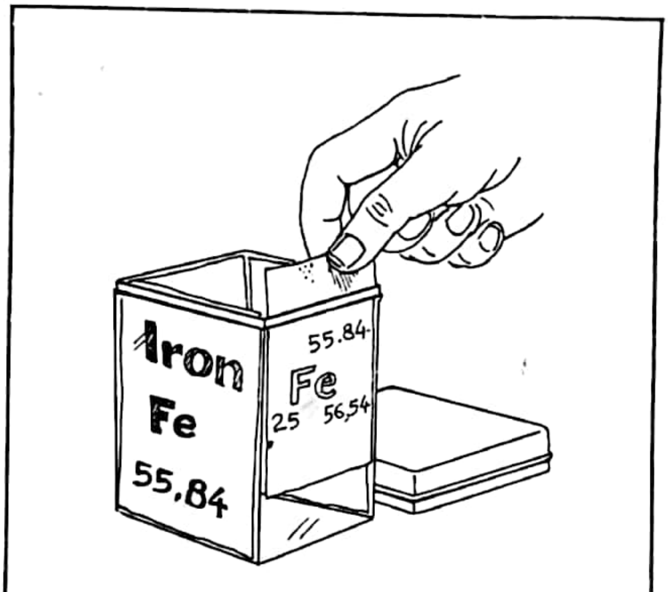

Fig. 1

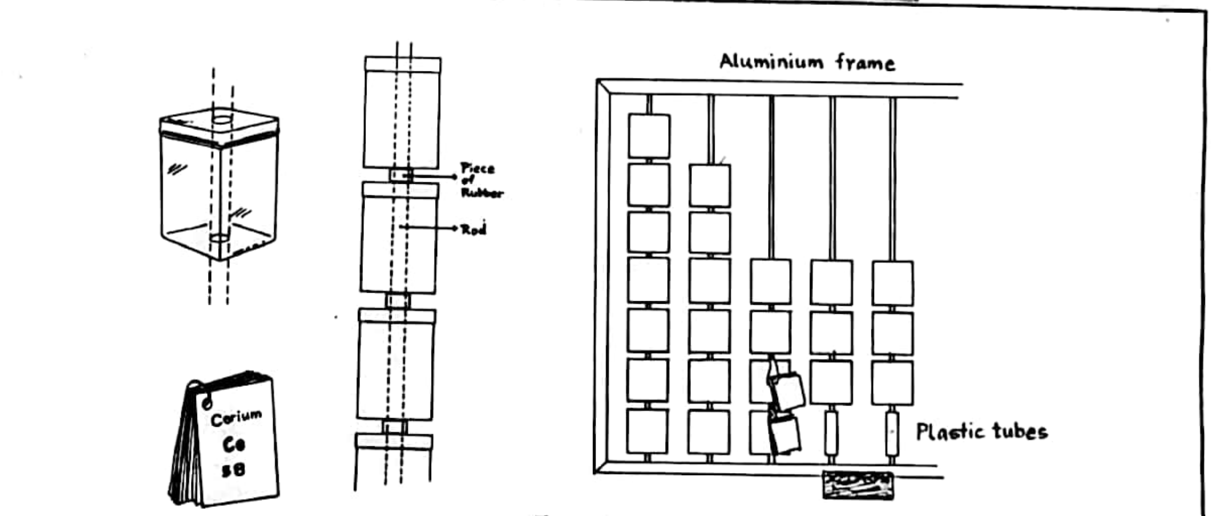

Fig. 2

3.4.6 The book on periodic table

As a part of the work on periodic table, a book on periodic table was written (Ladage and Kulkarni, 1993). This book essentially discusses the historical perspectives of the growth of chemistry relevant to the formulation of the periodic table. It attempts to present various concepts related to the development of the periodic table such as elements, concept of atomic weight and its determination by various people, the First Chemical Congress and its impact on attempts of formulation of the periodic table, some of the important attempts at formulation of the periodic table before and after the Congress and the incorporation of rare earths, rare gases and transition elements in the periodic table. Briefly, the book discusses the modern basis of the periodic table. The book is aimed primarily at higher secondary level. While most of the concepts discussed in the book are covered in the syllabus at +2 level, it is hoped that serious students at the secondary level will find it useful since attempts are made to explain the concepts which are outside the syllabus in a lucid manner. There is yet another purpose for writing such a book. Science, especially chemistry and physics tends to be presented in a dry, impersonal manner, which can hardly be expected to let the readers appreciate the thrills and disappointments of people who made these sciences. This book is an attempt to fill this gap. The book is published by Oxford University Press and is enclosed in (appendix 3).

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CHAPTER IV

WORK ON CHEMICAL EQUATIONS AND FORMULAE

4.1 Introduction

This chapter presents the analysis of work done regarding students' understanding of chemical equations and formulae. Section 4.2 describes various concepts required for understanding of the chemical equations and gives the background of this study. Subsequent sections describe various tests and interviews conducted to learn students' conceptions of the topic and analysis of these tests and interviews.

4.2 Background

The primary purpose of chemistry is to describe and to explain chemical changes on the basis of which we understand how one substance is converted into another. Chemical changes are expressed in a symbolic language, that is, in the language of chemical formulae and chemical equations (representational aspect of chemistry). In other words, chemical equations are the means to describe in a precise symbolic language, all the necessary information, such as, the composition of reactants and products, the state and proportion of reactants and products and the energy changes. It is, therefore, necessary for students of chemistry to be well-acquainted with this symbolic language of chemistry. However, it is observed that the representational aspect of chemistry is perceived to be difficult by students especially at the secondary school level (Ben-zvi et al., 1988; Yarroch, 1985; Savoy, 1988). As stated in the introductory chapter, the survey conducted by the researcher herself revealed that the topic of `chemical formulae and chemical equations' is perceived as one of the most difficult topics at the school level (see chapter I, section 1.3.1.2).

To understand and to balance any chemical equation, knowledge of a number of concepts in chemistry is essential, in the absence of which, students would not be able to express or understand chemical changes. Savoy (1988) has described the different concepts required for understanding of chemical equations along with their hierarchy. Figure 4A represents the different concepts and their hierarchy as described by him.

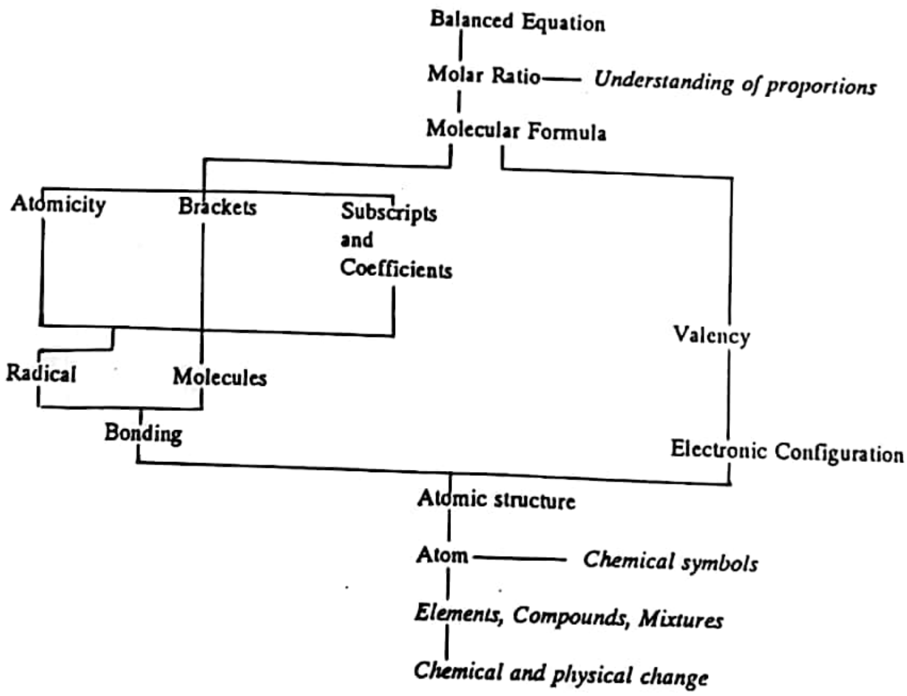


Figure 4A : Different chemical concepts and their hierarchy for an undersatnding of chemical equations

The concepts in italics are modifications suggested by the researcher.

Most of these concepts are covered in the school chemistry syllabus prescribed by the government of Maharashtra (chapter I, section 1.3). In brief, topics such as classification of matter, physical and chemical change and atoms and molecules including their chemical symbols, are introduced at class VIII while topics of atomic structure, valency, chemical formulae and equations are introduced at class IX. It is important that students should understand various concepts and their interconnections mentioned in the above diagram for a meaningful learning of representational aspect of chemistry. Studies about understanding of chemical equations which have been conducted so far are reviewed in chapter II (section 2.4). The work described in the thesis attempts to study students' conceptions and misconceptions regarding chemical equations and various related concepts which are mentioned above. Different diagnostic tests were prepared and were administered to students to learn their understanding of these concepts.

4.3 Test on balancing equations

4.3.1 Methodology

i) <u>Tests</u>

Two tests on chemical equations were administered to the students of class X and XI. The first test consisted of seven skeleton equations to be balanced (see appendix 4.01). The second test consisted of correcting and then balancing of five different equations containing some errors (see appendix 4.02). Corrections of errors in the equations required an understanding of concepts such as atomicity, subscripts coefficients, use of brackets and valencies and their representation in the formulae. This test was administered to the same students to whom the first test was administered. Apart from this sample, the second test was also administered to the students of class XI. Table 4.01 presents the details of the tests administered.

Table 4.01 : Tests on balancing equations

Test	Number of questions	Time taken (min.)	Appendix number	Class
Test on balancing	7	10 - 15	4.01	X
Test on identifying and correcting errors and balancing equations	5	20 - 40	4.02	X & XI

ii) Sample

As stated above the tests were administered to class X and XI. At class X, both the tests were given in two schools, one from Solapur (girls' school) and another from Bombay. Both these schools had `Marathi' as medium of instruction. The total sample consisted of 73 students. The performance of students from the school at Bombay (chemistry) was average or below average, while that of the students from Solapur school was average (mean marks = 24 out of 40). As the marks of the students from the school at Bombay were not available to the researcher, the description is based on the information provided by the science teachers. The age range was about 14 to 16 years (this data was not available for the Solapur sample).

At class XI, the test was administered in two colleges, one from Bombay and one from Dahanu. In both the colleges, the students had average performance in chemistry (mean chemistry marks at Dahanu = 50/100, at Bombay = 54/100). The total sample consisted of 78 students. The age range was 16 to 18 years. The distribution of the total sample for the two tests is presented in table 4.02.

Table 4.02 : Sample of students for test on balancing equations

Class	Test on balancing	Test on error & balancing	Age range (years)	Time when the test was administered
X	73 S = 35, B = 38	73 S = 35, B = 38	15 - 16	S = beginning of 2nd term, B = end of 2nd term
XI	-	78 D = 43, B = 35	15 - 18	D & B = end of 2nd term

S = Solapur, D = Dahanu, B = Bombay

4.3.2 Analysis of the tests

The analysis of the first test revealed that even after learning and using the chemical equations for more than a year, students had difficulties in balancing the given equations. Table 4.03 displays the number and percentage of successful and unsuccessful students on the test of balancing equations. It is important to note that the analysis is done for the total sample, that is, all the students from class X. Discrimination indices (D.I.) for different equations are also given in the table. The D.I. is calculated as follows -

D.I. = No. of students in in top 25% of class - No. of students in bottom 25% of class

The total number of students in top 25% of the class was 26 whereas the number of students in bottom 25% of the class was 27.

Table 4.03 : Students' performance on the balancing chemical equations test (N=73)

Equations	Number and % of			D.I.
	successful students	partly successful students	unsuccessful students	
1. $KI + Br_2$ -- $KBr + I_2$	58 (80%)	5 (7%)	10 (14%)	3
2. $NaOH + H_2SO_4$ -- $Na_2SO_4 + H_2O$	44 (60%)	17 (23%)	12 (16%)	11
3. $Al + O_2$ --- Al_2O_3	31 (43%)	13 (18%)	29 (40%)	16
4. $Al_2O_3 + HCl$ --- $AlCl_3 + H_2O$	38 (52%)	12 (16%)	23 (32%)	17
5. $ZnSO_4 + Al$ ---- $Al_2(SO_4)_3 + Zn$	40 (55%)	12 (16%)	21 (29%)	16
6. $C_3H_8 + O_2$ --- $CO_2 + H_2O$	25 (34%)	29 (74%)	19 (26%)	17
7. $NO_2 + H_2O$ --- $HNO_3 + NO$	23 (32%)	8 (11%)	42 (58%)	17

The discrimination indices indicate that almost all the equations except equation 1 were able to discriminate between the performance of successful and unsuccessful students to almost the same extent. It is also clear from the above table that equation 3, 4, 6 and 7 were the most difficult equations for the group whereas equations 1 was the easiest one.

Table 4.04 presents students' performance on the test of correcting errors. The students' responses to the errors can be classified in five categories -i) not identified (code - 0),

ii) identified and corrected (code- 1),

iii) identified but corrected wrongly (code - 2),

iv) blank (code - 4).

Table 4.04 : Students' performance on the identification and correcting errors test (class X, N = 73)

Errors	0	1	2	4
K_2*	52 (71%)	15 (21%)	1 (1%)	4 (9%)
$2NaSO_4$	49 (67%)	20 (27%)	2 (3%)	2 (3%)
2HO	5 (9%)	64 (88%)	2 (3%)	2 (3%)
HO_2	2 (3%)	66 (90%)	-	5 (7%)
$ZnOH_2$	24 (33%)	32 (43%)	12 (16%)	5 (7%)
2O	10 (14%)	54 (74%)	-	9 (12%)
Al_2O_2	43 (59%)	18 (25%)	3 (4%)	9 (12%)
$Al_3(SO_4)_2$	44 (60%)	11 (15%)	10 (14%)	8 (11%)
$NaSO_4$	31 (43%)	18 (25%)	16 (22%)	8 (11%)

* - The correct representation is 2K.

Table 4.04 indicates that the percentage of students who identified and corrected the errors for formula of water or for molecular formula of oxygen was high (about 80%). However, for all the other errors, this percentage was small and varied mostly between 15% to 28%.

The test containing errors was also administered at class XI. Similar analysis for the test was conducted for the total sample of students from class XI. The results of this analysis is presented in table 4.05 (the codes are the same for the responses).

Table 4.05 : Students' performance on identifying and correcting errors test (class XI, N = 78)

Errors	0	1	2	4
K2*	66 (85%)	12 (15%)	-	-
$2NaSO_4$	31 (40%)	45 (58%)	2 (3%)	-
2HO	10 (13%)	68 (87%)	-	-
HO_2	18 (23%)	57 (73%)	1 (1%)	2 (3%)
$ZnOH_2$	35 (45%)	37 (47%)	4 (5%)	2 (3%)
2O	22 (28%)	52 (67%)	-	4 (5%)
Al_3O_2	50 (64%)	22 (28%)	2 (3%)	4 (5%)
$Al_3(SO_4)_2$	50 (64%)	12 (15%)	2 (3%)	14 (18%)
*$Na(SO_4)_2$	32 (41%)	20 (26%)	10 (13%)	14 (18%)

(* - The tests at class X and class XI differed only for this error. At class X, the error given was NaSO4 instead of $Na(SO_4)_2$.)

The above table reveals that the performance of students at class XI is almost as poor as that of students at class X. Even after studying chemistry for almost four years, these students had problems in identifying and correcting the given errors. The percentages of students who were unable to correct various errors (except that of water and oxygen) varied between 40% to 85%. In other words, exposure to the subject for an additional year has not changed the performance of the students.

4.3.3 Discussion

The results presented in Table 4.03 indicated that even the simplest equation, that is, equation 1, was not balanced by all the students. While the success rate of 80% seems high in comparison to that for other equations, failure of nearly 20% of students on so simple a task does not augur well for the eventual progress of the class, and therefore, deserves attention. In the case of the other equations, more than 50% of the students have failed to balance them. In general, the wrong responses in balancing the equations can be classified into four different categories-

i) balancing of only one or two elements (12%- 24%),

ii) balancing by changing the subscripts or by adding new products (7% - 21%),

iii) wrong numerical balancing (especially for equations 6 & 7 - 33% & 26%),

iv) blank (5% - 8%).

The same table also indicates that equation 7 was the most difficult equation to solve. Two possible reasons for the difficulties could be -

i) the element oxygen occurs in all the reactants and in all the products; a situation which is probably unfamiliar and more complicated than one in which all the atoms of a given element are lumped in one substance.

ii) the total number of oxygen atoms on the reactant side is odd whereas that on the product side is even, which defies the familiar trick of finding a simple multiplier to balance the equation.

In case of equation 7, students changed the product NO to NO_2. Equation 3 was also difficult for the students, once again probably due to the fact that the number of oxygen atoms in the reactant is even whereas it is odd in the product. Regarding this equation, students concentrated on aluminium, ignored oxygen and tried to balance it by adding a coefficient of 2 on the reactant side. Some students balanced it as; $2Al + 3O_2$ ---- Al_2O_3 (that is, paying attention to subscripts of products and adding same numbers as coefficients on the reactant side). Attempts were also made to balance it by changing the reactant Al to Al_2 or Al_3, by changing O_2 to O_3 or O_6 (similar errors were committed in equation 5 -changing Zn to Zn_2 or Zn_3 or Al to Al_2). Sometimes students tried to balance the equations by matching the product to reactant or vice versa, for example, in equation 4 the product $AlCl_3$ was converted to Al_2Cl_3 or the product H_2O was changed to H_2O_3 (similar to the reactant Al_2O_3). Such attempts were also made by a few students for equation 5 by changing $ZnSO_4$ to $Zn(SO)_3$ which resembles the product $Al_2(SO_4)_3$.

The above analysis reveals that students try to balance chemical equations in a mechanical manner, that is, they try to equalize the number of 'atoms' in reactants and products by adjusting numerical subscripts, disregarding the sanctity of molecular formulae. Another example illustrating this point was provided by a student who balanced equation 6 as $C_3H_8 + 2O_2$ ---- $CO_2 + H_2O$, by adding a new product $(CH_3)_2O$. The student simply counted the number of atoms of all elements which were excess on the L.H.S. and added them on the R.H.S. as a new product. Such responses indicate that students consider chemical equations as a numerical exercise, and probably draw upon their experience in tackling algebraic equations, in balancing atoms on both sides without understanding the `symbolic language'. It is worthwhile investigating if current instruction fails to zoom in on the `symbolic language' part of chemistry. The concern for balancing equations correctly needs to be based on understanding of chemical concepts and hence on the chemical language.

It is also clear from the above discussion that inadequate responses of students are only partly due to errors in numerical calculations. Lack of understanding of chemical concepts and chemical language appears to be a more important source of errors. The precise meaning of a subscript in a molecular formula, and the coefficient applied to the entire formula which constitutes an important aspect of chemical language are not understood. Balancing equations by writing Al_3 instead of 3Al and similar other errors mentioned above indicate that students fail to distinguish between subscripts and coefficients. Such responses also reveal that students have a poor understanding of the elemental or molecular nature of elements. The change of chemical formulae such as NO_2 (for NO), H_2O_3 (for H_2O), Al_2Cl_3 (for $AlCl_3$), $Zn(SO_4)_3$ (for $ZnSO_4$) illustrates how students, over-concerned by the need to balance the number of atoms, disregard valencies of elements and radicals even though they have been exposed to these concepts. Clearly, attention is needed to convert `exposure' into `internalization'.

In connection with the second test, Table 4.04 reveals that the percentages of students who failed to identify and correct the errors was high in general. Nearly, 71% of the students failed to identify the error K_2, while 14% of the students have not been able to identify the difference between 2O and O_2. Similarly, new errors were also created by the students in attempting to balance equations, for example, Br or Br_3 for Br_2, Al_3 or Al_2 for 3Al and 2Al. It once again indicates that atomic and molecular nature of different elements, as well as the significance of subscripts and coefficients, are not understood by the students. The wrong chemical formula $2NaSO_4$ in equation 2 was not identified by 67% of the students. For the same error in equation 5, about 22% of students have made wrong corrections, such as, $Na(SO_4)_2$ or $Na2(SO_4)_3$ or $Na_2(SO_4)_2$. For the same equation, 60% of the students have either failed to identify the error $Al_3(SO_4)_2$. Some students tried to correct it as Al_3SO_4 or $Al_2(SO_4)_2$ or $Al_3(SO_4)_3$. All these changes in formulae of sodium sulphate and aluminium oxide were essentially made simply to balance the number of atoms in the given equation. In the case of equation 4, a wrong formula of aluminium oxide (Al_3O_2) was not identified by 59% of the students. Al_3O_2 may be slipped over and read as Al_2O3 in a running test (proof reader's error) but not in balancing an equation. Most of the students did not make any attempt to balance this as the given equation itself appeared to be balanced (3Al + 2O --- Al_3O_2). In the case of equation 3, 33% of the students failed to identify or to correct the error $ZnOH_2$. Nearly, 16% of the students tried to correct it as $Zn+(OH)_2$, $ZnO_2 + H_2$, ZnH_2O or as $ZnOH_2$ + H_2O. Thus, it becomes clear from these responses that the understanding of valencies is poor and that importance of brackets as well as the concept of radicals are not clear to the students. All these responses also raise doubts whether classroom exposure to chemical reactions has led to an understanding of the concept of `compound'. Responses such as Zn + $(OH)_2$, ZnO_2 + H_2 indicate that $Zn(OH)_2$ is not viewed as an entity. Such responses also raise doubts regarding students' understanding of the interactive aspect of chemical reaction (that is, bond breaking and bond formation).

After discussing the test for class X, it will be useful to see the responses of the students in class XI for the same test. It is possible to compare the percentage of the students who failed to correct given errors at these classes. For corresponding percentages, see table 4.04 (for class X) and 4.05 (for class XI).

From table 4.05, it is clear that the performance at class XI was also poor in general. It indicates that even after considerable exposure to the subject, the representational aspect and its connections to other concepts of chemistry is still not internalised by students. Like class X, the percentage of students who failed to correct error K_2 , that is, error due to atomicity, was 85% (class X - 71%). In case of 2O (that is, oxygen), the percentage of unsuccessful students at class XI is 28% (the corresponding percentage at class X was 14%). These responses once again indicate that the atomic and molecular nature of different elements and significance of subscript and coefficient are not clearly understood by the students. Some new errors of similar type such as Al_3 or Al_2 instead of 3Al or 2Al in equation 4 and 5 were committed by 31% and 17% of students respectively.

The percentage of students who failed to correct the error $2NaSO_4$ was less compared to the corresponding percentage of class X, but still substantial (at class X - 67%, class XI - 40%). The same pattern was repeated in equation five of the test at class XI for the error $Na(SO_4)_2$. While correcting the same error, almost 13% of the students created new errors such as $Na_2(SO_4)_2$ or $Na_3(SO)_4$. In the same equation, the error $Al_3(SO_4)_2$ was not corrected by 64% of the students (class X = 60%). For the formula of aluminium oxide in equation 4 of the test, almost 64% of the students failed to correct the formula (class X = 59%). It once again indicates that students are not aware of the valencies of different elements and radicals and their representation in the chemical formulae.

In the case of $ZnOH_2$, the percentage of students not correcting the error was 45% (at class X, it was 33%). It means that the significance of brackets in chemical equations is not clear to the students. Apart from these students, almost 8 students created new errors such as ZnH_2O, ZnO_2H_2 , ZnH_2 + O_2 , or ZnOH. This error, that is, the change of chemical formula raises doubts about students' knowledge of valencies of different elements and radicals and of their symbolic representation. Such responses also indicate that the concept of `chemical compound' or of interactive nature of chemical reaction is not understood by students. Attempts to balance equations in this manner reveals that a chemical equation is perceived from a purely algebraic point of view, that is, treating the chemical product as an addition of reactants, rather than from the chemical point of view. Students are attempting to equate the two sides of the equations through various possible algebraic ways with little regard to the laws of chemistry.

Before concluding the analysis of the two tests, it will be useful to look specifically at the performance of the sample of students from class X who successfully balanced almost all the equations from the first test (eighteen in number). Generally, one would like to assume that these students would exhibit a deeper understanding of the necessary sub-concepts as compared to other students. However, the analysis of their performance on the second test revealed that most of these students also possessed poor knowledge of the necessary chemical concepts in general. Of these 18 students, only one student (from the Bombay school) identified and corrected all the errors. The student also correctly balanced all these equations. Four other students identified and corrected almost all the errors but failed to balance the equations. However, the performance of the remaining 13 students was poor in general. Most of them failed to identify several of the given errors. A few students created additional new errors such as H_4O_2 , Al_3SO_4 , $Na(SO_4)_2$. One of the students, while correcting the error 2HO, reasoned that the given molecular formula of water, 2HO which means H_2O_2 , is wrong. This reasoning clearly indicates that the student thinks that when the subscript is common, it is written as coefficient as it would be in algebra class (2 from H_2O_2 is taken as common factor and written as 2HO). Thus, it appears that most of the students who could successfully balance equations on test 1, owe their success probably to rote memory or to some numerical skill rather than to an understanding of chemistry.

4.4 Test and interviews on interpretation of given equation

4.4.1 Methodology

a) Tests

In this test, students were expected to describe the information presented in the given chemical equation (see appendix 4.03). Students were asked to explain the given reaction qualitatively (that is, the name and other details of reactants and products, question 1) and quantitatively (that is, number of molecules of the substances involved in the reaction, question 2 and 3). Other questions in the test concerned the reversible sign and meaning of subscripts and coefficients with respect to symbolic representation of an element and a compound (question 4, 5 and 6 respectively). The time taken for completion of the test was 5 to 15 minutes. A similar test was administered at class XI and is shown in appendix 4.04. (This test had one additional question. However, this question was deleted from the analysis as almost 60% or more of the students had left it unanswered while most of the remaining answers revealed that the question was not clear to the students). Table 4.06 presents the details regarding the test.

Table 4.06 : Tests on interpretation of equation

Test	Number of questions	Time taken (min.)	Appendix number	Class
Test 1 - interpretation of equations	6	10 - 15	4.03	IX, X
Test 2 - interpretation of equations	5	10 - 15	4.04	XI

b) Interviews

Interviews were conducted for students of class X and concentrated on four different aspects related to chemical equations. Initially, the students were given four different equations to balance. Then they were asked to explain the meanings of the subscripts and coefficients with respect to elements and with respect to compounds. The next set of questions were about atoms and molecules. Lastly, students were asked to represent the chemical equations pictorially using simple circles. The general outline of the interview is presented in appendix 4-I.

ii) Sample

The test was administered to students from class IX, X and XI. The distribution of total sample in different classes is presented in table 4.07. Please note that at class IX and X the medium of instruction was Marathi whereas at class XI, the medium of instruction was English.

Table 4.07 : Sample for test on interpretation of an equation

Class	Test 1	Test 2	Total	Age range (years)	Time when the test was administered
IX	B_{NM} = 18, B_M = 15	-	33	13 - 16	towards end of 2^{nd} term
X	B_{NM} = 20, B_M = 18	-	38	14 - 16	towards end of 2^{nd} term
XI	-	D = 40, B = 37	77	15 - 18	towards end of 2^{nd} term

B = Bombay, D = Dahanu
B_{NM} = Bombay Non-Municipal school, B_M = Bombay Municipal school

Table 4.07 shows that two schools from Bombay were selected for administering the test at class IX and X. Of these two schools, one school was a Municipal Corporation school and its students had low scholastic performance in chemistry. The second school was a Non-Municipal school and its students had average scholastic performance in chemistry (Please note that these statements are based on the information provided by the science teachers). Interviews about chemical equations were conducted in the second school. The number of students interviewed were 15 and all these students belonged to class X.

At class XI, the test was administered to the students from one college in Bombay and the another college in Dahanu area. The students of both these colleges had average performance in chemistry (mean marks of students at Dahanu 50/100, & at Bombay 56/100).

4.4.2 Analysis of the tests

The performance of the students was analyzed class-wise. Table 4.08 displays the numbers and percentages of the students' responses to various questions at class IX and X. The results of analysis at class XI is presented in table 4.08A.

Table 4.08 : Responses of students to questions in the test (class IX and X)

Questions	Number & % of successful students (class IX, N = 33)	Number & % of successful students (class X, N = 38)
1. names & symbols of reactants & products	7 (21%)	0 (-)
2. no. of molecules of reactants	7 (21%)	2 (5%)
3. no. of molecules of product	6 (18%)	8 (24%)
4. meaning of reversible sign	0 (-)	0 (-)
5. in $3H_2$ 3 = ?, 2 = ?	7 (21%)	4 (10%)
6. in $2NH_3$ 2 = ?, 3 = ?	2 (6%)	2 (5%)

Table 4.08A : Responses of students to questions in the test (class XI, N = 77)

Questions	Number & % of successful students
1. describe the given reaction in words	5 (6%)
2. meaning of reversible sign	65 (84%)
3. in $3H_2$ 3 = ?, 2 = ?	24 (31%)
4. in $2NH_3$ 2 = ?, 3 = ?	17 (22%)

The above tables reveal that the number and percentage of the students who are successful in answering the given questions is small and varies between 5% and 24% for class IX and X. The same is true for performance of students at class XI (except for question 3).

4.4.3 Discussion

It will be useful to look at the different types of wrong answers given by the students to various questions (the equation given in both the tests was $N_2 + 3H_2$ -- $2NH_3$). The responses to the first question from the test given to class XI can be compared to the first three questions of the test which was administered to class IX and X. The answers at class IX and X revealed that students had problems with stating the names of the product of the reaction, that is, ammonia. Around 16 students out of 33 (50%) stated names like nitric oxide, sodium hydroxide, nitrogen oxide, nitrogen and hydrogen for the product ammonia. Almost the same number of students did not state the formula of ammonia, that is, NH_3. A similar trend was observed for symbols of hydrogen and nitrogen (that is, H_2 and N_2). Regarding the question about the number of molecules of reactants, it was observed that most of the students stated the same number of molecules for hydrogen and nitrogen (about 20 students = 61%). The number stated often was two. It appears that this wrong answer was stated by paying attention to the subscripts of the two reactants and ignoring the coefficients (that is, 2 from N_2 and $3H_2$). Some other numbers which were stated by the students, were 6 and 8. In case of molecules of ammonia, the number 3, 4 and 1 were stated by 15 students (45%). The answer 3 can be assigned to the subscript 3 in the formula of ammonia, NH_3. These answers reveal that students have not internalised the symbolic representation of molecules. Apart from these answers there were 5 students who stated, `in case of the product, 2 molecules of nitrogen and 6 molecules of hydrogen would be obtained'. The two probable reasons for such an answer could be that - i) students are seeing ammonia as a mixture of nitrogen and hydrogen or ii) students are confused about the product as the stated reaction is reversible. However, since the reversible reactions are not dealt with at class IX, the first reason may be more probable than the second.

At class X, once again, it was observed that students had problems naming ammonia, and 16 students (42%) stated names such as nitrogen oxide, nitride, nitrogen dioxide, nitrogen hydroxide. Regarding the symbols and formulae of the reactants and products, it was observed that 20 or more students (53%) did not give any answers. Regarding the molecules of reactants, 15 students (39%) stated the answer 2 for nitrogen (that is, subscript in the formula N_2) and 6 for hydrogen (that is, multiplication of coefficient 3 and subscript 2 in $3H_2$). The answer 6 indicates that even though students pay attention to the coefficients and subscripts, they are confused by the symbolic representations of molecules, in spite having used them for two years. Regarding the molecules of ammonia, 14 (37%) students had stated answers such as 2 molecules of nitrogen and 6 or 3 molecules of hydrogen. Once again, it appears that students are confused either because the given reaction is a reversible one or because they are perceiving the product ammonia as a mixture of nitrogen and hydrogen. Unlike class IX, at class X, both the reasons are possible because the sign of reversibility is more familiar to students of class X (as compared to class IX) who are taught many reversible reactions, even though there is little discussion about their reversible character.

At class XI, it was observed that most of the students stated the names of the reactants and products correctly. However, students did not mention the number of molecules or moles of substances involved, and/or the physical state of the substances, and/or the reversible nature of the reaction. In other words, either the students have problems in interpreting various symbols in the given equation, or they do not realise the importance of these various symbols and tend to interpret the equation in a slip-shod manner.

Before discussing the answers for the reversible sign, it is important to note that at class IX, there is no discussion about reversible reactions even though such reactions are stated in the textbook (the question asked was what does the $\rightleftharpoons$ sign indicates?). Even in class X, there is little discussion about reversible reactions although many reactions of reversible type are stated in the textbook (especially in the lesson on solutions and ionization). This question was asked in order to see whether students try to interpret the sign in some way. In general, the number of students who left the question blank was small. At class IX, there were three categories of answers -

i) answers mentioning some characteristics of the reactions - `reaction is going on' or `reaction is over' or `chemical reaction has taken place and ammonia is formed'

ii) answers related to heat and chemical reactions - answers such as `it indicates heating', `heat is conducted equally between reactants and products', `reactants when heated give ammonia'

iii) for balancing.

Even at class X, similar answers were obtained. Other answers stated the type of chemical reaction, such as, chemical combination or displacement reaction or homogeneous reaction.

At class XI, most of the students gave the correct answers. However, almost half of the successful students (that is, 41 students) stated, the answer `the sign indicates reversible sign' or `the sign indicates forward and backward reaction' without giving further explanation. Among the other students who explained the meaning of the sign, three types of answers were observed - i) reversible - reactants are converted into products which in turn gives reactants, ii) reversible - that is, product is converted into reactants iii) reversible - reactants are converted into product and then product is converted into reactants. Out of the three the first answer is the most correct while the last answer (stated by few students) indicates that students probably believe that the forward reaction is completed first and then the backward reaction begins.

Regarding interpretation of subscript and coefficient for an element, the following wrong answers were obtained at class IX, X and XI -

i) subscript indicates molecule and coefficient indicates atom.

ii) coefficient is for balancing.

iii) coefficient or subscript indicates valency.

In a similar question about a compound, the wrong answers at class IX, X and XI were more or less the same and they were of the following types-

i) coefficient indicates atoms or molecules of nitrogen alone.

ii) coefficients indicate molecules of N & H or NH.

iii) coefficients and/or subscripts are for are balancing.

iv) subscripts indicated molecules of hydrogen.

v) partial answers, such as, it indicated atoms or it indicated molecules.

Some of the other answers which were obtained at class XI for the same question were - `subscript indicates atoms' or `valency of ammonia' or `valency of nitrogen'. All these answers reveal that students fail to interpret coefficients and subscripts in equations. The analysis reveals again, that students fail to understand the various symbols used to represent the information regarding chemical reactions, even after considerable exposure to the subject. In other words, a lot more attention should be paid to students' difficulties, for meaningful learning of the symbolic language of chemistry.

4.4.4 Analysis of interviews

As stated before, 15 students (from class X) were interviewed for their understanding of chemical equations. The analysis of various questions is presented below.

a) Students' responses to balancing equations, subscripts and coefficients

In the initial stage of the interview, students were asked the meaning of `balancing' of a chemical equation and were given three equations for balancing. After the students balanced the given equations, questions regarding meanings of subscripts and coefficients with respect to the elements and compounds were asked. Table 4.09 displays students' responses to various questions.

Table 4.09 : Students' responses to questions on balancing, subscripts and coefficients (N = 15)

Category	Balancing definition	Balancing equations	Subscript & coefficient for an element		Subscript & coefficient for a compound	
			sub_e	coe_e	sub_c	coe_c
no idea	2	-	-	3	-	3
correct	12	11	11	8	11	6
others	1	4	4	4	4	6

From the above table, it is clear that of the 15 students, 12 students were able to explain the meaning of 'balancing' of an equation. The remaining students stated that balancing means 'makingtwo sides equal'. Most of the students who answered correctly stated, that balancing means number of atoms (or molecules) of different substances in reactants and products (or in the two sides of reactions) should be equal. Regarding balancing of the given equations, 11 students were able to balance all the three equations correctly. In case of the remaining four students, two failed to balance one of the given equations and the other two failed to do so for two or all the three given equations.

Regarding the subscript of an element, four students stated different answers such as 'it indicates molecules' (2 students), or 'valency' (1 student) or 'molecularformula' (1 student). The coefficient of an element was interpreted as 'ion', 'atom', 'total number of atoms' and 'proportion' by one student each, while three more students said that they did not know the meaning of 'coefficient'. For subscript written in the compound, similar answers were obtained from four students (molecules - 2 students, molecular formula - 1 student, valency - 1 student). In interpreting the coefficient of a compound, answers such as, molecules or atoms of nitrogen and hydrogen (3 students), proportion (1 student), ion (1 student) and, for balancing (1 student) were obtained. All these answers indicate that students have problems in understanding subscripts and coefficients in the given equations.

b) Students' responses to questions on atoms and molecules, elements compound and mixtures

Students were asked to explain the words 'atoms' and 'molecules'. Similar question was asked about elements, compounds and mixtures. Table 4.10 displays students' responses to these questions.

Table 4.10 : Students' responses for questions on atoms and molecules (N = 15)

Category	Atoms	Molecules	element	compound	mixture
not asked	-	-	4	3	4
no idea	-	-	-	-	1
correct or almost correct	12	7	9	7	8
others	3	8	2	5	2

Regarding atoms, 6 of the 12 students who answered correctly, described an atom as 'the smallest particle of a substance' and five described it correctly as 'the smallest particle of an element'. One student defined atom as the smallest particle of an unstable element. This student explained `unstable element' correctly but stated oxygen and carbon (non-metals) as unstable elements and Fe, Ni and Zn (metals) as stable elements. Three students who defined atom correctly stated that a single atom would have several physical properties and two others stated that atoms do not participate in reactions (but molecules do). Of the remaining three students, one student did not describe an atom but stated that `it is smaller than molecule', the second described it as `small particle which is visible through simple microscope' and the third described it correctly but believed that atoms would be visible through simple microscope. The second student who believed that atoms are visible through simple microscope stated further that for combining similar atoms, heat is required whereas for different types of atoms no heat is essential.

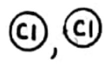
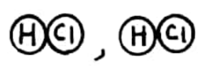
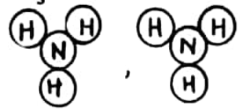
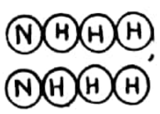
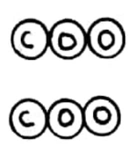
In case of molecules, those who answered correctly described a molecule as a combination of 2 or more atoms. Of the remaining 8 students, 3 students defined molecule as `the smallest particle of a substance' (no further explanation), 2 students stated that `n' atoms come together to form a molecule, 1 student believed that `physical properties are present in a single molecule' and 1 student perceived it to be the smallest particle of liquids such as kerosene, glycerine. The remaining student defined molecule to be a cluster of atoms which is chemically reactive. This last student explained the concept of a molecule with the example of air. The student believed that in air, atoms of different gases like oxygen, hydrogen, nitrogen react with one another.

Regarding elements, most students answered correctly. They stated that 'element is made up of one single substance or one kind of atoms'. One of these students stated that elements are destroyed in chemical reactions. Yet another student stated that an element has many substances. This student gave methane and hydrocarbon as examples of elements. The same student classified hydrogen, oxygen as gases and stated further that these substances could not be classified as elements, compounds or mixtures. With regard to compounds, five students defined a compound to be a mixture of two or more substances. Two students gave alloys as an example of compounds. One student each believed that compounds are not found in nature (elements are found in nature) and that compounds are destroyed in reactions (the same students had stated that elements are destroyed in chemical reactions). In case of mixtures, students did not have problems.

c) <u>Pictorial representations of reactions</u>

The students were asked to represent pictorially the chemical equations which they balanced, by using simple circles. The prescribed text-book does not present such diagrams. This question was asked in order to learn whether and how students draw diagrams for the given equation so as get a feel for their perceptions of chemical equations. It was observed that most of the students did not have problems in drawing the diagrams. If a student did have a problem then different diagrams were drawn by the researcher asking the student to select the diagram which he or she found appropriate. Table 4.11 presents the diagrams drawn by the students for different reactions.

Table 4.11 : Students' pictorial representation of chemical equations (N=15)

For $H_2 + Cl_2$ -- $2HCl$	For $N_2 + 3H_2$ --- $3NH_3$	For $2CO + O_2$ --- $2CO_2$
for H_2 1 	for N_2 1 	for O_2 1 
for Cl_2 1  2 	for $3H_2$ 1  2 	for 2CO 1  2 
for 2HCl 1  2  3 	for $2NH_3$ 1  2  3  4 	for $2CO_2$ 1  2  3 

Different types of diagrams were drawn by students. Most of these students were able to balance the given equations. For the equation of formation of HCl, 4 students were able to draw correct diagrams (3 of these, described chemical reaction as bond breaking and bond formation process). The second drawing (table 4.11 - drawing shown for 2HCl under number 2) indicates that attention was paid only to the number of particles in the given equation. These students were not taking into account the information presented by coefficient 2 Of HCl. Such a response also raises doubt about whether students have understood interactive nature of chemical reactions (in fact, one student stated that in a reaction, old bonds are not broken and another stated that bond formation takes place between H_2 and Cl_2). The last drawing for 2HCl (table 4.11 - drawing shown as number 3) indicates that students have some feel about the bond formation between hydrogen and chlorine atoms. One student stated that particles of all substances before the reaction (that is, substances on the left side of an equation) should be separate and particles of substances after the reaction (that is, substances on the right side of an equation) should be connected to each other as the reaction has taken place. Similar responses were observed for the other two equations. The drawings presented as number 2 for $3H_2$, $2NH_3$, 2CO and $2CO_2$ in the above table once again indicate that students are not able to understand the significance of subscripts and coefficients in the given equations (some of the drawings obtained especially for ammonia are similar to those obtained by Yarroch, 1985). In the case of ammonia, the last drawing for $2NH_3$ (number 4) indicates that students assign coefficient to the first element (that is, nitrogen) and subscript to the second element (that is, hydrogen).

4.5 Tests on quantitative interpretation of the equation

4.5.1 Methodology

a) Tests

Different tests were given regarding the quantitative interpretation of the equations. The first test (test 1) consisted of three questions on stoichiometry (see appendix 4.05). Another test consisting of five questions was developed (test 2) and administered at class X. As before, students were asked to give the number of molecules of the reactants required, given the number of molecules of the product or vice versa (see appendix 4.06). Along with this test, one more test (test 3) on understanding of proportions was administered to students of class X. This test was equivalent to the chemistry test (see appendix 4.07). Understanding of proportion is essential for answering questions regarding stoichiometry. The aim behind administering the equivalent test on proportion was to learn whether students' difficulties, if any, are due to lack of relevant mathematical knowledge or due to lack of relevant chemistry knowledge. One question of the test could not be considered for the analysis as some error was committed while framing the mathematics question and was noticed after the tests were administered. At class XI, a test similar to test 2 was administered (see appendix 4.08). Once again, the medium of instruction was Marathi for class IX and X and English for class XI. The details of the tests are shown in table 4.12.

Table 4.12 : Tests on quantitative interpretation of equations

Test	Number of questions	Time taken (min.)	Appendix Number	Class
Test 1 (chemistry)	3	5 - 10	4.05	IX & X
Test 2 (chemistry)	5	30 - 40	4.06	X
Test 3 (Mathematics)	5	20 - 30	4.07	X
Test 4 (chemistry)	6	30 - 40	4.08	XI

ii) Sample

To begin with, test 1 was given to the same sample of class IX and X students to whom the test on interpretation of equation was administered. So the total sample for the test consisted of 71 students which included students from class IX (33 students) and class X (38 students). Test 2 and test 3 were administered to a different sample of students of class X. The total number of students who took both tests was 38. Test 4 (similar to test 2) was administered at class XI, once again to the same sample in class XI to whom the test on interpretation of equation was administered. Table 4.13 indicates the details of the sample.

Table 4.13 : Sample for tests on quantitative interpretation of equation

Class	Test 1	Test 2 & 3	Test 4	Age range (years)	Time of administration of the test
IX	33 (B_M = 18, B_{NM} = 15)	-	-	13 - 16	end of second term
X	38, (B_M = 18, B_{NM} = 20)	38 (B_M = 9, B_{NM} = 29)	-	14 - 16	same as above
X (for intervention)		B_M = 17	-	14 - 16	same as above
XI	-	-	77 (D = 40, B = 37)	15 - 18	same as above

D = Dahanu, B = Bombay.
B_{NM} = Bombay Non-Municipal school, B_M = Bombay Municipal school

iii) Interviews

Seventeen students from class X were interviewed about understanding of chemical equations. The questions as before were focused on the meanings of balancing, subscripts, coefficients, atoms and molecules and on balancing the given equations. These students were selected from the sample of students from a Municipal school to whom test 2 and test 3 had been administered. A typical interview lasted for 30 - 40 minutes. Detailed analysis of the interviews is presented in section 4.5.5.

iv) Intervention

In one of the schools (that is, the Municipal school) intervention was conducted for the students of class X after conducting the tests and interviews. The intervention was conducted without any prior planning and the main reason was that the students who took the test requested the researcher to do so. Otherwise, the researcher had not planned an intervention. The intervention was conducted for two days (90 min. on each day). These intervention sessions started with a discussions of the concepts of elements, compounds and mixtures followed by one on concepts of atoms, molecules and their symbolic representations. Towards the end of the intervention session, one chemical equation (formation of water) was discussed in detail. Five days after the intervention, the chemistry test given before (test 2) was administered to the students without any prior intimation. The performance of these students before and after the intervention was compared. The number of students who were present for the intervention and pre and post-test was 17. The performance of these students is discussed separately. For this intervention, there was no control group.

4.5.2 Analysis of the tests

The responses of students to the test were analyzed class-wise. Table 4.14 displays the number and percentages of class IX and X students giving correct answers to different questions in test 1.

Table 4.14 : Students' responses to questions from test 1

Questions*	No. & % of successful students at class IX (N = 33)	No. & % of successful students at class X (N = 38)
1. for $6NH_3$, N_2 = ? H_2 = ?	5 (15%)	4 (11%)
2. given $2N_2$ & $9H_2$, NH_3 = ?	7 (21%)	4 (11%)
3. given N_2 = 10 & H_2 = 10, after the reaction, any unreacted molecules will be present?	2 (6%)	3 (8%)

(* = questions from the test are given in brief)

From table 4.14, it is clear that the number of successful students is small. Generally, the number varied for class IX between 2 and 7 (that is, 6% to 21%). For class X, the number of successful students is 3 or 4 (8% or 11%). It indicated that students in general had poor understanding of quantitative aspects of the given equation both at class IX and X.

For test 2, which was administered at class X, responses of the students to various questions are shown in Table 4.15. Responses to the corresponding questions on the mathematics test which was administered with this test are also shown in the Table 4.15 (this sample excludes those 17 students who were involved in the intervention).

Table 4.15 : Students' responses to chemistry and mathematics tests (class X, N=38)

Questions*	No. & % of successful students on chemistry test	No. & % of successful students on mathematics test
1. given N_2 = 1, NH_3 = ?	17 (45%)	37 (97%)
2. given H_2 = 1, NH_3 = ?	16 (42%)	32 (84%)
3. for $6NH_3$, N_2 = ? H_2 = ?	6 (16%)	27 (71%)
4. given N_2 = 2 & H_2 = 9, NH_3 = ?	9 (24%)	25 (66%)
5. from 10 NH_3 N_2 = ? & H_2 = ?	9 (24%)	30 (79%)

(* = questions from chemistry test are given in brief)

From table 4.15, it is clear that the performance of the students on the mathematics test (test 3) was good in general. Of the 38 students, the number of students who successfully solved the different questions varied between 25 to 37 (66% - 97%). However, in the case of the chemistry test (test 2), the number of successful students varied between 9 to 17 (24% - 45%). In other words, almost half the students who solved mathematics questions correctly failed to solve the corresponding chemistry questions successfully.

Performance of students for whom the intervention was conducted is presented in table 4.16. Once again, it reveals that the performance on the mathematics test is better compared to that on the chemistry test. The table also presents the performance of students after intervention.

Table 4.16: Students' responses to the chemistry test & mathematics test (intervention group, class X, N =17)

Qu. No.	No. & % of successful students on mathematics test	No. & % of successful students on chemistry test (before intervention)	No. & % of successful students on chemistry test (after intervention)	t- values with one tailed prob.
1	14 (82 %)	7 (41 %)	10 (59%)	1.43 (p=0.09)
2	8 (47%)	5 (29%)	7 (41%)	1.43 (p=0.09)
3	12 (71%)	0 (-)	8* (47%)	3.17* (p=0.00)
4	8 (47%)	3 (18%)	10* (59%)	4.78* (p=0.00)
5	8 (47%)	3 (18%)	10* (59%)	6.13* (p=0.00)

* = significant improvement

From table 4.16, it is clear that for all the questions on chemistry test, the performance of students after intervention improved. In order to see if the performances differed significantly, a paired t-test was conducted question-wise, using the mean marks received by the students for a given question on the pre and post-test. For the t-test, a null hypothesis (H_0) that there was no difference in the mean performance on pre and post-test was tested against the one tailed alternative hypothesis (H_1) that the mean performance on the post-test was better than the mean performance on the pre-test. Of the five questions, the alternative hypothesis (H_1), was accepted for three questions. In other words, for these three questions the mean performance on the post-test was significantly better as compared to the mean performance on the pre-test.

Table 4.17 displays class XI students' responses to various questions in the chemistry test administered to them.

Table 4.17 : Students' responses to questions on chemistry test (class XI, N= 77)

Questions	No. & % of successful students
1. N_2 = 1, NH_3 = ?	50 (65%)
2. H_2 = 1, NH_3 = ?	31 (40%)
3. for $6NH_3$, N_2 = ? & H_2 = ?	38 (49%)
4. given N_2 = 2 & H_2 = 9 NH_3 = ?	24 (31%)
5. from 10 NH_3, N_2 = ? & H_2 = ?	37 (48%)
6. given N_2 = 10 & H_2 = 10, after the chemical reaction, whether there will be any unreacted molecules?	23 (30%)

The number of successful students at class XI was more as compared to class IX and X students, but yet it was not satisfactory. The percentage of successful students at class XI varied generally between 30% to 65%. Such responses support the earlier observation that students' understanding of stoichiometry of chemical equation is poor in general. In fact, considerable exposure to the subject has not affected the understanding significantly.

4.5.3 Discussion

The performance of students at class IX, X and XI on stoichiometry test was poor in general. When the chemistry test was accompanied by the mathematics test, it was observed that the performance on the mathematics test was much better. Almost 50 % of the successful students on mathematics test were unsuccessful in solving the corresponding questions on the chemistry test. In other words, student did not have problems regarding the mathematical component involved in the chemistry test, but rather they had problems regarding the chemical component of the test, that is, understanding of atoms and molecules and their symbolic representations (which was also revealed in the interviews of students which are discussed in detail after this section). The intervention conducted for the small group, which essentially discussed atoms and molecules and their symbolic representation and classification of substances as elements, compounds and mixtures led to a significant improvement on the performance of students in the chemistry test. In teaching and learning of chemistry, it is important to take into account all these difficulties otherwise the significance of the symbolic language in presenting the information regarding the chemical reactions will not be understood by the students. This will certainly affect students' understanding of chemistry itself.

Before concluding the discussion about the tests, the incorrect answers stated by the students to various questions of chemistry tests are presented in table 4.18 (only the answers with maximum frequency are given).

Table 4.18 : Incorrect answers of students for test 1

Questions	Class IX	Class X
1. given $6NH_3$, N_2 = ?, H_2 = ?	2,1(for N) 2,3,1 (for H)	2 (for N) 3,2 (for H)
2. given N_2 = 2, H_2 = 9, NH_3 = ?	7,6,18	18,6
3. given N_2 = 10, H_2 = 10, after the reaction, whether there will be any unreacted molecules?	all the molecules of both reactants will be consumed	all the molecules of both reactants will be consumed

Unlike the previous tests, it is difficult to state how students arrive at these answers. However, some comments about the answers presented in the above table can be made. For question 1 of the test, it was observed at both class IX and X that the same number of molecules was stated for both the reactants. Such responses indicate that students do not pay attention to the number of molecules of reactants involved in the reactions, that is, the coefficients in the equations. The answer 2 stated for this question further indicated that most probably the subscript 2 for both the reactants, N_2 and $3H_2$ was taken into account. The answer 3 for hydrogen indicated that the coefficient of hydrogen in the given equation (that is, $3H_2$) was taken into account rather than calculating the number of hydrogen molecules required for formation of $6NH_3$. The answer to the last question is interesting. This answer indicates that students believed that all the molecules of different reactants participate in the reaction and after the reaction there is no unreacted molecule.

The answers of students to test 2 (at class X) and test 4 (at class XI) are given in table 4.19. The first five questions for both the tests were the same. Some questions of these tests are same as the questions in test 1 (for example, question 3 of test 2 and test 4 with question 1 of test 1, question 4 of test 2 and test 4 with question 2 of test 1 and question 6 of test 4 with question 3 of test 1).

Table 4.19 : Incorrect answers of students to questions on test 2 and test 4

Questions	Class X (test 2)	Class XI (test 4)
1. N_2 = 1, NH_3 = ?	1,6	1,3,6
2. H_2 = 1, NH_3 = ?	2,6	3,2
3. for 6NH_3, N_2 = ? H_2 = ?	2,6 (for N) 3,6 (for H)	2,6 (for N) 3,6,18 (for H)
4. given N_2 = 2, H_2 = 9, NH_3 = ?	18,2	0,2,3
5. from 10 NH_3, N_2 = ?, H_2 = ?	6,2 (for N) 5,3 (for H)	2 (for N) 5 (for H)
6. given N_2 = 10 & H_2 = 10, after the reaction, whether some unreacted molecules will be present?	-	0 (for N) 0 (for H)

Once again, for these tests it was observed that some students tended to state the same number of molecules for both the reactants. As before, the same answers, that is, 2 and 3 are stated both at class X and XI for question 3. The other answer 6 for the same question is probably obtained from the number of molecules of ammonia which was stated in the question. Unlike the first test, in case of question 6 of test 4, at class XI, there were very few students who stated that no molecule would remain after the reaction. It is not possible to comment about other answers.

From the above discussion, it is clear that students fail to understand the stoichiometry of the given reaction. Even at class XI, the performance is not satisfactory. The poor quantitative understanding of the reactions may be attributed to lack of understanding of relevant chemical knowledge (specially atoms, molecules and their symbolic representation) rather than lack of relevant mathematical knowledge. The intervention conducted indicates that appropriate inputs on relevant chemistry knowledge do help students in improving their performance.

4.5.4 Discussion about the interviews

Seventeen students were interviewed about balancing of equations, subscripts and coefficients, and atoms and molecules. The questions were similar to the ones asked in the interviews conducted on understanding of chemical equations. The responses of students to various questions are discussed below.

a) Students' responses to questions on balancing of equations

The students were asked to explain the meaning of `balancing of an equation' and were asked to balance the given equations. Table 4.20 displays the students' responses to these questions.

Table 4.20 : Students' responses to questions on balancing of equations (N = 17)

Category	Balancing (meaning)	Balancing of equations
not asked	-	2
correct	6	5
others or unsuccessful balancing	6	9
no idea	5	1

Regarding the meaning of balancing equations, 5 students were unable to explain the term, and the other six students stated that balancing indicated that the two sides of the equations should be made equal. They were unable to explain this further. Regarding the balancing of equations, of the nine students who made errors, seven students balanced two or more equations wrongly and the other 4 did the same for one of the equations. Most of these students changed the subscripts given in the formulae, for e.g., H_2Cl_2 for HCl or N_2H_3 for NH_3.

b) <u>Students' responses about subscripts and coefficients</u>

Table 4.21 displays the responses of students for questions regarding subscripts and coefficients. Students were asked to explain the meaning of subscript and coefficient with respect to elements and compounds.

Table 4.21 : Students' responses to questions on subscripts and coefficients (N = 17)

Category	Element		Compound	
	subscript	coefficient	subscript	coefficient
not asked	-	-	6	5
correct	7	4	-	3
others	7	6	6	5
no idea	3	7	5	4

As seen from table 4.21, it is clear that students' responses to these questions were poor in general. There were five students who stated that they could not explain the subscript and coefficient for a compound. The same was observed for the coefficient written along with the symbol of an element. In the case of the subscript of an element, students' interpretations were - molecular formula (3 students), molecules (2 students), atomic number (1 student) and no difference between subscript and coefficient (1 student). In the case of the coefficient of an element the interpretations were - atoms (3 students), proportion (1 student), for balancing (1 student) and atomic weight (1 student). In the case of the subscript of a compound once again answers such as molecular formula or molecular formula of hydrogen (1 each), number of atoms or atoms of ammonia (1 each) and atomic number (1 student) were obtained. Yet another student stated that there was no difference between subscripts and coefficients of an element and compound. For coefficient of ammonia, the other answers were atoms (3 students) and molecular formula of nitrogen (1 student). All these answers indicate, that students are confused about the meaning of subscripts and coefficients for element and compound. They tend to interpret these numbers differently.

c) Students' responses to questions regarding atoms and molecules

Students were asked to describe the words atoms and molecules and whether atoms and molecules are visible to the naked eye or through simple microscope. Table 4.22 displays the responses of students.

Table 4.22 : Students' responses to questions on atoms and molecules (N = 17)

Category	Atoms	Molecules
not asked	1	-
almost correct	5	6
others	2	6
no idea	9	5

The above table shows that the number of students who stated that they did not know or they could not explain the terms atoms and molecules was high (9 and 5 respectively). In case of molecules, three students stated chalk powder as an example of a molecule and one students stated molecule as the smallest particle of a gas. There were two students who stated that molecules are different from atoms. Those who answered almost correctly described molecules as 'made up of atoms' or as 'small particles of substances'. Almost all these students knew that molecules are not visible to the naked eye or through a simple microscope. In case of atoms, most students who were almost correct, described an atom as "the smallest particle of a substance" rather than "the smallest particle of an element". Once again, most of these students knew that atoms are not visible to the naked eye or a simple microscope. There was one student who stated that atoms are smaller than molecules (the student had given chalk powder as an example of a molecule), and yet another student who referred to small drops of water as atoms.

d) Pictorial diagrams drawn by students

Despite the fact that students had poor understanding of atoms and molecules they were asked to draw simple pictorial diagrams for the reactions they balanced. The diagrams are shown in the table 4.23.

Table 4.23 : Students' pictorial diagrams for different reactions (N = 17)

For $H_2 + Cl_2$ -- 2HCl	For $N_2 + 3H_2$ --- $2NH_3$	For 2CO + O_2 --- $2CO_2$
for H_2 1 (H)(H)	for N_2 1 (N)(N)	for O_2 -- (O)(O) for O_2 + CO -- (C) (O)(O)(O)
for Cl_2 1 (Cl)(Cl) 2 (Cl) (Cl)	for $3H_2$ 1 (H)(H) (H)(H) (H)(H) 2 (H)(H)(H)(H)(H)(H) 3 (H)(H)(H) (H)(H)(H)	for 2CO 1 — 2 (C)(C)(O)(O) 3 (C)(C)(O)
for 2HCl 1 (H)(Cl) (H)(Cl) 2 (H)(H)(Cl)(Cl) 3 (H)(H)(Cl) ; (H)(H) (Cl)	for $2NH_3$ 1 — 2 (N)(N)(H)(H)(H)(H)(H)(H) 3 (N)(N) (H)(H)(H) ; (N)(N)(H)(H)(H) 4 (N)(H)(H)(H) (N)(H)(H)(H)	for $2CO_2$ 1 — 2 (C)(C)(O)(O)(O)(O) 3 (C)(C)(O)(O)

It was observed that some of the students had difficulties with the question asked. They were not able to answer the question and hence their responses are not considered for analysis. In the case of HCl reaction, there were three students who drew correct pictorial diagrams. The second response for HCl (table 4.23, for 2HCl- drawing number 2) indicates that students are taking into account the total number of particles and connecting these to one another or presenting them separately. The drawings presented as number 3 for 2HCl, indicates that students are assigning coefficient only to the first element of the formula (that is, hydrogen). In the case of ammonia equation, students are paying attention to the coefficient of given element and ignoring the subscript. The drawing shown as number 4 for ammonia (that is, for $2NH_3$) indicates that these students have some feel for the chemical reaction and they are able to interpret subscripts and coefficients in the given formula. The responses shown as number 3 for $2NH_3$ indicate that students assigned coefficients to the first element (that is, nitrogen) and subscript to the second element (that is, hydrogen). Similar responses were obtained for the CO_2 equation. Regarding this equation, there were two students who combined oxygen from CO with O_2 and then drew the drawing for C and O_3 (see table 4.23, drawing for C + O_3). All these responses in general indicate that students perceive chemical reactions differently from the scientifically accepted perceptions. As before, these diagrams also suggest that probably students have not understood the interactive nature of chemical reactions.

4.6 Test on symbolic representations of atoms and molecules

4.6.1 Methodology

i) <u>Test</u>

In this test students were asked to interpret the given symbols such as H , H_2 , 2H , $2H_2$, H_2O and $2H_2O$ in words and pictorially. The test was administered to students of class IX studying in two schools at Bombay. The test is shown in appendix 4.09. The time taken for the test varied between 10 to 25 min. Table 4.24 presents the necessary details regarding the test.

Table 4.24 : Test on symbolic representation of atoms & molecules

Test	No. of questions	Class	Appendix No.	Time taken
Test on symbolic representations	6	IX	4.09	10 - 25 min.

ii) <u>Sample</u>

The test was administered to students of class IX of two schools. One was a Municipal Corporation school and the other was a regular school. The sample from the Non-Municipal school consisted of 29 students and that from the Municipal school consisted of 26 students. In general, the Municipal school students had below average chemistry performance while students of the other school had average chemistry performance. For details, see table 4.25.

Table 4.25 : Sample for test on symbolic representations

Class	No. of students	Age range (years)	Time of administration of the test
IX	B_{NM} = 29, B_M = 26	14 - 16	mid of second term

B_{NM} = Bombay Non-Municipal school
B_M = Bombay Municipal school

4.6.2 Analysis of the tests

The number and percentage of the successful students on various questions is presented in table 4.26.

Table 4.26 : Students' performance on the test of symbolic representations (N= 55)

Symbols	Both correct	Written interpretation correct	Pictorial diagram correct
H	9 (16%)	9 (16%)	45 (82%)
H_2	13 (24%)	27 (49%)	27 (49%)
2H	0 (--)	6 (11%)	8 (15%)
$2H_2$	1 (1%)	1 (1%)	3 (5%)
H_2O	0 (--)	3 (5%)	4 (7%)
$2H_2O$	1 (1%)	5 (9%)	1 (1%)

Table 4.26 indicates that students did badly on verbal as well as on pictorial responses. It revealed that even though students were using these notations for more than six months, the significance of these symbols, specially of the subscript and coefficient was not understood by them. The percentage of students who did not answer the question varied between 18% to 45%. These percentages were larger for pictorial diagrams in general as compared to those for interpretation of symbols in words.

4.5.2 Discussion

The table 4.27 presents various incorrect responses made by the students. The table presents the responses which were observed a maximum number of times. Since the discussion is qualitative the type of response is important rather than the frequency of an individual response.

Table 4.27 : Students' responses to various symbols (N = 55)

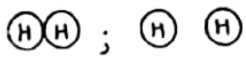
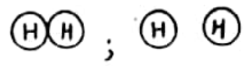
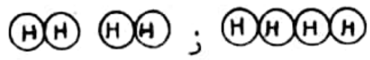
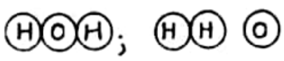
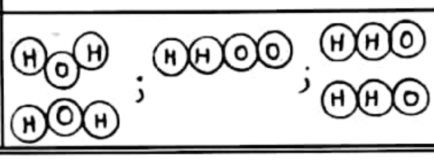
Symbol	Word response	Pictorial response
H	Hydrogen, molecule of hydrogen	
H_2	2 molecules of hydrogen	
2H	2 molecules of hydrogen; molecule of hydrogen	
$2H_2$	4 molecules of H; 2 atoms & 2 molecules of H	
H_2O	water; molecules of H & 1 molecule of O; other names	
$2H_2O$	2 molecules of H & O each, 2H & 2O, other names	

Table 4.27 indicates the various responses which are self explanatory. The written responses for the formula for water indicates that water is not perceived as a compound of hydrogen and oxygen. It is, rather, considered as a mixture of the two elements. This is also reflected in the pictorial diagrams where hydrogen and oxygen are shown separately. In the case of symbols for hydrogen, students sometimes showed all the particles connected to each other or sometimes all the particles were shown separated from each other. All these responses indicate that students' interpretation of symbolic language is very different from the accepted interpretations and the same is true about students visual perceptions of the symbols.

4.6 Conclusion

The analysis of different tests and interviews has revealed various misconceptions held by students regarding the representational aspect of chemistry and other related concepts. The test on balancing equations and on identifying errors indicated that students commit numerical and other errors which are due to lack of understanding of various different chemical concepts such as valencies and their symbolic representation, the significance of subscripts, coefficients and brackets and the concept of atomicity. These tests also indicate that students treat chemical equations mathematically, where they try to balance the two sides disregarding laws of chemistry and end up with equations that violate chemical laws. For meaningful learning of chemical equations, it is important that tests aimed at identifying errors present in the given equations should be used in schools and colleges.

The test on interpretation of equations revealed that the significance of subscripts and coefficients was not understood by the students who interpreted these numbers in different ways (subscript as valency or molecular formula or molecules and coefficients as atoms or for balancing). Students tended to assign a coefficient to the first element in the compound rather than the total compound without realising that the entire compound is placed in an invisible bracket. At class IX and X, students had problems regarding naming the reactants and products. Even though this difficulty was not observed at class XI, it was noted that most of the students failed to give a total description of the given reaction. Students did not mention the state and/or the number of molecules and/or reversible nature of the reaction. In the case of questions regarding subscript and coefficients, responses similar to those discussed above were obtained at all the three classes. Interviews of students on understanding various aspects of chemical equations revealed several misconceptions regarding atoms and molecules such as, both atoms and molecules have physical properties, or atoms do not participate in the reaction or these particles are visible to the eye or through a simple microscope. Students also failed to distinguish between compounds and mixtures. In the case of elements, students were able to give examples but were unable to state the correct description. Regarding properties, it was observed that students had problems with properties such as melting, rusting and formation of water. The pictorial diagrams indicated that students' perceptions about reaction is different from the scientifically accepted ones. These diagrams indicated that students are concerned about the total number of particles on both sides of the equation and do not pay attention to the subscripts and coefficients. These diagrams also indicated that students' viewed chemical reactions as mathematical additions and did not take into account the interactive nature of the reaction. It is important that pictorial diagrams become an integral part of the chemistry textbook. If used in an appropriate manner, such diagrams can help students understand the symbolic language of chemistry effectively.

The test on quantitative interpretation reveals that poor performance on the chemistry test can be assigned to the lack of relevant chemical knowledge rather than to the lack of relevant mathematical knowledge. Once again the concept of particulate nature of matter and symbolic representation was the major hurdle for students. Similar observations were made on the test on symbolic representations. It was observed that in most cases, the performance of the students did not change even after considerable exposure to the subject. In other words, most of the misconceptions persisted across different school years. The study suggests various difficulties of students which should be taken into account in the teaching and learning of chemistry. It also suggests that different diagnostic tests should be used in the routine school system since such tests help in the understanding of students' difficulties. If the difficulties described in the study are taken into account in teaching and learning, then the result will be a meaningful learning of chemistry.

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CHAPTER V

THE PERIODIC TABLE

5.1 Introduction

This chapter presents the work conducted with respect to the topic of periodic table. Three experimental studies were conducted using the periodic table model which was prepared as a part of remedial measures to teach the topic of the periodic table. Section 5.2 of the chapter presents the background which describes the importance of the topic of periodic table in learning of chemistry and also explains the aims behind the preparing of the periodic table model. The other sections present the analysis of the experimental work conducted.

5.2 Background

It is important that students of chemistry be exposed to the relation between chemical properties of elements and the atomic/ molecular structure of materials, that is, understanding of macro aspect of chemistry in terms of the micro aspect. Such an exposure helps students understand why a particular element or a compound has to have certain characteristic properties. The concept that forms the very basis for such an understanding, is the Periodic Table of Elements. The periodic table not only displays the interconnections of properties and the atomic structure, but also reveals how the periodicity in the electronic shell structure leads to the periodicity of properties of elements. It would be natural, therefore, to expect that attempts at instruction in chemistry at the secondary school level (that is, an understanding of properties, chemical formulae and equations etc) would be built around the periodic table. However, this is not the practice. In the chemistry syllabus of Maharashtra State the topic of the periodic table is introduced in the last year of schooling, that is, at standard X, while the topics of atomic structure, valency, chemical equations are introduced at standard IX (this is also true for the new suggested syllabus of chemistry). The researcher suggests that the periodic table be introduced as a basis for understanding chemistry and not treated separately. Operationally, if the topic of periodic table is introduced soon after the topics, atomic structure and valency, it will help students understand the basis of classification of elements, the regular variations in valencies of elements in the periodic table and the connections between atomic structure, properties of elements and valencies. The periodic table can also be used effectively in understanding the chemical formulae of different compounds. Unfortunately, no inter-connections between these topics and the periodic table can be revealed to the students as the periodic table is introduced a year later. Even at the class X examination, the topic of periodic table is introduced as an independent topic and has considerably low weightage in terms of examination, carrying only 3 marks out of 40. All these factors reduce the topic of periodic table to an unimportant, unconnected piece of information.

The periodic table of elements, that is, the long form of the periodic table which is introduced in standard X, as a two dimensional array of elements displays symbols, atomic weights and atomic numbers of elements. This information reveals neither the periodic patterns nor the interconnection between structure and properties (Lehman, 1984). Thus, students find it difficult to understand the significance of the periodic table. If the relevance of the periodic table is to be brought out, its information content must be chosen properly and exhibited in a manner suitable for highlighting the periodic nature of properties and their relation to atomic structure (Campbell, 1989). Apart from this difficulty, the periodic table is generally taught using charts, which are hung high on walls makeing it difficult for students to read the information being displayed (Campbell, 1989). These charts do not provide any opportunity for students to play with the given information, or to seek more relevant information. In other words, wall charts of the periodic table do not provide an opportunity for students to construct their own periodic table, filling the required information. Charts therefore, are not necessarily the best teaching-learning aid, with reference to the periodic table.

To present information in an interactive mode and to overcome the shortcomings of the conventional, two dimensional periodic table of elements, an attempt has been made to develop, a model of the periodic table, at the HBCSE. The description of the model is already presented in chapter III (see section 3.4.4.1).

5.3 The Experimental Studies

As mentioned above, three experimental studies using the periodic table model were conducted at Bombay and Solapur. All these studies were conducted for students from the vernacular medium (medium of instruction was Marathi). The first study, that is, experiment 1, was conducted for class X in a school run by the Bombay Municipal Corporation, which caters to the weaker sections of the society. This particular school was located conveniently near HBCSE's office premises and permitted the researcher to conduct her experiment. Generally, it is difficult to get a sample at class X for research purpose as teachers are expected to complete the prescribed syllabus by month of December and the preliminary examinations are conducted by end of January. Thus, making changes in the timetable for conducting an experiment is difficult for schools. At the same time, most of the students are often busy with private tuition classes or extra classes conducted after the school timings by schools and so they may not be available for participating in experiments. Despite these reasons, the school mentioned above allotted to the researcher a time span of one week (after the school timings). The next experimental work (that is, experiment 2) was also conducted in the same school, but in a different academic year. Once again, the work was conducted for students from class X. As before, one week was allotted to the researcher by the school authorities for intervention purposes. Both these studies were conducted in the first semester and after the topic of periodic table was covered in the school. The students who participated in the study were average or below average in their routine school chemistry performances. The last experiment (that is, experiment 3) was conducted in a Girls' school at Solapur. This time the intervention was carried out through the regular school science teacher, as opposed to the earlier experiments where the researcher conducted the intervention programme herself. The experiment was conducted for the students of class IX and the students were above average or average in their routine school chemistry tests performances. This school was selected because the school and the science teacher were involved in the Solapur project conducted by HBCSE (1990-1993) and the teacher and the school were willing to conduct the study. Once again, five days were made available for the intervention. In all the experimental studies, excellent co-operation was offered by the students, teachers and other school authorities. The details of the studies are presented below.

5.3.1 Experiment 1

5.3.1.1 The Methodology

a) Research Design:

The research used a quasi-experimental design (for details see chapter III, section 3.4.1). It used the control-experimental group design and the pre-post-test procedure for assessing the performance of students, as shown in table 5.01.

Table 5.01 : Research design of the experiment 1

Group	Pre-test	Intervention	Post-test
Control	Yes	____	Yes
Experimental	Yes	using model	Yes

Students were assigned to control and experimental group by means of the following procedure. Students were given two tests as pre-tests before assigning them to groups. These tests were then numbered as 1,2,3,4,...... The students with paper numbers 5 or multiples of 5, or close to 5 were assigned to experimental group. In other words, students with paper numbers 4, 5 and 6 and multiple of these number were assigned to the experimental group and students with paper numbers 1, 2, and 3 and multiple of these numbers were assigned to the control group. However, it was observed that the two groups were not equivalent with respects to distribution of sex and so a few students were shuffled. As no difference was observed in the mean performance of control and experimental group on the pre-test, both the groups were assumed to be equivalent even though the groups were not matched on all possible variables.

b) The Sample :

The sample consisted of a class of 49 students studying in standard X. Of these 49 students, only 38 students appeared for the post-test, reducing the actual sample to 38 students. The control group consisted of 21 students and the experimental group consisted of 17 students.

c) Tools

i) **Tests**

Two tests consisting of fifteen questions altogether, were given to both the groups (appendices 5.01 & 5.02). The same tests were given as post-tests. Students were supposed to answer these questions by referring to charts of the periodic table provided with the tests. The average time taken for completing the tests was about 30 minutes. The first test included questions on elements belonging to one row or one group, heaviest element, element with smallest atomic number, alkaline earth elements, nonmetals, transition elements and representative elements, electronic configuration and the connection between group number and number of electrons in outermost shell. The second test dealt with questions regarding the placement of elements on the basis of atomic number, element with smallest atomic size, strong oxidizing element, writing of formulae, properties of oxides, classification of elements as acceptors, sharer or donors of electrons or inert elements and properties of elements forming one group. In short, the first test dealt with the structure of the periodic table while the second test dealt with properties of elements and their variations.

ii) **Interviews**

After the pre-tests, 30 students from the class were interviewed for their understanding of the periodic table. Each interview lasted for about 30-40 minutes. The general outline of the interview is presented in appendix 5-I.1. A number of supplementary questions were asked depending on the responses of the students. The interviews were mainly aimed at students' knowledge of a) prerequisites (that is, atomic weight, atomic number, valency and physical and chemical properties of element) b) the periodic table (meaning of the information filled in the periodic table chart shown in the text-book, and the basis for the arrangement of elements) and c) meanings of newly introduced words related to the periodic table such as period, periodic event, periodic function.

d) Intervention

The intervention consisted of three sessions of 90 minutes each. An attempt was made to make all the sessions interactive so that the students handled the model. In the first session, the face revealing the name, the symbol, and atomic weight was introduced to the students who were asked to describe the presented information. The students checked whether the elements were arranged on the basis of increasing atomic weights. Students were then provided with blank cards on which they were asked to write either the name or the atomic weight of an element. The cards were then handed over to other students who were asked to place the cards at their proper places in the model. The students were asked to classify the cards for a few elements provided to them (on each card some properties of an element were written). This activity was performed to facilitate the understanding of groups in the periodic table.

The second session began with students conducting a revision of concepts covered in the first session. Then, the students were introduced to the second face of the box, showing the atomic number and symbol of elements to initiate discussion on this aspect. Throughout the session, atomic number remained the focal point of discussion. Initially, the atomic structure was discussed in brief, and the term, atomic number was explained. Students used the model to check how the atomic number varied in the periodic table. They were asked to guess the number of electrons in a given atom from its atomic number. Students then drew the electronic configuration of the element on the cards provided to them. They placed these cards at their proper places in the model and studied how electronic configuration varied in the table. Attention was drawn to the group number and number of electrons in the outermost shell. They were asked to guess whether an element would be an electron donor, or accepter, or sharer, on the basis of the number of electrons in the outermost shell. This activity enabled students to engage themselves in discussions related to oxidizing and reducing properties of elements. Students were asked to calculate the difference between the atomic numbers of successive elements in the group and to see how these differences varied from one group to another.

The third session was devoted to the concept of valency. Each student was invited to the blackboard and was asked to write down the atomic number, the number of electrons, electronic configuration and the expected valencies of any one element. This activity was performed for all the elements in the 3rd row. Students also wrote down the formulae of the oxides of the 3rd row elements. They were then given other elements from different groups and were asked to write down the formulae of their oxides, for example, once they wrote Na_2O, they were asked to write down the formula of potassium oxide. Another element from oxygen group, that is, sulphur was selected and students were asked to write down the formulae of sulphide of different elements. At this stage, discussion was focused on the variation of properties of oxides in the table. At the end of the session, revision of concepts in all the three sessions was conducted.

5.3.1.2 Analysis of Pre-tests

As stated before, the pre-test and the post-test consisted of two tests given together. The performance of students on the pre-test was poor in general. A two tailed t-test on the mean marks received by the experimental and control group was computed in order to ascertain whether there was any significant difference between the control and experimental group on the pre-test. The null hypothesis (H_0) that there was no significant difference between the two groups was tested against the alternative hypothesis(H_1) that there was a significant difference between the two groups. Table 5.02 gives the result of the t-test.

Table 5.02 : t-tests analysis for pre-tests (N =38)

Test	Mean marks of student		degrees of freedom	t-values with two tailed prob.
	Control	Experimental		
Test 1	2.53	1.76	36	1.25(p=0.22)
Test 2	5.35	4.14	36	1.15(p=0.26)

As the probability of t-calculated is greater than p= 0.05, the null hypothesis (H_0) is accepted. This indicates clearly that there was no significant difference between the mean marks received by both the groups on the pre-tests. The question-wise analysis of the tests was also carried out to see whether the performance of the control group and experimental group differed significantly on any particular question in the tests. Tables 5.03 and 5.04 shows the result of the analysis.

Table 5.03 : t-tests analysis for questions of test 1

Qt. No.	Control group (Mean marks of students)	Experimental group (Mean marks of students)	t-values with two tailed prob.
1	0.33	0.77	-2.85* (p=0.01)
2	0.24	0.24	0.02 (p=0.98)
3	0.05	0.18	-1.21 (p=0.24)
4	0.10	0.00	can not compute
5	0.52	0.94	-1.31 (p=0.20)
6	0.38	0.18	1.38 (p=0.18)
7	0.07	0.12	-0.62 (p=0.52)

* = significant difference

Table 5.04 : t-tests analysis for questions of test 2

Qt. No.	Control group (Mean marks of students)	Experimental group (Mean marks of students)	t-values with two tailed prob.
1	0.33	0.41	-0.24 (p=0.81)
2	0.05	0.00	can not compute
3	0.00	0.18	can not compute
4	0.10	0.18	-0.72 (p=0.48)
5	0.00	0.24	can not compute
6	0.68	0.83	-0.47 (p=0.64)
7	1.14	1.41	-0.78 (p=0.44)
8	1.86	2.12	-0.56 (p=0.58)

The question-wise t-test analysis revealed that the two groups differed significantly only on one question (that is,Q.1 of test 1). It is clear from the analysis that the control group and the experimental group did not differ significantly in their performance on the pre-tests.

5.3.1.3 Analysis of interviews

The main aim of interviews, conducted after the pre-test but before the intervention was to learn more about the students' understanding with respect to the pre-requisites, the structure of the table and the meaning of newly introduced words related to the periodic table. Students' understanding of different topics revealed in these interviews is presented below.

a) Knowledge of pre-requisites:

For understanding the periodic table, it is essential that students should know the meanings of terms like, atomic weight, atomic number, valency and relative valency. Table 5.05 shows students' responses to the questions regarding the pre-requisites.

Table 5.05 : Responses of the students to different questions on pre-requisites (N = 30)

Categories	Atomic number	Atomic weight	Valency	relative valency
can not answer	15	15	22	20
correct answer	-	2	1	1
incorrect answers	9	5	3	1
not asked	6	8	4	8

As discussed before, the curriculum expects that students have understanding of the properties of the elements, the atomic structure and valency before they learn the periodic table. It was observed that most of the students were able to distinguish between the physical and chemical properties of the elements (colour, smell, state were some of the physical properties mentioned by the students). However, it was observed that the understanding of the atomic structure especially that of valency was poor. Nearly 15 students (that is, 50% of the students) failed to explain the terms atomic number and atomic weight. Some of the students interpreted atomic number as number of electrons in the outermost shell, or number given on the basis of discovery of elements, or number given on the basis of the places of elements in the periodic table. It was also observed that students were confused between the terms atomic number, atomic weight and mass number. One probable reason for this confusion could be that all these terms (and some other terms) are introduced in quick succession in standard IX in the topic on 'atomic structure'. Also, the equivalent technical terms in Marathi are very similar to one another for example, atomic number- anukramank, atomic weight-anubharank, mass number- anuvastumanank.

The concept of valency appeared to be the most difficult for students to understand. Most of the students failed to give a definition of the term 'valency'. A common misconception was equating the number of electrons in the outermost shell to valency. Students also failed to calculate the valencies from the given chemical formulae. The understanding of valency requires the knowledge of a number of sub-concepts such as atomic number, electronic configuration and the concept of stability of a filled shell. To calculate valency from the configuration, one should see how many electrons (that is, number of electrons an element can accept, donate or share) are required to complete the outermost shell. Probably the multi-parametric nature of this concept makes it difficult for the students to understand. Another probable reason could be that all these concepts are taught in a short span of time without giving sufficient time to students for assimilating them. It is, therefore, essential that these concepts be revised and referred to repeatedly while studying other related topics such as properties of different elements and compounds.

b) General awareness of the table

The chart of the periodic table given in the text-books is expected to help the students understand the symbols and the significance of the two numbers appearing in the periodic table. During the interviews, students were asked questions relating to the meaning of the symbols and the numbers and were also asked to point out the row, group/group number and comment on the basis of arrangement of elements in the table. Table 5.06 shows the analysis of responses of students to various questions. The numbers in the columns show the actual number of students giving that response.

Table 5.06 : Responses of students to questions on structure of periodic table (N = 30)

Categories	Symbol	Upper no.	Lower no.	Period	Basis
can not answer	-	13	20	5	12
correct answer	26	7	5	16	8
incorrect answers	2	9	4	8	8
not asked	2	1	1	1	2

Table 5.06 table shows that nearly 13 or more students could not explain the meaning of the numbers given in the periodic table, and the basis on which elements are placed in the periodic table. While 13 of the students could not answer questions relating to the significance of the upper number (atomic number), there were 9 students who interpreted the upper number wrongly. Some students thought that this number showed the number of molecules or atoms in a given element. Some others thought that it indicated total number of electrons in the outermost shell. One student used the term 'atomic structure' for the upper number but was unable to explain its meaning. The interviews also revealed that students had not understood the basis of the periodic table. About 8 students thought that the elements are arranged on the basis of the sequence in which they were discovered or on the basis of the valency or on the basis of total number of electrons. On the other hand, almost 16 students (that is, nearly 50% or more), were generally able to show the period, group and group number. Those students who gave wrong answers considered period as group and vice versa. Most of the students, that is, 26 students (nearly 85%), were aware that the symbols in the table

represented elements. In short, students had a poor understanding of the structure of the periodic table, its information content and little appreciation of the basis of arrangement of elements in the table.

c) Understanding of newly introduced words

Students were asked to explain the meaning of words related to the periodic table such as period, periodic, periodic event, periodic function. The understanding of these words is essential for a better grasp of the periodic table.

Table 5.07 : Responses of the students to questions on meanings of new words (N=30)

Categories	Period	Periodic	Periodic event	Periodic function
can not answer	18	12	19	25
correct answer	-	4	6	-
incorrect answers	7	12	4	2
not asked	5	2	1	3

As table 5.07 indicates, almost 18 or more students could not explain the meanings of the words listed above. The term 'periodic function' was the most difficult word which could not be explained by a single student. As the students had no concept of a periodic function, they failed to explain the meaning of the periodic law. The word 'period' was interpreted either as 'a horizontal line' or as 'belonging to the periodic table'. The word 'periodic' was interpreted as 'horizontal', 'initial', 'complete' or 'again'. Few of the students also fumbled with the word 'event'. They related this word with incidents like an accident or a fight or a quarrel. This indicates that students assign different meanings to newly introduced words. Thus, it is necessary to explain the meaning of newly introduced words, and of words loosely used in daily parlance but which have a specific meaning in scientific context. In the absence of explanation of meanings, wrong interpretation of the words and terms results which hampers the understanding of any topic.

5.3.1.4 Analysis of post-tests

The tests which were given as pre-tests were re-administered as post-tests. A one tailed t-test was computed on the mean marks received by the experimental and control group of students to see the effects of intervention. The null hypothesis (H_0) that there was no significant difference between the two groups in the mean marks received was tested against the one tailed alternative hypothesis (H_1) that the mean marks received by the experimental group were more than the mean marks received by the control group on the post-tests. The results of analysis are given in the following table.

Table 5.08 : t-tests analysis for post-tests (N = 38)

Test	Mean marks of students		Degrees of freedom	t-values with one tailed probabilities
	Control	Expt.		
Test 1	1.71	4.94	36	- 4.46* (p=0.00)
Test 2	5.62	11.35	36	- 6.04* (p=0.00)

* = significant differences

As the probability of t-calculated was less than the p = 0.05, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted. Thus, performance of the experimental group was significantly improved after the intervention. The question-wise analysis similar to the pre-test analysis was carried out to study the question-wise improvement in the experimental group after intervention. Tables 5.09 and 5.10 give the results of the analysis.

Table 5.09 : t-test analysis for questions in test 1

Qt. No.	Control group (Mean marks of students)	Experimental group (Mean marks of students)	t- values with one tailed prob.
1	0.43	0.82	-2.63* (p=0.01)
2	0.24	0.53	-1.89* (p=0.03)
3	0.00	0.53	can not compute
4	0.10	0.41	-2.37* (p=0.02)
5	0.52	1.47	-2.92* (p=0.00)
6	0.29	0.65	-2.33* (p=0.01)
7	0.10	0.56	-3.36* (p=0.00)

* = significant difference

Table 5.10 : t-test analysis for questions in test 2

Qt. No.	Control group (Mean marks of students)	Experimental group (Mean marks of students)	t- values with one tailed prob.
1	0.57	3.06	-4.99* (p=0.00)
2	0.10	0.41	-2.27* (p=0.02)
3	0.00	0.12	can not compute
4	0.10	0.41	-2.27* (p=0.02)
5	0.10	0.47	-1.61 (p=0.06)
6	1.00	2.12	-2.86* (p=0.00)
7	1.29	1.77	-1.37 (p=0.09)
8	2.48	3.06	-1.21 (p=0.16)

* = significant difference

The question-wise analysis of the tests revealed that the experimental group showed significant improvement on six questions (out of seven) of test 1 and four questions (out of eight) of test 2.

In general, questions where students were asked to select the element with the smallest atomic number (Q.4 of test 1), the element with the highest atomic weight (Q.3 of test 1), or the element with the smallest atomic size (Q.2 of test 2), show considerable improvement in the experimental group. All these questions require scanning of one single property (like, atomic weight or atomic number or atomic size) in the table. It is interesting to note that similar improvement was not seen on complex questions (calling for multi-parameter considerations). For example, in case of question 3 and 5 of test 2, where students' were asked to select the strongest oxidizing element and to write down the formula of a compound respectively, the performance did not improve much even after intervention. These questions require much more understanding than the questions mentioned before. For example, to locate the strongest oxidizing element, it is essential to know the electronic configuration of the element, whether the element will be an electron donor or acceptor, the meaning of term oxidizing or reducing property and how it varies along a row and column. In short, even after intervention, the performance on such questions was not improved.

The weakness of this experiment was that the intervention was conducted with the experimental group alone whereas no treatment was given to the control group. Thus the improved performance of the experimental group can be attributed to merely being in the experimental conditions rather than the intervention itself. In fact it is not advisable to do so. Thus, in the next experimental study, both the experimental and the control were provided intervtion and the performance of the two groups was compared before and after the intervention.

5.3.2 Experiment 2

5.3.2.1 Methodology

a) <u>Research Design</u>

The research design was similar to that of experimental study 1 with some modification. As stated above in this study both the groups were provided intervention by the researcher. For the control group, the intervention limited to regular teaching using the textbook, whereas for the experimental group, the intervention used the periodic table model was used. The research design for this study was as follows

Table 5.11 : Research design of the experiment 2

Group	Pre-test	Intervention	Post-test
Control	Yes	using text books	Yes
Experimental	Yes	using model	Yes

A procedure some what similar to matching of students in both the groups was followed to assign students to experimental and control group. The chemistry marks of students on previous year's final examination were available to the researcher. The students were matched for their performance from the available data. However, the matching was not pair-wise. If four students had marks above 25, then two students were placed per group. If there were 5 students between marks 20 to 25, then three were put in one group and the remaining two were put into another groups. Some other precautions were also taken. One precaution was that both the groups had equal distributions by sex.

b) Sample

Like the experiment 1, an entire class of 34 students from standard X was selected for the study. Out of these 34 students, 17 students were assigned to each of the control and experimental group. However, 2 students from each group dropped-out, reducing the actual sample to 30 students.

c) Tools

i) **Tests**

The tests which were used in the experiment 1 were used as pre-tests with slight modifications. Equivalent tests were developed and administered as post-tests two days after the intervention (appendices 5.03 to 5.06).

ii) **Interviews**

As before, interviews were conducted after the pre-tests. Equal number of students, that is, five students, from each group were interviewed. The nature of interviews was similar to those conducted for experiment 1. However, this time students were probed more for their understanding of the chemical terms 'elements, compounds, mixtures and chemical and physical properties'. In general, the other questions about structural understanding, understanding of prerequisites and understanding of new words related to periodic table were more or less the same. As before. the questions were varied to limited extent depending upon students response and the duration of the interview was about 30-40 minutes.

d) Intervention

In this study, the intervention was conducted for both the experimental and control group. The experimental group was taught using the periodic table model whereas the control group was taught using the periodic table from the textbook. The control group, students had their chemistry textbooks with them during the intervention whereas the experimental group was asked not to bring the textbooks. Three sessions of almost two hours duration were conducted for each group. Attempts were made to keep the content taught in any particular session the same for both the groups. Detailed notes of each session were kept by the researcher.

The first session for experimental group began with an introduction to the model. The first face of the model was introduced to students and they were asked to describe the information. From the clinical interviews, it was observed that students had problems in understanding the concepts elements, compound and mixture. Therefore, this session concentrated on these concepts and the concept of atoms and molecules and their symbolic representation. Students were asked to read names and symbols of elements from the model. Attention was drawn to symbols retained from Latin names and students were asked to locate such elements from the model and read the corresponding Latin name and symbol. The next point of discussion was basis for arrangement of elements in the periodic table. In this discussion, the term atomic weight was explained to the students initially. While observing atomic weight sequence, students observed that in case of Ar and K the atomic weight sequence was reversed. At this point, another question about how to decide which elements should be placed one below the other was posed to the students by the researcher. This initiated a discussion which helped students to conclude that some other parameter apart from atomic weight must also be used for arranging the elements in the periodic table.

In the second session, students revised the concepts covered in the previous session and some of the students stated that properties of elements may have been used as the basis for arrangement of elements in group along with the atomic weight. When asked to explain, they presented examples of elements from alkali metal group and inert gases. This point was discussed in detail and attention was drawn to gaps (left by Mendeleev and which were displayed in the model). Students were given some properties of other elements from the group and they were asked to guess the properties of the missing elements so that the importance of Mendeleev's work could be understood. The second face of the model which displayed symbol, atomic number, metal/nonmetal property was revealed to students. To begin with, the atomic structure was revised in brief. Then each student was provided with blank cards on which he/she was asked to write atomic number, number of electrons of one element. As homework, the students were asked to draw electronic configuration on the cards provided to them. The students then studied variation in metallic and non-metallic property.

In the third session, after a revision of what was covered earlier, the students were asked to place the prepared cards at their proper places in the model and then variations in the electronic configuration in the table were studied. The next discussion was about calculating valencies of elements and its variation in the table. The terms period, periodic and periodic function were explained to the students. After this, students wrote the formulae of oxides of different elements belonging to one period and one group. Oxidation-reduction properties of alkali metals and halogens were discussed in brief.

For the control group, the content taught per session was almost the same. The main difference was that the textbook was used instead of the model. Even though the sessions were interactive in nature, it was not possible to conduct the activities which the periodic table model permitted. For example, while discussing the symbols retained from Latin names, the names of elements were told to the students (as this information is not given in the periodic table presented in the textbook) or in the second session, while discussing the importance of Mendeleev's work, it was not possible to show the gaps in the table as the table in the book displays the elements for which gaps were left. About electronic configuration, students were asked to write a table in the notebook which stated the atomic number, number of electrons and electronic configuration (instead of preparation of cards as in the experimental group). Students then studied variation in electronic configuration of these elements while taking into account their placement in the periodic table. In the last session once again valency and chemical formulae of oxides was the focal points of discussion.

5.3.2.2 Analysis of Pre-tests

Like experiment 1, t-tests were used to see whether there were any significant differences between the performances of the experimental and control group in the pre-test. The null hypothesis (H_0) that there was no significant difference between the mean performances of the two groups was tested against the two-tailed alternative hypothesis (H_1) that the mean performance of experimental and control group differed significantly. The result of the t-tests are shown in table 5.12.

Table 5.12 : t-test analysis for pre-tests

Test	Mean marks of student		degrees of freedom	t-values with two tailed probabilities
	Control	Experimental		
Test 1	2.23	2.00	28	0.48 (p=0.64)
Test 2	3.07	3.77	28	1.25 (p=0.22)
Total	5.30	5.77	28	0.55 (p=0.59)

From the table 5.12, it is clear that the probability of t-values for test 1, test 2 and the total score are greater than $p = 0.05$. So the null hypothesis (H_0) is accepted. It indicated that the mean marks obtained by the two groups on the pre-tests did not differ significantly. The question wise analysis of the tests was also done to see whether there are significant differences between the performances of the two groups on a particular question from the tests. The results of this analysis are presented in table 5.13.

Table 5.13: Question wise t-test analysis for test 1

Qt. No.	Mean marks of Students		t - Values with two tailed probability
	Control	Experimental	
1	0.58	0.31	1.38 (p = 0.18)
2	0.46	0.31	0.78 (p = 0.44)
3	0.00	0.06	can not compute
4	0.13	0.00	can not compute
5	0.50	0.57	0.48 (p = 0.64)
6	0.67	0.27	2.18* (p = 0.04)
7	0.41	0.69	1.69 (p = 0.11)

* = significant difference

Table 5.14: Question wise t-test analysis for test 2

Qt. No.	Mean marks of Students		t - Values with two tailed probability
	Control	Experimental	
1	0.04	0.17	0.94 (p = 0.36)
2	0.08	0.25	1.68 (p = 0.11)
3	0.00	0.04	can not compute
4	0.125	0.00	can not compute
5	0.14	0.15	0.05 (p = 0.96)
6	0.71	0.83	0.67 (p = 0.51)
7	1.31	1.43	0.32 (p = 0.75)
8	1.00	1.19	0.78 (p = 0.44)

The above tables reveal that the mean performance of the two groups differed only on one question (that is, question 6 of test 1). For all other questions there are no significant differences. Thus, the two groups were equivalent in their performances on the pre-tests.

5.3.2.3 Analysis of interviews

The interviews were conducted after the pre-tests and prior to the interventions. The students were interviewed about their understanding of i) pre-requisites ii) structural aspects of periodic table and iii) new words related to periodic table. These interviews were almost similar to those conducted for experiment 1. The analysis of the interviews is presented below.

a) <u>General awareness about the periodic table</u>

The questions asked to the students were related to information shown in the periodic table from textbooks. The students were asked to show groups, period, group number, the sequence in which the table should be studied. The following table displays students' responses to various questions.

Table 5.15: Understanding of structural aspects of periodic table (N = 10)

Type	Sym.	Up. No. (at. No.)	Lo. No. (at. Wt.)	Seq.	Gr./ period	Gr.No.	Basis
can't answer	-	3	7	3	2	7	5
correct	8	1	2	3	7	3	3
others	2	6	1	3	1	-	2
not asked	-	-	-	1	-	-	-

Regarding symbols, groups and period, most of the students provided correct answers. For symbols in the table, words such as 'formula' and 'equation' were used by one student each and these students were unable to explain the meanings of these words. Regarding upper number (that is, atomic number) in the periodic table, six students stated that the number indicated valency or number of atoms in the element. One student while describing this number stated "there are 2 elements for He, 3 elements for lithium and so on". Most of the students were unaware of the meaning of the lower number (that is, atomic weight). Similar response were obtained from five students for the basis on which the elements are arranged in the periods. One student stated that elements were arranged according to the periods. The box in the periodic table, that is, $\boxed{Li^3}$ was shown as period. As far as reading of the periodic table was concerned, 6 students failed to show correct sequences. Out of these six students, three stated that they did not know and the rest started with Hydrogen and read the 1st column and then went to the next column (that is, from H --> Li --> Fr --> Be -->).

b) <u>Pre-requisites</u>

As the topic of atomic structure and valency is covered in class IX, students were questioned about atomic number, atomic weight, valency. Some attempts were also made to know what the term elements, compounds, mixture and chemical and physical properties means to the students. The following tables 5.16, 5.17 and 5.18 present students' responses to all these questions.

Table 5.16: Students' response for question on atomic weights and atomic number (N=10)

Category	Atomic Weight	Atomic Number
no idea	5	4
correct	-	2
others	3	4
meaningless answers	2	-

Table 5.17 : Students' response to question on valency (N=10)

Category	Definition	Calculation from	
		electronic configuration	formulae
no idea	5	4	5
correct	-	3	2
others	4	2	2
not asked	-	1	1

Table 5.18: Students' responses to questions on elements, compounds,mixtures and properties (N=10)

Category	Elements		Compounds		Mixtures		Properties	
	Def.	e.g.	Def.	e.g.	Def.	e.g.	Def.	e.g.
no idea	9	-	2	-	-	-	-	-
correct	-	3	2	3	2	2	3	2
other	1	5	6	7	8	6	6	7
not asked	-	2	-	-	-	2	1	1

From Table 5.16, it is clear that most of the students were not able to explain the term 'atomic weight'. In the case of atomic number, 3 students thought that atomic number indicated the number of atoms in a given element, whereas another student interpreted it to be the mass number. With respect to valency, five students were not able to give a definition (table 5.17). Out of the four students who provided other answers, two students stated that valency is related to electrons, one interpreted it to be the number of electrons in outermost shell and yet another thought that compound is called as valency. This confusion most probably arises out of the fact that technical terms used for valency and compound in marathi are similar to each other (valency - sanyuja, compound - sanyug). Regarding calculation of valencies from the electronic configuration, six students were not able to calculate valencies. Out of these six, four students stated that they did not know how to calculate valency and two others considered it to be the number of electrons in outermost shell.

In the case of chemical formulae, five students did not know how to calculate valencies and two others stated that valencies could not be calculated from chemical formulae. The above discussion reveals that the definition of valency is complex for students and so they fail to define it. Most of the students failed to calculate valencies from electronic configuration and formulae which indicated that this concept of valency has not been internalized by students.

The responses on elements, compounds and mixtures indicated that students could not differentiate between these classes (table 5.18). Regarding the word 'element', not a single student was able to give any description of this concept in his/her words. Only one student stated that elements occur in nature and all other students said that they could not state any characteristics. However, regarding examples of elements, only three students gave some wrong examples or classified given examples wrongly along with correct examples. When asked on what basis such a grouping was done, the answers received were - i) 'it is given in the book' ii) 'we have studied' or iii) 'teacher has told'.

Only two students were able to differentiate between compounds and mixtures. They both stated that a new substance is formed in the case of compounds whereas in the case of mixtures, no new substance is formed. Most of the other students stated that in the formation of the mixture or a compound, two or more substances are required. Regarding examples of compounds, seven students gave wrong examples. Iron was included as a compound by three students. Nitrogen, copper, mercury and hydrogen were some other examples. In case of mixtures, there were six students who gave wrong examples or classified the given example wrongly. Iron, copper, oxygen, salt, sugar and water were the substances which were classified as mixtures. The student who classified sugar and salt as a mixture stated " these substances are mixtures because they can be mixed easily with other substances ". The same student classified iron as a compound since it could not be mixed with any other substance. Another student had classified oxygen as a mixture since this student believed that air was present along with oxygen. In the case of mixtures, one student had stated liquid substances (which included mercury, sherbet) as examples.

Regarding properties, six to seven students either stated a wrong property or classified the given property wrongly. Non-metal was not considered as property by six students and the same was observed for colour, state (2 students each) melting and rusting (one student each). Melting was classified as a chemical property by three students. Of these three, two students stated the use of heat as the reason for considering melting as chemical property. Rusting was classified as a physical property by two students and one student explicitly stated, " rusting cannot be a chemical property as no heat is used ". Yet another student classified colour, gas, heat conductor and reaction as chemical properties since he thought chemical properties were those which could not be changed. He classified formation of H_2O as physical because " You can obtain H_2 and O_2 from water and so the change is not permanent ". He, thus, thought that formation of water was a temporary change. The same student classified formation of FeO and $FeCl_2$ as chemical properties as he believed the iron could not be obtained back from these substances.

The above discussion indicated that student had not understood the concept of elements, compound and mixtures. Even though they knew the fact that at least two substances were required for obtaining compounds and mixtures, they failed to differentiate between the two. The student who has classified oxygen as a mixture has drawn his reason from the fact that oxygen is present in air. The student was unable to think of oxygen as a single substance. The other student who classified salt, sugar and water as mixture had drawn his reason from the fact that solutions are mixtures and so the individual component of a solution should also be a mixture. Regarding chemical and physical properties, it was observed that students connect 'use of heat' with chemical change. It appears that the students are not familiar with the meaning of the word 'non-metal' and this may be the cause why they do not classify it as a property. As against this, 'being metal' was always classified as a property since they do have some feel about word metal.

The student who classified formation of H_2O from O_2 as a physical property whereas formation of FeO or $FeCl_2$ as a chemical property had studied decomposition of water but had not seen separation of Fe from FeO. So even though students were able to classify various properties correctly they did have problems with some properties.

5.3.2.4 Analysis of Post-test

The analysis of post-tests was similar to that of pre-tests. The null hypothesis (H_0) that there are no significant differences between the mean performances of the two groups was tested against the one-tailed alternative hypothesis (H_1) that the mean performance of the experimental group was better as compared to the mean performance of the control group. The results of t-tests are presented in table 5.19.

Table 5.19 : t-test analysis for the post-tests (N = 30)

Test	Mean marks of control group	Mean marks of experimental group	Degrees of Freedom	t-values with one tailed prob.
Total	7.47	11.43	28	2.80* (p=0.00)
Test 1	3.17	3.83	28	1.11 (p=0.14)
Test 2	4.30	7.60	28	3.23* (p=0.00)

* = Significant differences

The above table 5.19 indicates that the overall mean performance of the experimental group is significantly better as compare to overall mean performance of the control group. However, the test-wise analysis indicated that the two groups did not differ significantly on test 1. However, for test 2, the mean performance of the experimental group was once again significantly better as compared to that of the control group. Thus, it appears that the intervention has helped the experimental group perform better than the control group.

Question wise t- test analysis was also conducted for the post-test. For this analysis the null hypothesis and the one tailed alternative hypothesis were the same as above. The results of this analysis are presented in the table 5.20 and 5.21.

Table 5.20 : Question-wise t-test analysis for test 1

Qt. No.	Mean Marks of		t-values with one tailed probabilities
	Control group	Experimental group	
1	0.4	1.00	can not compute
2	0.47	0.47	0.00 (p=1.00)
3	0.20	0.08	-0.91 (p=0.19)
4	0.36	0.53	0.93 (p=0.18)
5	0.79	0.75	-0.23 (p=0.41)
6	0.57	0.43	-0.74 (p=0.23)
7	0.54	0.73	1.28 (p=0.10)

* = significant difference

Table 5.21 : Question-wise t-test analysis for test 2

Qt. No.	Mean Marks of		t-values with one tailed probabilities
	Control group	Experimental group	
1	0.47	1.39	3.11*(p=0.00)
2	0.00	0.13	can not compute
3	0.20	0.29	0.62 (p=0.27)
4	0.23	0.00	can not compute
5	0.37	0.86	1.46 (p=0.08)
6	1.00	1.40	1.57 (p=0.06)
7	0.79	2.07	3.32*(p=0.00)
8	1.54	1.77	1.07 (p=0.09)

*** = significant difference**

The above tables indicate that the intervention has helped the experimental group significantly, on question 1 and 7 as compared to the other questions in test 2. For test 1, there are no significant differences for any questions.

The analysis so far has indicated that the intervention helped the experimental group as compared to the control group on the overall performance in two tests. The test-wise analysis showed that the intervention helped the experimental group significantly on the second test, than on the first test. The question-wise analysis of each test revealed further that in the case of the second test, even though there was some overall improvement, the improvement was significant on questions 1 and 7, as compared to that on the other questions of the test.

Before concluding about this experiment, it will be useful to look at how the intervention has helped the individual group. For this purpose, paired t- test analysis for pre and post test was conducted for the experimental and control group separately. The results of the analysis are shown in tables 5.22 and 5.23. For this analysis (that is, within group analysis) the null hypothesis (H_0) that there was no significant difference between the mean score of the experimental group on the pre-tests and the post-tests was compared with the one tailed alternative hypothesis (H_1) that the mean score on the post-test was better than the mean score on pre-tests. Please note that the same hypotheses were used for the control group.

Table 5.22 : t-tests analysis for pre- and post-tests administered to the experimental group (N = 15)

Qt. NO.	Mean marks on test 1		t- values one tailed prob.	Mean marks on test 2		t -values one tailed prob.
	post	pre		post	pre	
1	1.00	0.33	4.69* (p = 0.00)	1.39	0.18	5.67* (p = 0.00)
2	0.46	0.31	0.81 (p = 0.27)	0.14	0.25	-0.82 (p = 0.21)
3	0.08	0.08	0.00 (p =1.00)	0.25	0.04	1.60 (p = 0.07)
4	0.50	0.00	3.61* (p = 0.00)	0.00	0.00	-
5	0.81	0.54	1.62 (p = 0.07)	0.67	0.17	1.39 (p = 0.09)
6	0.43	0.29	1.47 (p = 0.08)	1.40	0.83	5.26* (p = 0.00)
7	0.81	0.70	0.90 (p = 0.19)	2.07	1.43	2.09* (p = 0.03)
8	-	-	-	1.85	1.19	3.58* (p = 0.00)
Tot	3.83	2.00	5.13* (p = 0.00)	7.60	3.77	6.05* (p = 0.00)

* = significant difference

Table 5.23 : t-test analysis for pre- and post-tests administered to control group (N = 15)

Qu. No.	Mean marks on test 1		t-value one tailed prob.	Mean marks on test 2		t- value one tailed prob.
	post	pre		post	pre	
1	0.33	0.58	-1.15 (p = 0.14)	0.50	0.04	1.96* (p = 0.03)
2	0.54	0.46	0.43 (p = 0.34)	0.00	0.08	-1.48 (p = 0.08)
3	0.20	0.00	1.87* (p = 0.04)	0.23	0.00	2.52* (p = 0.01)
4	0.36	0.07	1.75* (p = 0.05)	0.30	0.05	1.46 (p = 0.08)
5	0.82	0.46	2.19* (p = 0.03)	0.39	0.14	1.45 (p = 0.08)
6	0.67	0.67	0.00 (p = 1.00)	1.04	0.71	1.46 (p = 0.08)
7	0.59	0.41	0.84 (p = 0.21)	0.50	1.33	-2.16* (p = 0.02)
8	-	-	-	1.58	1.08	1.56 (p = 0.07)
tot	3.17	2.23	1.65 (p = 0.06)	4.3	3.07	1.81* (p = 0.05)

*** = significant differences**

From table 5.22, we see that the null hypothesis was rejected and one tailed alternative hypothesis accepted for the total mean performance of the experimental group on both the post-tests. Question-wise analysis indicated that the alternative hypothesis was also accepted for the mean performance of the experimental group on questions 1 and 4 of test 1 and questions 1,6,7 and 8 of test 2.

Regarding the control group, it was seen that the null hypothesis that there was no difference in the mean performance of the group on the pre-test and the post-test was rejected for the total mean performance on test 2 and also for questions 1,3 and 7 of test 2 (see table 5.23). In the case of test 1, the null hypothesis was once again rejected for questions 3, 4 and 5 of test 1. But, for the overall mean performance of the control group on test 1 the null hypothesis was accepted.

In other words, the intervention helped the experimental group, significantly on questions about elements from the same period and about element with largest atomic number as compared to other questions. In case of test 2, the intervention helped significantly on questions on the placement of elements on the basis of atomic number, regarding elements as electron donor or acceptor or sharer or inert, regarding the nature of oxides formed and about the properties of elements belonging to one group.

In the case of control group, the intervention helped on questions regarding element with lowest atomic weight and with largest atomic number. In case of test 2, significant differences were observed for questions on placement of elements in the table according to their atomic numbers (that is, question 1) and question regarding the reducing agent (that is, question 3). However, in case of question 7, there was significant decrease in the performance (questions regarding oxides).

Thus, it is observed from the post-test analysis between the two groups that after intervention the overall mean performance of the experimental group differed significantly and in particular on the performance on test 2. The pre- post-test comparison within the groups indicated that the experimental group has gained significantly on both the tests whereas the control group has gained only on test 2. In other words, it means that the intervention has affected the performance of both the groups. However, the gain is significantly more for the experimental group. Thus, the analysis indicates that intervention with the help of the model has helped students better as compared to the intervention using the textbook.

Even though, the intervention was conducted for both the groups, in spite of taking all possible precautions, there is a chance that the personal biases of the researcher who had developed the model might have influenced the experimental work. In order to overcome this drawback, it was decided that the regular science teacher should use the model in the school. In the next experiment the model was used by the teacher for teaching the topic of periodic table and other related concepts.

5.3.3 Experiment 3

5.3.3.1 Methodology

a) Research Design

The research design for this study was the same as that for experiment two. The only difference was that in this study intervention for both the groups was conducted by the school science teachers and not by the researcher. The other difference was that the chart of the periodic table was used for teaching the control group. The research design for the work was as follows.

Table 5.24 : Research design of the experiment 3

Group	Pre-test	Intervention	Post-test
Control	Yes	using periodic table chart	Yes
Experimental	Yes	using model	Yes

Once again, the marks of all these students on routine chemistry examination were available to the researcher. The matching of the two groups was done as discussed before. As usual, the two groups were tested for their mean performance on a routine chemistry test and also for their mean performance on the pre-tests which were administered to them.

b) Sample

Two classes of class IX students from a girls' school at Solapur were selected for the experimental work. The classes had strengths of 51 and 54 students respectively. But for the experimental purpose, due to various reasons (such as not present for pre-tests or post-tests or intervention) there was a reduction in sample size. The experimental group consisted of 40 students whereas the control group consisted of 35 students except for one test. For this test (test 4), the sample was reduced further to 33 (experimental) and 29 (control).

c) Tools

i) **Tests**

Six different tests were administered as pre-tests. All these tests are given in (appendices 5.07 to 5.12). These tests were about chemical/physical properties, symbols of elements, atomic structure and electronic configuration, valency and writing chemical formulae. No test on the periodic table was administered as this topic is not included in the syllabus for class IX. Most of the tests are self explanatory and do not require much discussion. In brief, the tests on atomic structure and electronic configuration (that is, test 2 and 3) expected students to know the term atomic number and calculation of number of electrons from it, representation of electronic configuration, representation of changes in electronic configuration in ion formation etc. The test on valency (that is, test 4) includes questions on definition of valency, calculation of valency from electronic configurations, valency and reactivity and valency and properties of elements. The test on chemical formulae (that is, test 5) included questions on writing formulae using valencies and writing chemical formulae for elements with similar valencies (using the given information). Apart from these tests, there was one test on properties of elements (that is, test 1) and one more on symbols of elements (that is, test 7).

Equivalent post-tests were prepared and administered after a gap of 4 to 5 days after intervention without prior intimation to the students. The post-tests were administered for both the groups by the science teacher. A test on periodic table was also administered in the post test (that is, test 6).

Table 5.25 : Tests for experiment 3

Test	Pre	Post	Appendix No.	Time taken (min)
Test 1 (properties)	Yes	Yes	5.07* 5.07a	5
Test 2 (at. stru.)	Yes	Yes	5.08* 5.08a	5 -10
Test 3 (ele. con.)	Yes	Yes	5.09* 5.09a	5 - 10
Test 4 (valency)	Yes	Yes	5.10* 5.10a	20 - 40
Test 5 (formulae)	Yes	Yes	5.11* 5.11a	15 -20
Test 7 (symbols)	Yes	Yes	5.12*	5
Test 6 (per.table)	-	Yes	5.13*	15 - 20

* - pre-test, a - post-test

ii) Interviews

After the pre-tests, 10 students were interviewed by the researcher. The questions in the interviews were about elements, compounds and mixtures, atoms and molecules, chemical and physical properties and valency. Unlike the prior interviews, there were no questions on the periodic table as the chapter is not covered in the syllabus for class IX.

d) Intervention

The intervention for both the groups was conducted for 4 days. Each intervention session was conducted for about 80 minutes. The experimental group was taught using the model whereas the control group were taught using wall charts. Both the groups were taught on the same day (experimental group was taught first). All the sessions were attended by the researcher.

Detailed discussions regarding the nature of sessions were conducted with the science teacher. The science teacher herself noted various points during the discussions and gave some suggestions. The contents of each session along with the pedagogical instructions were provided in writing to the teacher.

Like the intervention in the earlier experimental works, attempts were made to discuss various related concepts in the intervention sessions. No textbooks of chemistry were permitted in the classroom for both the groups.

The first session for both groups focused on elements, properties, atoms and molecules and atomic structure. While discussing elements, meaning of the word 'element' (other similar words for liquid- , solution -, matter -) and examples of gaseous, liquid and solid elements were discussed. After this, different properties were discussed. While discussing the concepts of atoms and molecules, it was emphasised that the single atom or molecules would have all the chemical properties whereas physical properties (that is, properties related to bulk of substance) could not be displayed by a single atom/molecule. Regarding atomic structure, the points which were revised were the different particles present in an atom and their charges, the charge on atom and the terms atomic weight and atomic number (This topic was covered in detail in the school before the experiment).

For the experimental group, the next session began with an introduction to the model. The first face of the model which displays symbol, the name, atomic weight of an element was introduced to the students.

Students discussed the symbols of various elements, symbols derived from Latin names (Latin names were written in the model) and studied atomic weight sequence and how to read the periodic table. A similar session covering all these points was conducted for the control group using the wall chart. The elements whose symbols were retained from Latin names were shown by the teacher as this information was not presented on the chart. In the next session, the experimental group studied the second face of the model (displaying atomic number, metallic/nonmetallic property and the state of the element at NTP). Initially, variations in metallic and nonmetallic properties was studied. The next point of discussion was electronic configuration. It was expected by the researcher that students draw electronic configuration of different elements (20 elements to begin with) and place them in the model and then study the variation in the electronic configuration. However, the teacher preferred to use prepared cards for this purpose. For the control group, the teacher taught the variation of metallic and non-metallic properties. The chart was used to teach variation in electronic configuration.

In the next session, valency was the focal point of discussion. Students calculated valencies and studied their variation in the table. Discussion was then focused on the ionic bond (between metal and nonmetal) and covalent bond (between nonmetals). This session was almost similar for both groups.

The last session, concentrated on writing chemical formulae of oxides of different elements. The activity began with alkali metals. Initially the students were asked to write the formulae of the first three alkali metals.

The fourth face of the model which displayed the chemical formulae was then revealed to the students. This face also displayed the formulae of respective chlorides. The students were asked to check these formulae. The students then completed this activity for the remaining alkali metals (that is, the last three elements). Then, this activity, was extended progressively to cover alkaline earth elements, group IIIA elements and so on. At this point, the concept that even though the chemical properties of the elements in one group are alike, the same need not be true for physical properties was explained to the students with the help of halogen group which the students have studied as a part of their chemistry syllabus. In case of the control group, the teacher taught chemical formulae and presented the formulae of different elements on the blackboard.

5.3.3.2 Analysis of Pre-tests

As stated before six tests were administered as pre-tests. For each of these, t-tests were conducted separately to see whether there were any significant differences between the mean performances of the two groups. The null hypothesis (H_0) that there was no significant difference between the mean performance of the two groups was tested against the two-tailed alternative hypothesis (H_1) that the mean performance of both the groups was significantly different.

Table 5.26 : t-tests analysis for pre-tests

Test	Mean Marks of		t- values with two tailed probabilities
	Experimental	Control	
Test 1	4.37	4.65	0.88 (p=0.38)
Test 2	7.55	8.06	0.87 (p=0.39)
Test 3	2.10	2.68	1.28 (p=0.21)
Test 4**	6.57	6.76	0.17 (p=0.86)
Test 5	1.54	0.42	2.70*(p=0.01)
Test 7	2.74	3.23	1.36 (p=0.18)

*** - Significant difference**
**** - For this test the sample size (N) was 62 students. (experimental = 33, control = 29).**

The above analysis indicates that the two group differed in their performance, on one test, that is, test 5 (writing chemical formulae). For all the other tests, the null hypothesis that there was no difference between the mean performance of the two groups was accepted. Thus, the two groups were assumed to be equivalent except for their performance in test 5 in which the performance of the experimental group was significantly better.

5.3.3.3 Analysis of Interviews

The interviews conducted concentrated on understanding of elements, compounds and mixture, chemical/physical properties, atoms and molecules and valency. The analysis of interviews conducted is presented below.

a) Understanding of elements, compounds and mixtures

The students' responses for the questions on elements, compounds and mixtures is presented in table 5.27. Students were asked to explain the meaning of these words and state examples.

Table 5.27 : Students' responses to questions on elements, compounds and mixtures (N = 10)

Category	Element		Compound		Mixtures	
	Def.	e.g.	Def.	e.g.	Def.	e.g.
no answer	-	1	-	-	-	-
correct	5	6	5	5	8	7
others	5	3	5	5	2	3

The above table indicates, that of 10 students, 5 students were able to define elements, compounds and mixtures. In case of elements, three students interpreted elements to be liquid substances or substances obtained from liquid substances. This is most probably due to the fact that the words used in Marathi for 'element' and 'liquid' are similar enough to cause confusion (Element - Muldravya, Liquid - Drave). Another student stated symbols as characteristics of elements. In case of examples, two of the students who interpreted elements to be liquid substances stated liquids, such as, milk, kerosene, spirit, tincture iodine as examples of elements. The third student stated Fe, H_2 and O_2 as examples of element with the explanation that all these substances are obtained from liquid substances. NH_3 was stated to be an element by one student whereas sugar and salt were stated as elements by another student.

Regarding compounds, there were five students who defined compounds in different ways. One student perceived compound to be substances which are not soluble in water. The examples given by the student were dust, sand, pieces of zinc, yellow phosphorus. Another student stated that for compounds, one substance should dissolve into the other substance. This student stated water + salt or sugar, liquid Fe + liquid Cu and water as examples of compounds. For water, the student stated, "gaseous hydrogen and oxygen dissolve like water and salt to form water". Solution of sugar, $KMnO_4$ were classified as compounds using the criteria that components of compound could not be separated. The same student, however, classified solution of salt and alum in water as mixtures because salt and alum could be obtained back from the solutions. Another student classified water salt + water and sugar + water as compounds as in these cases the components could be separated.

All the above responses indicate, that in general, these students were not able to differentiate compounds from mixtures. Students were using a single criteria of separability of components to classify substances specially the solutions. Substances which dissolve in water form mixtures and so the individual substances were also believed to be mixtures. Water is a confusing example because the experiment of electrolysis of water is performed in the school. Students see water as a mixture rather than a compound, as the components are separable without much trouble. These students had not taken into consideration that a chemical reaction has taken place in the formation of water.

In case of mixtures, most of the students were able to give correct answers, definition and examples. However, there was one student who thought substances which dissolve in water to be mixtures. Thus, water, O_2, tea and coffee were classified under mixture.

b) Understanding of atoms/molecules

The students were asked to explain these words, whether atom/molecule is visible to the naked eye or through the simple microscope which they use in the school laboratory. The students were also shown diagrams of element, compound and mixture in terms of atoms and molecules. They were asked to identify the diagram and also provide reasons for their answer. Even though such diagrams are not used in their text-books, this question was asked to see whether these students are able to perceive elements, compounds and mixtures in terms of particular nature or whether they have difficulties in doing so. The responses of students on atoms/molecules are displayed in the table 5.28.

Table 5.28 : Students' Responses to questions on particular nature of matter (N =10)

Category	Atoms	Molecules	Pictorial representation of		
			element	compound	mixture
correct	9	6	8	8	8
others	1	4	2	2	2

Regarding atoms, most students stated that atom is the smallest particle of an element. Seven students stated that atoms were not visible to the naked eye or through simple microscope. However, three students thought that atoms were visible through a simple microscope. Regarding molecules, six students stated the correct definition. Of the remaining four students who presented some other definitions, one student thought molecule to be the smallest particle of atom and the other two defined molecule to be smallest particle of any substance which has free existence. There was one student who thought that the smallest particle of substance if visible to the naked eye was a molecule. This student stated that the smallest particles of substances such as gold, silver, copper, iron or water should be referred to as molecules as these particles were visible to the naked eye. However, smallest particle of a gas was an atom. If the gas was coloured then the smallest particle should be called as a molecule. In other words, according to this student a visible particle was a molecule whereas an invisible particle was an atom. Regarding the visibility of molecules, there were two more students who thought molecules were visible through a simple microscope. In order to cross-check student' answers about atoms and molecules, especially those of students who gave correct answers, students were given a list of substances and were asked what the smallest particle of these different substances would be. Most of these students answered correctly given a variety of examples.

Regarding chemical and physical properties, seven students were able to state correct properties of substances. Most of the students stated colour, state, smell, taste, conductivity to be the physical properties. However, of these seven students, five students thought that a single atom or molecule would possess all the physical properties of a substance. The other two stated almost the same answer, but one of them thought that a single atom or a molecule would not have colour and the remaining students thought that a single atom or a molecule would differ only with respect to weight. Of three students who did not give correct answers for properties, one student did not have any idea about properties. Another student stated physical properties as chemical and vice versa and the third student classified properties like smell and colour to be physical properties and properties such as being heavier (that is, weight) or state of aggregation was chemical properties, as these latter properties could not be changed. However, this student also thought that a single atom or a molecule would possess all the physical properties. All these responses indicate that students have not totally abandoned the continuous model of substances. The definition of atoms or molecule presented in the book may be probable cause for such answers. The definition states atom to be the smallest conceivable particle of an element which has all the properties of that element and which can take part in a chemical reaction. The term 'molecule' is defined in a similar way. It appears that both these definitions are interpreted literally and if these definitions are taken into account, then the students' answers are not surprising. The connection of atom and molecules and free existence of the same stated by some students is correct if definitions from their prescribed text-books are taken into account.

Regarding pictorial identification of 'element, compound and mixture', there was not a single student who did not answer this question. In fact, eight students out of ten recognised the diagrams correctly. This indicates clearly that the students did have 'some' perceptions regarding elements, compounds and mixtures in terms of particulate nature of matter. The word 'some' is used because it was observed that students had difficulties explaining their answers. Only three students were able to give explanations and one student was not asked this question. The remaining students were able to explain the diagram of element and mixture, but could not give explanation for diagram of compound. The question was not asked to yet another student who stated that 'there was little difference in element, compound and mixture '. One student identified all the diagrams wrongly. The diagram for mixture was identified as element and the diagrams of 'compound' and 'element' were identified as mixture. The student further stated that such a diagram could not be drawn for compound. This student had stated that for 'compound', one substance should dissolve into another substances. The two answers appear to be consistent with one another.

c) <u>Question on Valency</u>

Lastly, students were asked questions regarding valency. They were asked to define valency and also explain and calculate valency from the electronic configuration. The responses of students are presented in table 5.29.

Table 5.29 : Students' Responses to questions on valency (N = 10)

Category	Definition	Calculation
no idea	3	3
correct	4	4
others	2	-
not asked	1	1

It was observed that 4 students out of 10 were able to define valency correctly. Three students stated that they did not have any idea regarding valency. Of the two students who defined valency differently, one student interpreted valency as number of protons and neutrons. The other student was able to explain valency but thought that the number of electrons required for stability vary with the orbits, for example, in the case of third orbit this student thought that 18 electrons are required for stability.

5.3.3.4 Analysis of Post-tests

Equivalent post-tests were prepared and were administered to the students. The test on symbols, that is, test 7 was administered, both as pre-test and post-test as there was not much scope for variation. One new test on periodic table, that is, test 6 was also given to the students. The t-test analysis was conducted for all these tests except for test 5 in order to see whether there were any significant differences between the mean performances of the two groups (in the pre-tests, significant difference was observed in the performance of the two groups for test 5). The null hypothesis (H_0) that there was no significant difference between the mean performances of the two groups was tested against the one tailed alternative hypothesis (H_1) that the mean performance of experimental group was better as compared to the mean performance of the control group. The result of t-test analysis are presented in table 5.30.

Table 5.30 : t-tests analysis for the post-tests

Tests	Mean marks obtained by		t-values with one tailed probability
	Experimental	Control	
Test 1	4.48	4.18	1.47(p=0.07)
Test 2	9.28	8.82	1.04(p=0.15)
Test 3	4.73	3.99	1.13(p=0.13)
Test 4	11.70	11.00	0.55(p=0.29)
Test 6	6.44	6.02	0.72(p=0.24)
Test 7	4.84	4.32	1.73*(p=0.04)

* = significant difference

The above table indicates that the performance of the experimental group was better than that of the control group only on one test, that is, test 7. For all other tests, there was no significant difference in the mean performance of the two groups.

In order to see whether the intervention has made any differences within the groups, paired t-test analysis was conducted for the experimental and control groups separately. The results of this analysis for the experimental group are presented in table 5.31 and those for control group are presented in table 5.32.

Table 5.31: Paired t-test analysis for pre-post tests for an experimental group (N=40)

Tests	Mean performance in		t-values with one tailed probability
	Post-test	Pre-test	
Test 1	4.48	4.38	0.52 (p=0.30)
Test 2	9.28	7.55	4.47* (p=0.00)
Test 3	4.73	2.10	6.17* (p=0.00)
Test 4	11.70	6.58	6.75* (p=0.00)
Test 5	2.70	1.54	2.15* (p=0.03)
Test 7	4.84	2.74	8.84* (p=0.00)

Table 5.32 : Paired t-test analysis for pre-post test of control group (N=33)

Tests	Mean performance in		t-values with one tailed probability
	Post-test	Pre-test	
Test 1	4.18	4.63	-1.65*(p=0.05)
Test 2	8.81	8.03	1.97*(p=0.03)
Test 3	3.99	2.68	3.74* (p=0.00)
Test 4	11.00	6.76	7.02* (p=0.00)
Test 5	2.99	0.42	4.30* (p=0.00)
Test 7	4.32	3.23	4.65* (p=0.00)

*** - Significant difference**

This analysis indicates that in the case of the experimental and the control group the intervention made significant differences for all the tests except for test 1. This analysis reveals further that the intervention has made a difference in both the groups to a similar extent. The between group analysis for the post tests also did not show significant differences between the mean performance of the two groups (table 5.30). In other words, both the model and the periodic table chart have affected the performance of the corresponding groups to a similar extent. However, one important point is that sequencing of different concepts and discussions about the interconnections between these concepts has helped students of both the groups significantly as seen by the significant improvement in the performance of the two groups on pre-tests and post-tests.

Before concluding about the experiments, it will be useful to look briefly at the different errors made by the students on different tests. The types of errors made by students in two groups on pre-tests and post-tests were the same even though the frequency of a particular error varied. As this discussion is qualitative, the type of error will be discussed rather than its frequency.

Students in general did not have many difficulties in identifying the physical and chemical properties. Regarding the atomic structure, the students were not able to state the atomic number correctly. The students either left this question blank or stated the total number of protons + neutrons as an answer and not the number of protons. Similar error was committed in relating the number of electrons to the atomic number. Regarding the charge on the atom, both answers 'positive' and 'negative' were stated by the students. Regarding the charge on the nucleus, however, many students were able to give correct answers.

In case of electronic configuration, the number of electrons in the second orbit was varied by the students between 3 to 9. In interpreting the ionic symbols, it was observed that most of the students failed to interpret the symbols in words. Some of the explanations obtained were mathematical, that is, N^{-3} indicated that electrons were given where as the other symbol N^{+5} indicated that electrons were taken. Regarding the diagrams drawn, it was observed that students tried to match the charge on the ion with the number of electrons in the shells. The question asking them to draw a covalent bonding between atoms pictorially was either left blank or only one atom was drawn instead of two atoms along with the bonding. A few students had drawn the diagram almost correctly, but they made errors in the number of electrons shared.

Regarding valency, it was observed that defining valency was difficult for the students. Regarding calculation of valency for a given element, students confused valency with the number of electrons in the outermost orbit. For example, oxygen = 6, fluorine = 7 and Ne = 8. In case of element Boron, many students answered 5 (that is, number of electrons required to complete the last orbit) instead of 3 (same was observed for element lithium, valency 7 was stated instead of 1). In other words, students simplify the complex definition of valency (that is, number of electrons in outermost orbit or number of electrons required to complete outermost orbit) for calculation purposes. While stating the elements with lowest valency or highest valency, students have given multiple answers (such as Li,B,Be or Li,B,C or Li,F,B,N for elements with lowest valency or N,F,O for highest valency). From these answers, it appears that for answering such a question, rather than going towards two extremes of the row (that is, alkali metal and halogen element), students tend to state the elements situated at one end (that is, either the alkali end or the halogen end). The inert element was also stated as answer for element with highest valency by some students (it appears that students have once again paid attention to the number of electrons in the outermost shell). In case of the question regarding most reactive elements, once again multiple answers such as Li,B or N,C or Ne,F or C,B,N were obtained and it was observed that the element with maximum valency was stated by the students as most reactive. As examples of electron donors, students stated non-metals such as O,F and N whereas for electron acceptors metals such as Li, B or Be were stated. The question on writing of chemical formulae revealed that students failed to write the formulae correctly even though the valencies were given to them. The formulae stated by students varied largely and randomly. Some of the examples are as follows - KO_2 for K_2O; Mg_2Cl or $MgCl_3$ for $MgCl_2$; CO_4 for CO_2 or PO3 for P_2O_3. In these formulae, it appears that students did not know how to represent valency in the formulae or while writing the formulae attention was paid to valency of one element only. Answering the questions where valencies were not stated (like question 2,3 and 4 of test 5) was even more difficult for the students.

5.4 Conclusion

The chapter presents the analysis of the work done regarding the periodic table. From the experimental studies conducted in class X, it was observed that students have many difficulties regarding the topic of periodic table and other related concepts. In fact, students fail to understand the significance of the periodic table in learning chemistry. Interviews conducted with the students (at class X & IX) revealed that students confuse the technical terms such as atomic number, atomic weight (specially in marathi, the technical terms appears to be more confusing). Valency was another difficult concept for students. Students failed to define valency and often tried simplify the definition. They were not aware about whether and how the valency was represented in the chemical formulae. Understanding of properties was good in general. However, students had problems regarding some properties such as nonmetal, melting, rusting.

Students hold a continuous model of matter rather than a particulate one. This is reflected in their answers that a single atom or molecule would have different physical properties. The definition of atoms and molecules presented in the textbook can be one of probable cause for such a conception. Some of students also believed that atoms or molecules would be visible through simple microscope.

Regarding elements, compound and mixtures, it was observed that even though students had some idea about compounds and mixtures, they were unable to differentiate between the two. Solutions in water and water itself were confusing examples for students. The concept of element was also difficult for students. The interviews at Solapur indicated that students have some perceptions of these classes in terms of atoms and molecules even though the textbook did not use such pictorial diagrams. Students were able to identify the given diagrams correctly even though they could not give proper explanations (specially for the diagram of compound).

Studies in class X also revealed that students had problems regarding reading the periodic table. Students also tended to interpret new words related to periodic table differently.

The prepared model proved to be useful at the experiments conducted in class X even though the intervention time was limited. In class IX, however, the model has not proved to be better than the chart, but sequential discussion of the different concepts and their interconnections proved to be useful leading to a significant increase in the performance of both the groups on the post-tests. One probable reason why the model did not prove to be better could be that in class IX, the activities with the model were not performed as the intervention time was limited. In other words, the interactive potential of the model was not exploited in a class. In class X, where attempts were made to use the interactive potential of the model by the researcher (as against, the science teacher in the experiment in class IX) the model proved to be useful. With more time, activities such as constructing the periodic table could be given to the students, and may prove the model to be more useful. Moreover, potentially powerful teaching aids like the periodic table model require considerable in-depth teacher training to bring out their effectiveness.

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CHAPTER VI

SUMMARY AND CONCLUSION

Work in this thesis attempted to study students' conceptions and misconceptions related to important concepts in chemistry and also to develop remedial measures for teaching some of the concepts. The two topics selected for the study were chemical equations and formulae and the periodic table. Concepts such as chemical and physical properties, elements, compounds and mixtures, atoms and molecules, valency, understanding of symbolic language (that is, subscripts, coefficients and brackets) were studied.

As a part of the remedial measures, a three dimensional model of the periodic table was developed. This model was aimed at interactive teaching of the periodic table. Three experimental studies were conducted using the model in order to test usefulness of the model. Along with the model of the periodic table, a book 'The Fascinating Story of the Periodic Table' describing the historical perspectives of the growth of chemistry relevant to the formulation of the periodic table was written.

The work on chemical equations was conducted at class IX, X and XI. At class IX and X, students from Municipal (catering to weaker sections of society) and Non-Municipal schools participated in the study. The students at class XI were from colleges of Bombay and Dahanu.

The experiments related to the testing of the model of the periodic table were conducted at class X (Bombay Municipal School) and at class IX (Solapur).

The main observations of the study are summarised in the following sections.

6.1 The perception of chemistry syllabus

A survey regarding perceptions of different topics in chemistry led to the following findings

i) Students at class IX perceive the topic of 'chemical equations and formulae' as the most difficult topic one. Teachers support this view and perceive this topic as the most difficult topic for students.

ii) Students' ratings of the topics according to their difficulties and teachers' ratings for the same differed significantly on seven topics (out of 12) at class IX. These topics were halogens; atomic structure; valency; oxides, oxidation and reduction; gaseous state; combustion and fuels; and metals and metallurgy. In general, teachers perceive all these topics to be more difficult for the students than the students do themselves. Similar results were obtained at class X for four chapters. These topics were the periodic table; solutions and ionisation; rates of chemical reactions and phosphorus.

6.2 Study on chemical equations and formulae

Tests on chemical equations and formulae revealed the following

i) The test on balancing equations and identifying errors indicated that students treat chemical equations algebraically. The attempts at balancing equations do not take into consideration the laws of chemistry. Thus, students commit errors which are mainly due to a lack of understanding of chemical concepts such as valencies and their symbolic representation, the significance of subscripts, coefficients and brackets and the concept of atomicity.

ii) The test on interpretation of equations revealed that significance of the subscripts and coefficients was not understood by students. Students interpret these numbers in various ways, for example, subscript as 'valency' or 'molecular formula' or 'molecules' and coefficient as 'atoms' or 'for balancing'. Students tend to ascribe the coefficient to the first element in the given compound than to the entire compound.

iii) The other questions of the same test revealed that students committed errors in qualitative (that is, descriptions) and quantitative (that is stoichiometry) interpretation of the given equation. While describing the reaction, students failed to give the names of the substances involved (class IX & X), the state and/or the number of molecules or moles of substances involved and/or reversible nature of the reaction (class XI). Likewise, students performed poorly on other tests about stoichiometry. It was observed further that this poor performance is not due to a lack of essential mathematical skills but is due to a lack of knowledge of chemistry (that is, the concepts of atoms and molecules and their symbolic representations).

iv) All these tests revealed that such errors were committed at all the classes, that is, class IX, X and XI. In other words, these misconceptions persist despite continued exposure to chemistry.

6.3 Analysis of Interviews

The concepts about which the interviews were conducted included, balancing the given equations, subscripts and coefficients, atoms and molecules and valency, pictorial representations of balanced equations and understanding of the periodic table. The observations of interviews are as follows -

i) Atoms and molecules continued to be a sourece of misconceptions. The important misconceptions are

  a) a single atom and a single molecule will have the physical properties (this answer indicates that students might still hold a continuous model of matter rather than a particulate one),

  b) atoms do not participate in the reactions,

  c) these particle are visible to the naked eye or through a simple microscope used in the school laboratory.

ii) Valency was a difficult concept for students. Students failed to define valency and often tried to simplify the definition. Students were unaware how valencies were to be represented in the chemical formulae.

iii) Students also failed to distinguish between compounds and mixtures. Water and solutions in water were confusing examples for students. In case of elements, students were unable to define 'element', even though they could give a few examples.

iv) Regarding chemical and physical properties, it was observed that while the general understanding was good, students had problems with properties such as non-metal, melting, rusting and formation of water.

v) Students did have 'some' perceptions of 'element', 'compound' and 'mixture' in terms of atoms and molecules from the fact that they identified the given pictorial diagrams correctly even though the prescribed text-book of chemistry did not use such diagrams. However, students were unable to give correct explanations for these diagrams. The pictorial diagrams drawn by students for the given equations indicated that students' perceptions about the chemical reactions was different from the scientifically accepted ones. These diagrams indicated that most of students were concerned about the total number of particles on both sides of reactions and did not pay attention to information contained in the subscripts and coefficients in the equations. In other words, students did not take into account the full meaning of chemical equations and the interactive nature of chemical reactions.

vi) Interviews conducted with reference to the periodic table revealed that students confuse technical terms such as atomic number, atomic weight. These technical terms appear to be even more confusing in Marathi. The new technical words related to the periodic table (introduced at class X) were either not understood by students or misinterpreted by them.

vii) Interviews revealed that students in class X did not understand the significance of the periodic table in the study of chemistry. The students had problems in interpreting the information filled in the periodic table given in their textbook and also regarding the sequence in which the periodic table should be read.

6.4 The experimental studies

Three experimental studies were conducted for testing the effectiveness of the periodic table model for overcoming some of these misconceptions. Out of these three experiments, two experiments were conducted for students in class X from a Bombay Municipal school by the researcher. The last experiment was conducted by the school science teacher for students in class IX from girls' school at Solapur. For the first experiment at class X, the intervention was conducted only for the experimental group using the model of the periodic table. In the case of the next study, both the experimental and the control group were provided intervention by the researcher. The experimental group was taught using the periodic table model while the control group was taught using the text-book. At class IX, the intervention for the experimental group used the model whereas intervention for the control group used the chart of the periodic table. In all the experimental studies, equivalent pre and post-tests were administered to students before and after the intervention. The mean performance of the two groups on the pre-tests and on the post-tests was compared to see the effects of intervention (between group analysis). Along with this analysis, the mean performance of a particular group on the pre and post-tests was compared to see the effect of intervention on the performance of that particular group (within group analysis). The results of the these experiments were as follows

i) In both the studies at class X, no significant differences were observed in the mean performance of the experimental group and that of the control group on the pre-tests. However, after intervention, the mean performance of the experimental group was found to be significantly better than that of the control group. In other words, the intervention with the model was proved to be more effective (as compared to absence of intervention or intervention using the book).

ii) At class IX, once again, the two groups were equivalent with respect to their mean performance on the pre-tests. In this experiment the intervention was done by a schools teacher who used the model for the experimental group and a wall chart for the control group. While both groups showed significant progress in the post-tests, the progress of the experimental group was not significantly better than that of the control group.

6.5 Overview and Recommendations

The study suggests various difficulties of students with respect to the representational aspect of chemistry and the periodic table and the concepts related to these topics, which are significant for teaching and learning of chemistry. While teaching of chemistry, it is important to remember that the concepts of atoms and molecules, that is, the micro aspect plays a key role in understanding the various important concepts in chemistry. This micro aspect makes all these concepts abstract in nature which causes problems for students. At the same time, simultaneous considerations of the macro, micro and the representational aspects and their interconnections is also difficult for the students. Thus, at the early stage, students have difficulties in learning chemistry. It is, therefore, important that the interconnections between various concepts should be stressed from the beginning. The study makes the following recommendations

i) Use of different diagnostic tests is beneficial as such tests help in understanding students' difficulties. In fact, such tests should become the part of regular school tests.

ii) While teaching of symbolic language of chemistry, more attention is required to be paid to the subscripts, coefficients and the information contained in them. The same is also true for the use of brackets. In fact, the symbolic representation of an atom and a molecule is very important for understanding the information presented in a given chemical equations. It is important that students should understand chemical aspects of an equation along with the numerical ones. In the absence of chemical understanding of various symbols, students are bound to view the language of chemistry as a hurdle and will not appreciate the immense power it has for expressing so much information so precisely and elegantly.

iii) Simple pictorial diagrams, if used in a proper way, are very useful in understanding of symbolic language and also for giving a feel of concepts such as elements, compounds and mixtures and chemical reactions. Such diagrams should become an integral part of instruction in chemistry at school level. In fact, the balancing of equations can also be taught with the help of diagrams which will be more effective for learning of the symbolic language.

iv) The chapter on the Periodic Table should not be taught towards the end of the school chemistry syllabus, as a package of information that was not needed thus far. In fact, this chapter should be introduced at class IX and all other topics such as atomic structure, valency, bonding and chemical equations be taught around it (this is even true for the new chemistry syllabus). Such an introduction will help students to understand the interconnections between the various concepts and the patterns of variations in different properties especially the valency. This will also help students in writing of chemical formulae of different compounds effectively. In fact, students can study similarities and differences in chemical formulae of elements across the periodic table which will help them to write or at least guess the formula of any given compound. The study of electronic configuration with respect to the periodic table will help students understand whether the given element will be an electron donor or an electron acceptor or an electron sharer. The reactivities and formation of ionic or covalent bonds between different elements can only be understood by the basis of the periodic table. In fact, even at class VIII, where students are introduced to the symbols of elements the periodic table can be used. If the main purpose of teaching is to convert heaps of information into an understanding and knowledge, it is fairly obvious that concepts like atoms, molecules, valency, etc. be taught around the 'Periodic Table'.

v) A teaching aid like the periodic table model is important as it presents an opportunity to students to generate their own periodic table using information relevant to them. Such an activity gives some feel about how the periodic table was arrived at and also helps in better understanding of the periodic table. Thus, the researcher feels that the model of the periodic table along with the various activities which can be performed with the help of the model are useful in the study of the periodic table. All such activities may take some time but it will help students appreciate the discipline.

This problem can be studied in greater details. It is clear from the study that the interactive potential of the model could not be utilised fully as the time allotted for intervention was limited. As stated in the beginning of this section, understanding of various concepts and their interconnections requires time as well as appropriate activities over a prolonged period and therefore, extended intervention is needed.

Nevertheless the findings of this study can be useful for students, teachers, curriculum developers and researchers in science education.

Appendices

** The tests and interviews which were used for the work presented in the thesis are presented in the various appendices. Most of these tests (except the tests administered at class XI) and interviews were in Marathi. The Marathi version of a given test is enclosed immediately after the English version. No page numbers are given for the Marathi version. The same is true for interviews.

** Appendices 1,2 and 3 enclose the published papers and the book of the researcher.

APPENDIX 1.01

NAME :____________________________________

NAME OF SCHOOL :____________________________________

____

The names of the chapters from your text-book are stated below. Five different options regarding the difficulty level are given along with the chapters:

i) Most difficult ii) Difficult iii) Okay iv) Easy v) Most easy.

For each chapter tick whichever option you think is applicable.

Ch. No.	Name of the chapter	Most difficult	Difficult	Okay	Easy	Most easy
1	Nitrogen					
2	Ammonia					
3	Halogen					
4	Atomic Structure					
5	Valency					
6	Chemical Formulae & Equations					
7	Oxides, Oxidation & Reduction					
8	Gaseous State					
9	Combustion And Fuels					
10	Metals & Metallurgy I					
11	Metal & Metallurgy II					
12	Study of Common Compounds					

होमी भाभा विज्ञान शिक्षण केंद्र
टाटा इन्स्टिटयूट ऑफ फंडामेण्टल रिसर्च
होमी भाभा मार्ग, कुलाबा, मुंबई 400 005.

रसायनशास्त्र

नाव : --

शाळेचे नाव :--

इयत्ता :---------- तुकडी ----------- वय ------------

तुमच्या रसायनशास्त्राच्या पुस्तकातील पाठांची नावे खाली दिलेली आहेत. प्रत्येक पाठापुढे पाच पर्याय दिलेले आहेत.

1) अतिशय कठीण 2) कठीण 3) मध्यम 4) सोपा 5) अतिशय सोपा

दिलेला प्रत्येक धडा तुम्हाला कसा वाटतो ते दाखवणा-या पर्यायाखाली बरोबरची (✓) खूण करा.

धडयाचे नाव	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
1) नायट्रोजन					
2) अमोनिआ					
3) हॅलोजन					
4) अणु संरचना					
5) संयुजा					
6) रासायनिक सूत्रे आणि समीकरणे					
7) ऑक्साईड, ऑक्सीडीकरण व क्षपण					
8) वायुरुप अवस्था					

धडयाचे नाव	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
९> दहन आणि इंधने					
१०> धातू व धातू-विज्ञान(१)					
११> धातू व धातू-विज्ञान(2)					
१२> परिचित संयुगांचा अभ्यास					

लडगे/मिमस्तकार

APPENDIX 1.02

(Questionnaire for teachers)

NAME :________________________________

NAME OF SCHOOL :________________________________

The names of the chapters from class IX are stated below. Five different options regarding the difficulty level are given along with the chapters.

Please give your opinion regarding how most of the students from your class perceive the given chapter. For example if chapter " Nitrogen" is perceived as easy then tick as shown below.

No.	Name of the chapter	Most Difficult	Difficult	Okay	Easy	Most Easy
1	Nitrogen					

1	Nitrogen					
2	Ammonia					
3	Halogen					
4	Atomic Structure					
5	Valency					
6	Chemical Formulae & Equations					
7	Oxides, Oxidation & Reduction					
8	Gaseous State					
9	Combustion And Fuels					
10	Metals & Metallurgy I					
11	Metal & Metallurgy II					
12	Study of some Common Compounds					

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता नववी रसायनशास्त्राच्या पुस्तकातील पाठांची नावे खाली दिलेली आहेत. प्रत्येक पाठापुढे पाच पर्याय दिलेले आहेत.

1) अतिशय कठीण 2) कठीण 3) मध्यम 4) सोपा 5) अतिशय सोपा.

यापैकी प्रत्येक धडा बहुतेक मुलांना कसा वाटतो याबद्दलचे तुमचे मत खालील कोष्टकात लिहावे. उदा. नायट्रोजन हा धडा बहुतेक मुलांना सोपा वाटत असेल तर खालीलप्रमाणे खूण करावी.

	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
1) नायट्रोजन				✓	
1) नायट्रोजन					
2) अमोनिआ					
3) हॅलोजन					
4) अणु संरचना					
5) संयुजा					
6) रासायनिक सूत्रे आणि समीकरणे					
7) ऑक्साइड, ऑक्सिडीकरण व क्षपण					

	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
8) वायुरुप अवस्था					
9) दहन आणि इंधने					
10) धातू आणि धातू-विज्ञान I					
11) धातू आणि धातू-विज्ञान II					
12) काही परिचित संयुगांचा अभ्यास					

लडगे/मिमस्तकार

APPENDIX 1.03

NAME :______________________________

NAME OF SCHOOL :______________________________

The names of the chapters from your text-book are given below. Five different options regarding the difficulty level are stated along with the chapters :

i)Most difficult ii) Difficult iii) Okay iv) Easy v) Most easy.

For the given chapter tick the option which you think is applicable.

Chap. No.	Name of the Chapter	Most Difficult	Difficult	Okay	Easy	Most Easy
1	Phosphorus					
2	Periodic classification of Elements					
3	Solution and Ionization					
4	Rates of Chemical Reactions					
5	Metal and their compounds					
6	Radioactivity					
7	Sulphur					
8	SO_2, SO_3 and H_2SO_4					
9	Carbon					
10	Chemistry of Carbon compounds					
11	Chemistry in Industry I					
12	Chemistry in Industry II					

होमी भाभा विज्ञान शिक्षण केंद्र
टाटा इन्स्टिटयूट ऑफ फंडामेण्टल रिसर्च,
होमी भाभा मार्ग, कुलाबा, मुंबई 400 005.

रसायनशास्त्र

नाव : ---

शाळेचे नाव : ------------------------------------

इयत्ता : ------------- तुकडी ------------- वय -------------

तुमच्या रसायनशास्त्राच्या पुस्तकातील पाठांची नावे खाली दिलेली आहेत. प्रत्येक पाठापुढे पाच पर्याय दिलेले आहेत.

1) अतिशय कठीण 2) कठीण 3) मध्यम 4) सोपा 5) अतिशय सोपा

दिलेला प्रत्येक धडा तुम्हाला कसा वाटतो ते दाखवणा-या पर्यायाखाली बरोबरची ( ) खूण करा.

	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
1) फॉस्फरस					
2) मूलद्रव्यांचे आवर्ती वर्गीकरण					
3) द्रावणे आणि आयनीभवन					
4) रासायनिक अभिक्रियांचे वेग					
5) धातू व त्यांची संयुगे					

	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
6) किरणोत्सारिता					
7) गंधक					
8) $SO_2 SO_3$ आणि $H_2\ SO_4$					
9) कार्बन					
10) कार्बनी संयुगांचे रसायनशास्त्र					
11) औद्योगिक रसायनशास्त्र (I)					
12) औद्योगिक रसायनशास्त्र (II)					

लडगे/मेमस्तकार

APPENDIX 1.04
(Questionnaire for teachers)

NAME : ______________________

NAME OF SCHOOL : ______________________

The names of the chapters from class X are stated below. Five different options regarding the difficulty level are given along with the chapters.

Please give your opinion regarding how most of the students from your class perceive the given chapter. For example if chapter " Phosphorus" is perceived as easy then tick as shown below.

No.	Name of the chapter	Most Difficult	Difficult	Okay	Easy	Most Easy
1	Phosphorus					

1	Phosphorus					
2	Periodic classification of Elements					
3	Solution and Ionization					
4	Rates of Chemical Reactions					
5	Metal and their compounds					
6	Radioactivity					
7	Sulphur					
8	SO_2, SO_3 and H_2SO_4					
9	Carbon					
10	Chemistry of Carbon compounds					
11	Chemistry in Industry I					
12	Chemistry in Industry II					

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : ---

शाळेचे नाव : ---

इयत्ता दहावी रसायनशास्त्राच्या पुस्तकातील पाठांची नावे खाली दिलेली आहेत. प्रत्येक पाठापुढे पाच पर्याय दिलेले आहेत.

1) अतिशय कठीण 2) कठीण 3) मध्यम 4) सोपा 5) अतिशय सोपा.

यापैकी प्रत्येक धडा बहुतेक मुलांना कसा वाटतो याबद्दलचे तुमचे मत खालील कोष्टकात लिहावे. उदा. फॉस्फरस हा धडा बहुतेक मुलांना सोपा वाटत असेल तर खालीलप्रमाणे खूण करावी.

	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
1) फॉस्फरस				✓	
1) फॉस्फरस					
2) मूलद्रव्यांचे आवर्ती वर्गीकरण					
3) द्रावणे आणि आयनीभवन					
4) रासायनिक अभिक्रियांचे वेग					
5) धातू व त्यांची संयुगे					
6) किरणोत्सारिता					

	अतिशय कठीण	कठीण	मध्यम	सोपा	अतिशय सोपा
7) गंधक					
8) SO_2, SO_3 आणि H_2SO_4					
9) कार्बन					
10) कार्बनी संयुगांचे रसायनशास्त्र					
11) औद्योगिक रसायनशास्त्र (I)					
12) औद्योगिक रसायनशास्त्र (II)					

लडगे/मेमस्तकार

APPENDIX 4.01

NAME : ______________________________

SCHOOL NAME : ______________________________

STD :_________ DIV :_________ AGE :________

Balance the given chemical equations.

1) $KI + Br_2$ ---- $KBr + I_2$

2) $NaOH + H_2SO_4$ ---- $Na_2SO_4 + H_2O$

3) $Al + O_2$ ----- Al_2O_3

4) $Al_2O_3 + HCl$ ----- $AlCl_3 + H_2O$

5) $ZnSO_4 + Al$ ----- $Al_2(SO_4)_3 + Zn$

6) $C_3H_8 + O_2$ ----- $CO_2 + H_2O$

7) $NO_2 + H_2O$ ----- $HNO_3 + NO$

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : --------------- तुकडी : ----------------

खाली दिलेली रासायनिक समीकरणे संतुलित करा.

1) $KI + Br_2$ ----- $KBr + I_2$

2) $NaOH + H_2SO_4$ ------ $Na_2SO_4 + H_2O$

3) $Al + O_2$ ------ Al_2O_3

4) $Al_2O_3 + HCl$ ----- $AlCl_3 + H_2O$

5) $ZnSO_4 + Al$ ----- $Al_2(SO_4)_3 + Zn$

6) $C_3H_8 + O_2$ ----- $CO_2 + H_2O$

7) $NO_2 + H_2O$ ------ $HNO_3 + NO$

SAL/mmm/

APPENDIX 4.02

NAME :______________________________

SCHOOL/COLLEGE :______________________________

AGE :______________________________

Find out the errors in the given chemical equations. Correct the given errors and then balance the chemical equation.

1) KBr ------> K_2 + Br_2

Potassium Bromate	Potassium	Bromine

2) $NaOH$ + H_2SO_4 -----> $2NaSO_4$ + HO_2

Sodium Hydroxide	Sulphuric Acid	Sodium Sulphate	Water

3) ZnO + $2HO$ ------> $ZnOH_2$

Zinc Oxide	Water	Zinc Hydroxide

4) $3Al$ + $2O$ -------> Al_3O_2

Aluminium	Oxygen	Aluminium Oxide

5) $Al_3(SO_4)_2$ + Na -------> $Na(SO_4)_2$ + $3Al$

Aluminium Sulphate	Sodium	Sodium Sulphate	Aluminium

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ----------- तुकडी : ----------- वय : --------

खाली काही समीकरणे दिलेली आहेत. त्या प्रत्येक रासायनिक समीकरणात काही चुका आहेत. त्या चुका कोणत्या ते सांगा. चुका दुरूस्त करून दिलेले रासायनिक समीकरण संतुलित करा.

1) $KBr \longrightarrow K_2 + Br_2$

(पोटॅशियम ब्रोमाईड) (पोटॅशिअम) (ब्रोमीन)

2) $NaOH + H_2SO_4 \longrightarrow 2NaSO_4 + HO_2$

(सोडिअम हायड्रॉक्साईड) (सल्फयुरिक ॲसिड) (सोडिअम सल्फेट) (पाणी)

3) $ZnO + 2HO \longrightarrow ZnOH_2$

(झिंक ऑक्साईड) (पाणी) (झिंक हायड्रॉक्साईड)

4) $3Al + 2O \longrightarrow Al_3O_2$

(ॲल्युमिनिअम) (ऑक्सिजन) (ॲल्युमिनिअम ऑक्साईड)

5) $Al_3(SO_4)_2 + Na \longrightarrow NaSO_4 + Al$

(ॲल्युमिनिअम सल्फेट) (सोडिअम) (सोडिअम सल्फेट) (ॲल्युमिनिअम)

लडगे/मिमस्तकार

APPENDIX 4.03

NAME : ____________________

SCHOOL NAME : ____________________

STD : ____________ AGE : ____________

With the help of the chemical equation, answer the questions given below.

$$N2 + 3H2 \rightleftharpoons 2NH3$$

1) State the names and symbols of the reactants and the products in the given reaction.

----

2) Write down how many molecules of each reactant are participating in the given reaction.

----

3) State the number of molecules of each product fromed in the reaction.

----

4) Explain the meaning of '$\rightleftharpoons$'.

----

5) In 3H2, what do the numbers 3 and 2 stand for ?

----

6) In 2NH3, what do the numbers 2 and 3 stand for ?

होमी भाभा विज्ञान शिक्षण केंद्र

नाव :---

शाळेचे नाव : ---

इयत्ता : -------------- वय : -----------------

खाली दिलेल्या अभिक्रियेवरून ह्या खालील प्रश्नांची उत्तरे द्या.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

1) वरील अभिक्रियेतील अभिकारके व उत्पादके यांची नावे व संज्ञा लिहा.

----

2) प्रत्येक अभिकारकाचे किती रेणू रासायनिक क्रियेत भाग घेतात ते लिहा.

----

3) प्रत्येक उत्पादकाचे किती रेणू अभिक्रियेत तयार होतात ते सांगा.

----

4) '$\rightleftharpoons$' हे चिन्ह काय दाखवते ते सांगा.

----

5) $3H_2$ यामधील 3 व 2 हे आकडे काय दाखवतात ते सांगा.

----

6) $2NH_3$ यामधील 2 व 3 आकडे काय दाखवतात ते लिहा.

लडगे/मिमस्तकार

APPENDIX 4.04

(For class XI)

NAME :------------------------------------

SCHOOL NAME :------------------------------------

AGE :------------------------------------

Answer the following questions from the given reaction.

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

1) Describe the above reaction in words.

----

2) What does sign '$\rightleftharpoons$' indicate ?

----

3) What do the numbers 3 and 2 in $3H_2$ indicate ?

----

4) What do the numbers 2 and 3 in $2NH_3$ indicate ?

APPENDIX 4.05

(Test 1 on stoichiometry)

NAME :---

SCHOOL/COLLEGE NAME :---

AGE :---

Answer the following questions from the given rection.

N_2 + $3H_2$ -----> $2NH_3$

1) Give the minimum number of molecules of nitrogen and hydrogen required to form 6 molecules of ammonia.

----

2) Two molecules of nitrogen and nine molecules of hydrogen will give how many molecules of ammonia ?

----

3) Suppose, you have 10 molecules of nitrogen and hydrogen each. Do you think, at the end of the rreaction, some molecules of hydrogen and nitrogen would remain unreacted ? If yes, how many molecules of nitrogen and hydrogen would remain ?

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : ---

शाळेचे नाव :---

इयत्ता : ---------------- वय : ------------------

खाली दिलेल्या रासायनिक अभिक्रियेच्या आधारे त्याखालील प्रश्नांची उत्तरे द्या.

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

1) NH_3 चे 6 रेणू तयार होण्यासाठी N_2 व H_2 यांचे कमीत कमी किती रेणू लागतील ?

----

2) जर तुमच्याकडे N_2 ते 2 रेणू असतील व H_2 चे 9 रेणू असतील तर NH_3 चे किती रेणू अभिक्रियेत तयार होतील ?

----

3) जर तुमच्याकडे N_2 चे 10 रेणू व H_2 चे 10 रेणू असतील, तर अभिक्रिया झाल्यावर N_2 व H_2 यांचे काही रेणू तसेच शिल्लक रहातील का ? रहात असल्यास प्रत्येकी किती रेणू रहातील ते सांगा.

लडगे/मेमस्तकार

APPENDIX 4.06

(Test 2 on stoichiometry)

NAME :--

SCHOOL/COLLEGE NAME :--

AGE :--

Answer the following questions from the given reaction.

N_2 + $3H_2$ -----> $2NH_3$

1) How many molecules of amonia will be formed if you have one molecule of nitrogen ?

----

2) How many molecules of ammonia will be formed if you have one molecule of hydrogen ?

----

3) Give the minimum number of molecules of nitrogen and hydrogen required to form 6 molecules of ammonia.

----

4) Two molecules of nitrogen and nine molecules of hydrogen will give how many molecules of ammonia ?

----

5) If ten molecules of ammonia decompose, how many molecules of nitrogen and hydrogen will be obtained ?

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ----------- वय : --------------------------

दिलेल्या रासायनिक अभिक्रियेच्या आधारे खालील प्रश्नांची उत्तरे लिहा.

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

1) जर तुमच्याकडे नायट्रोजनचा (N_2) एक रेणू असेल तर अमोनियाचे किती रेणू तयार होतील ?

----

2) जर तुमच्याकडे हायड्रोजनचा (H_2) एक रेणू असेल तर अमोनियाचे किती रेणू तयार होतील ?

----

3) अमोनियाचे (NH_3) सहा रेणू तयार होण्याकरता नायट्रोजन व हायड्रोजन यांचे कमीत कमी किती रेणू लागतील ?

----

4) जर तुमच्याकडे नायट्रोजनचे दोन रेणू व हायड्रोजनचे नऊ रेणू आहेत, तर अमोनियाचे किती रेणू तयार होतील ?

----

5) अमोनियाच्या दहा रेणूचे विघटन झाले असता नायट्रोजन व हायड्रोजन यांचे प्रत्येकी किती रेणू तयार होतील ?

----

6) समजा, तुमच्याकडे नायट्रोजनचे दहा रेणू व हायड्रोजनचे दहा रेणू आहेत. वरील रासायनिक अभिक्रिया पूर्ण झाल्यावर, नायट्रोजन व हायड्रोजन यांचे काही रेणू तसेच शिल्लक रहातील का ? रहात असल्यास प्रत्येकी किती रेणू रहातील ते सांगा.

लडगे/मेमस्तकार

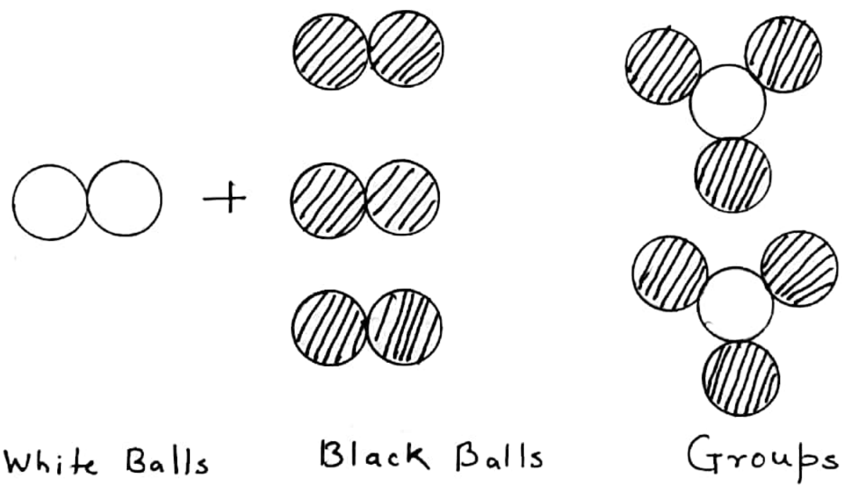
APPENDIX 4.07

NAME :_______________________________

SCHOOLS NAME :_______________________________

STD :______________ AGE :______________

You are given pairs of white balls and black balls. You are suppose to form groups from these balls. In each group, proportion of white balls to black balls should be 1:3. Answer following question by seeing the figure provided to you.



1) If you have one pair of white ball and plenty black balls, how many groups can you make?

----

2) If you have only one pair of black balls and plenty of white balls then how many groups can you make ?

----

3) If you have to make six groups, then how many pairs of black and white balls are required ?

----

4) If you have two pairs of white balls and nine pairs of black balls, how many groups can you form ?

----

5) You are given ten groups. After seperating balls from these groups, how many pairs of black balls and white balls can be obtained ?

होमी भाभा विज्ञान शिक्षण केंद्र

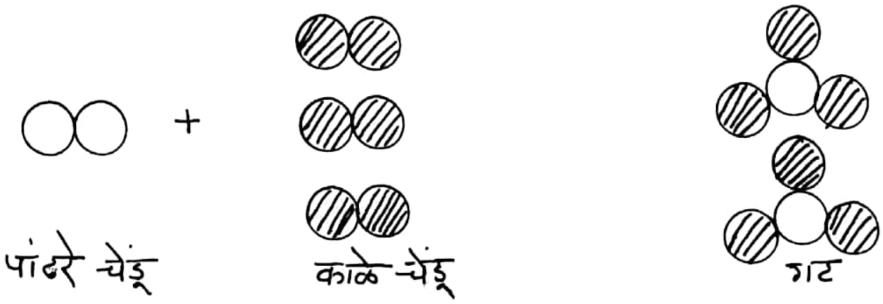
नाव : --

शाळेचे नाव : --

इयत्ता : ---------------------- वय ----------------------------------

----

तुमच्याकडे काही पांढ-या चेंडूच्या व काही काळया चेंडूच्या जोड्या आहेत. यापासून तुम्हाला गट तयार करायचे आहेत. गट तयार करताना प्रत्येक गटातील पांढ-या व काळया चेंडूचे प्रमाण 1:3 असे असले पाहिजे. (खालील आकृती बघा.) यावरून खालील प्रश्नांची उत्तरे द्या.



1) जर तुमच्याकडे पांढ-या चेंडूची एक जोडी व भरपूर काळे चेंडू असतील तर तुम्ही किती गट तयार करू शकाल ?

----

2) जर तुमच्याकडे काळया चेंडूची फक्त एकच जोडी व भरपूर पांढरे चेंडू असतील तर तुम्ही किती गट तयार करू शकाल ?

----

3) वरीलप्रमाणे सहा गट तयार करण्यासाठी पांढ-या व काळया चेंडूच्या प्रत्येकी किती जोडया लागतील ?

----

4) तुमच्याकडे पांढ-या चेंडूच्या दोन जोडया आहेत. तसेच काळया चेंडूच्या नऊ जोडया आहेत, तर तुम्ही किती गट तयार करू शकाल ?

----

5) समजा, तुम्हाला दहा गट दिलेले आहेत. प्रत्येक गटातील काळे व पांढरे चेंडू वेगळे केल्यावर, तुम्हाला पांढ-या व काळया चेंडूच्या प्रत्येकी किती जोडया मिळतील ?

APPENDIX 4.08

(For class XI)

NAME :---

SCHOOL/COLLEGE NAME :---

AGE :---

Answer the following questions from the given reaction.

$N_2 + 3H_2 \dashrightarrow 2NH_3$

1) How many molecules of amonia will be formed if you have one molecule of nitrogen ?

---

2) How many molecules of ammonia will be formed if you have one molecule of hydrogen ?

---

3) Give the minimum number of molecules of nitrogen and hydrogen required to form 6 molecules of ammonia.

---

4) Two molecules of nitrogen and nine molecules of hydrogen will give how many molecules of ammonia ?

---

5) If ten molecules of ammonia decompose, how many molecules of nitrogen and hydrogen will be obtained ?

---

6) Suppose, you have 10 molecules of nitrogen and hydrogen each. Do you think, at the end of the rreaction, some molecules of hydrogen and nitrogen would remain unreacted ? If yes, how many molecules of nitrogen and hydrogen would remain ?

APPENDIX 4 - I

INTERVIEWS ON CHEMICAL EQUATIONS

(Brief outline of the questions asked in the interviews)

While studying science, you learn chemistry. I am doing research on students' difficulties in understanding chemical formulae and equations. For this purpose, I am going to ask you some questions related to this topic. This interview is not your examination. I want to know about your understanding of the topic. So answer the questions in your own words. If you don't know the answers to some questions, it does not matter. The information given by you will be used only for my study.

1 In chemistry, you are asked to balance the given equations. Explain what is meant by 'balancing of an equation'.

2 Balance the following equations.

$H_2 + Cl_2$ ----> HCl

$N_2 + H_2$ ----> NH_3

$CO + O_2$ ----> CO_2

3 Explain the significance of numbers used in the following formulae.

$3H_2$, $2NH_3$

4 While explaining these numbers you used words 'atoms' and 'molecules'. Explain what these words mean to you?

a) Can you see atoms/molecules by a naked eye (if yes, give examples).

b) Can you see atoms/molecules through a microscope which you use in your laboratory?

5) While explaining atoms and molecules, you used terms 'elements' and 'compounds'. Explain these terms and also the term 'mixture'. (Give example for each).

6) Suppose, you have to explain the above equations using diagrams, for example, N - (N), H - (H). For ammonia, you have to use (N) and (H). Using such circles, show the above equations.

होमी भाभा विज्ञान शिक्षण केंद्र

रासायनिक सूत्रे व समीकरणे
(मुलाखतीत विचारलेल्या प्रश्नांची ढोबळ रूपरेखा)

तुम्ही सायन्सचा अभ्यास करताना रसायनशास्त्र हा विषय शिकता. मी रसायनशास्त्रात खास करून रासायनिक सूत्रे व समीकरणे याबद्दलच्या मुलांच्या काय अडचणी आहेत याचा अभ्यास करत आहे. यासाठी मी तुम्हाला रासायनिक समीकरणाबद्दल थोडे प्रश्न विचारणार आहे. ही मुलाखत म्हणजे तुमची परीक्षा नाही, त्यामुळे विचारलेल्या प्रश्नांची उत्तरे तुम्ही तुमच्या भाषेत द्या. तुम्हाला जे समजलेले आहे ते मला समजावून घ्यायचे आहे. एखाद्या प्रश्नाचे उत्तर माहीत नसले तरी हरकत नाही. तुम्ही दिलेली माहिती मला माझ्या अभ्यासासाठी उपयोगी पडेल व फक्त माझ्या अभ्यासासाठीच वापरली जाईल.

1) तुम्हाला रसायनशास्त्रात रासायनिक समीकरणे संतुलित करा असा प्रश्न विचारला जातो. दिलेले समीकरण संतुलित करायचे म्हणजे काय ते समजावून सांगा.

----

2) खाली तुम्हाला तीन समीकरणे दिलेली आहेत. ती संतुलित करून दाखवा.

$$H_2 + Cl_2 \text{ ---- } HCl$$

$$N_2 + H_2 \text{ ---- } NH_3$$

$$CO + O_2 \text{ ---- } CO_2$$

3) $3H_2$ यामधील **3** व **2** हे आकडे काय दाखवतात. तसेच $2NH_3$ यामधील **2** व **3** आकडे काय दाखवतात ?

----

4) दिलेल्या आकडयाचा अर्थ सांगताना तुम्ही 'अणू व 'रेणू हे शब्द वापरले. 'अणू' म्हणजे काय व रेणू म्हणजे काय ते समजावून सांगा.

अ) अणू/रेणू डोळयाला दिसतात का ? (असल्यास, उदाहरण द्या)

ब) अणू/रेणू तुमच्या प्रयोगशाळेत वापरता त्या सूक्ष्मदर्शकातून दिसतील का ?

----

5) अणू/रेणू यांचा अर्थ स्पष्ट करताना तुम्ही मूलद्रव्य तसेच संयुग हे शब्द वापरले . मूलद्रव्य/संयुग/ मिश्रण म्हणजे काय ? (प्रत्येकाची उदाहरणे द्या.)

----

6) समजा, वरील समीकरणे आकृत्यांच्या सहाय्याने स्पष्ट करायची आहेत. उदा. **N** - (**N**), **H** -- (**H**) अमोनिया दाखवताना (**N**) व (**H**) याचाच वापर करायचा आहे. अशा प्रकारची वर्तुळे वापरून वरील समीकरणे दाखवा.

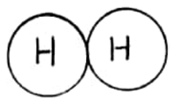
APPENDIX 4.09

NAME :---

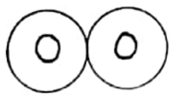
SCHOOL NAME :---

STD :---------------- AGE :----------------------

In your class VIII chemistry textbook, hydrogen and oxygen molecules are shown as below :



Hydrogen molecule



Oxygen molecule

Using this information, explain the following symbols and also draw diagrams for them.

1) H -----------
2) H_2 -----------
3) 2H -----------
4) $2H_2$ -----------
5) H_2O -----------
6) $2H_2O$ -----------

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ---------------- वय : ------------

तुमच्या आठवीच्या रसायनशास्त्राच्या पुस्तकात हायड्रोजनचा व ऑक्सिजनचा रेणू खालीलप्रमाणे दाखवलेला आहे.

हायड्रोजनचा रेणू

ऑक्सिजनचा रेणू

याच्या आधारे खालील संज्ञांचे अर्थ सांगून त्यांच्या आकृत्या काढा.

1) H ______________

2) H_2 ______________

3) $2H$ ______________

4) $2H_2$ ______________

5) H_2O ______________

6) $2H_2O$ ______________

लडगे/भेमस्तकार

APPENDIX 5.01

NAME :---------------------------------

SCHOOL NAME :---------------------------------

AGE :---------------------------------

MARKS OBTAINED IN STD 9TH :---------------------------------

MARKS OBTAINED IN STD 9TH IN CHEMISTRY :--------------------

Using the periodic table answer the following questions

1] State symbols of two elemets from the same group.

2] State the group number for the groups of elements having 2e- in outermost shell.

3] State the symbol of element with highest atomic weight

4] State the symbols of element with lowest atomic number

5] Give example for each given below. (write only number of elements).

Transition elements :-

Non - metals :-

Representative elements :-

Alkaline earth metal :-

6] Write down the symbols of two elements which will have same number of electrons in outermost shell.

7] The electronic configuration of Mg magnesium is 2,8,2. Using this information and given periodic table write down the electronic configuration for Silica (Si) and Argon (Ar).

होमी भाभा विज्ञान शिक्षण केंद्र

रसायन

नाव : ---

शाळेचे नाव :--

वय :-------------

इयत्ता 9वी मध्ये मिळालेले गुण :---------------------------

इयत्ता 9वी मध्ये रसायनशास्त्रातील गुण : -------------------------

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सोबत दिलेल्या आवर्तसारणीच्या आधारे खालील प्रश्नांची उत्तरे द्या.

1) एकाच गणात येणा-या दोन मूलद्रव्यांच्या संज्ञा लिहा.

----

2) ज्या गणातील मूलद्रव्यांच्या बाह्यतम कक्षेत दोन इलेक्ट्रॉन असतील त्याचा गणक्रमांक लिहा.

----

3) आवर्तसारणीत दाखविलेल्या मूलद्रव्यांपैकी सर्वात जड मूलद्रव्यांची संज्ञा लिहा.

----

4) आवर्तसारणीत दाखविलेल्या मूलद्रव्यांपैकी सर्वात कमी अणुक्रमांक असलेल्या मूलद्रव्याची संज्ञा लिहा.

----

5) खालीलपैकी प्रत्येकाचे एक उदाहरण द्या. (मूलद्रव्यांच्या फक्त संज्ञा लिहा).

संक्रमक मूलद्रव्य :

अधातू :-

प्रातिनिधीक मूलद्रव्य :-

अल्कधर्मी मृदा धातू :-

6) ज्या मूलद्रव्यांच्या बाह्यतम कक्षेत सारखेच इलेक्ट्रॉन आहेत अशा दोन मूलद्रव्यांच्या संज्ञा लिहा.

----

7) मॅग्नेशियम **(Mg)** या मूलद्रव्याचे इलेक्ट्रॉन संरुपण 2, 8, 2 असे आहे. याचा व दिलेल्या आवर्तसारणीचा उपयोग करून सिलिकॉन **(Si)**व अरगॉन **(Ar)** या मूलद्रव्यांचे इलेक्ट्रॉन संरुपण लिहा.

लडगे/मेमस्तकार

APPENDIX 5.02

NAME :____

____

Answer the following questions with the help of given periodic table.

1] Certain elements along with their atomic numbers are given below. Place these elements at their appropriate places in the periodic table.

Elements	Atomic Number
A	10
B	15
C	25
D	4

2] State the symbol of an element with largest atomic size.

3] State the symbol of best oxidising element.

4] Write down the symbol of an element whose carbonate can be found along with calcium carbonate in nature.

5] The formula for Magesium chloride is $MgCl_2$. Use this information and the periodic table to write down the formula of Calcium fluoride.

6] Four different elements are given below. Using the periodic table state which element will donate electrons, which element will accept electrons, which will share electrons, and which will be inert element.

a) Potassium (K)

b) Argon (Ar)

c) Carbon (C)

d) Chlorine (Cl)

7] State which of the following oxides is alkaline, acidic and amphoteric.

a) Aluminium oxide -

b) Sulphur di oxide -

c) Magnesium oxide -

8] Certain Properties of elements from IIA are stated below. Using this information, state the properties of element - Barium (Ba) which is placed in same group.

Element	Metal/Non-Metal	Oxide State/color	Oxide Acidic/ Alkaline	Chlorides
Beryllium (Be)	Metal	Solid, white	Alkaline	$BeCl_2$
Magnessium (Mg)	Metal	Solid, white	Alkaline	$MgCl_2$
Calcium (Ca)	Metal	Solid, white	Alkaline	$CaCl_2$
Stroncium (Sr)	Metal	Solid, white	Alkaline	$SrCl_2$
Barium (Ba)				

होमी भाभा विज्ञान शिक्षण केंद्र

रसायन

नाव : --

सोबत दिलेल्या आवर्तसारणीच्या आधारे खालील प्रश्नांची उत्तरे द्या.

1) खाली काही मूलद्रव्ये दिलेली आहेत. या मूलद्रव्यांची नावे दिलेली नाहीत पण त्यांचे अणुक्रमांक दिलेले आहेत. दिलेल्या अणुक्रमांकाच्या आधारे वरील आकृतीत या मूलद्रव्यांना त्यांच्या योग्य स्थानी दाखवा.

मूलद्रव्य	अणुक्रमांक
क	10
ख	15
ग	25
घ	4

2) वरील आवर्तसारणीतील ज्या मूलद्रव्याचा अणू आकाराने सर्वात मोठा असेल त्यांची संज्ञा लिहा.

----

3) दिलेल्या आवर्तसारणीतील सर्वात उत्तम ऑक्सिडीकारक मूलद्रव्याची संज्ञा लिहा.

----

4) निसर्गात सापडणा-या कॅल्शियम कार्बोनेट बरोबर ज्या मूलद्रव्याचे कार्बोनेट बरोबर ज्या मूलद्रव्याचे कार्बोनेट सापडण्याची शक्यता आहे त्यांची संज्ञा लिहा.

----

5) मॅग्नेशियम क्लोराईडचे सूत्र $MgCl_2$ आहे. याचा व दिलेल्या आवर्तसारणीचा उपयोग करून कॅल्शियम फ्लुराईडचे सूत्र लिहा.

----

6) सोबत दिलेल्या आवर्तसारणीत चार मूलद्रव्ये खाली दिलेली आहेत. आवर्तसारणीतील त्यांच्या स्थानाच्या आधारे यापैकी कोणते मूलद्रव्य रासायनिक क्रियेत इलेक्ट्रॉन देईल, कोणते इलेक्ट्रॉन घेईल, कोणते इलेक्ट्रॉनची भागीदारी करेल व कोणते मूलद्रव्य रासायनिक क्रियेत भाग घेणार नाही ते त्या त्या मूलद्रव्यांच्या समोर लिहा.

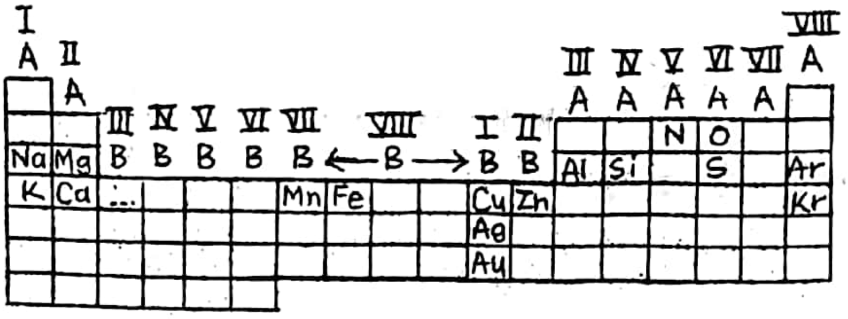
a) पोटॅशियम (K)
b) अरगॉन (Ar)
c) कार्बन (C)
d) क्लोरीन (Cl)

7) खाली दिलेल्या ऑक्साईड पैकी कोणते आम्लधर्मी, कोणते अल्कधर्मी व कोणते उभयधर्मी असेल हे सांगा.

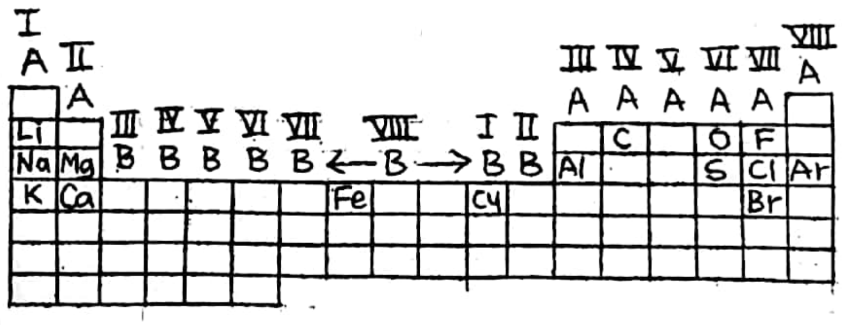
ॲल्युमिनिअम ऑक्साईड -
सल्फरडाय ऑक्साईड -
मॅग्नेशियम ऑक्साईड -

खाली **II A** या गणातील मूलद्रव्यांचे काही गुणधर्म दिलेले आहेत. यावरून त्याच गणात येणा-या बेरिअम **(Ba)** या मूलद्रव्याचे गुणधर्म लिहा.

मूलद्रव्य		धातु/अधातू	ऑक्साईड अवस्था/रंग	ऑक्साईड अल्कधर्मी/आम्लधर्मी	क्लोराईडचे सूत्र
बेरेलियम	(Be)	धातू	घनरूप, पांढरे	अल्कधर्मी	$BeCl_2$
मॅग्नेशियम	(Mg)	धातू	घनरूप, पांढरे	अल्कधर्मी	$MgCl_2$
कॅल्शियम	(Ca)	धातू	घनरूप, पांढरे	अल्कधर्मी	$CaCl_2$
स्ट्रॉनशिअम	(Sr)	धातू	घनरूप, पांढरे	अल्कधर्मी	$SrCl_2$
बेरिअम	(Ba)	- - -	- - -	- - -	- - -



Periodic table for test given in appendix 5.01



Periodic table for test given in appendix 5.02

APPENDIX 5.03

NAME :--------------------------------

SCHOOL NAME :--------------------------------

AGE :--------------------------------

MARKS OBTAINED IN STD 9TH :--------------------------------

MARKS OBTAINED IN STD 9TH IN CHEMISTRY :--------------------

Using the periodic table answer the following questions

1] State symbols of two elemets from the same group.

2] State the group number for the groups of elements having 2e- in outermost shell.

3] State the symbol of element with highest atomic weight

4] State the symbols of element with lowest atomic number

5] Give example for each given below. (write only number of elements).

Transition elements :-

Non - metals :-

Representative elements :-

Alkaline earth metal :-

6] Write down the symbols of two elements which will have same number of electrons in outermost shell.

7] The electronic configuration of Mg magnessium is 2,8,2. Using this information and given periodic table write down the electronic configuration for Silica (Si) and Argon (Ar).

होमी भाभा विज्ञान शिक्षण केंद्र

रसायन

नाव : ---

शाळेचे नाव :--

वय :------------

इयत्ता 9वी मध्ये मिळालेले गुण :------------------------

इयत्ता 9वी मध्ये रसायनशास्त्रातील गुण : ----------------------

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सोबत दिलेल्या आवर्तसारणीच्या आधारे खालील प्रश्नांची उत्तरे द्या.

1) एकाच गणात येणा-या दोन मूलद्रव्यांच्या संज्ञा लिहा.

----

2) ज्या गणातील मूलद्रव्यांच्या बाह्यतम कक्षेत दोन इलेक्ट्रॉन असतील त्याचा गणक्रमांक लिहा.

----

3) आवर्तसारणीत दाखविलेल्या मूलद्रव्यांपैकी सर्वात जड मूलद्रव्यांची संज्ञा लिहा.

----

4) आवर्तसारणीत दाखविलेल्या मूलद्रव्यांपैकी सर्वात कमी अणुक्रमांक असलेल्या मूलद्रव्याची संज्ञा लिहा.

----

5) खालीलपैकी प्रत्येकाचे एक उदाहरण द्या. (मूलद्रव्यांच्या फक्त संज्ञा लिहा).

संक्रमक मूलद्रव्य :

अधातू :-

प्रातिनिधीक मूलद्रव्य :-

अल्कधर्मी मृदा धातू :-

6) ज्या मूलद्रव्यांच्या बाह्यतम कक्षेत सारखेच इलेक्ट्रॉन आहेत अशा दोन मूलद्रव्यांच्या संज्ञा लिहा.

----

7) मॅग्नेशियम **(Mg)** या मूलद्रव्याचे इलेक्ट्रॉन संरुपण 2, 8, 2 असे आहे. याचा व दिलेल्या आवर्तसारणीचा उपयोग करून सिलिकॉन **(Si)** व अरगॉन **(Ar)** या मूलद्रव्यांचे इलेक्ट्रॉन संरुपण लिहा.

APPENDIX 5.04

NAME :____

Answer following questions with the help of given periodic table.

1] Certain elements along with their atomic numbers are given below. Place these elements at their proper places in the periodic table.

Elements	Atomic Number
A	10
B	15
C	25
D	4

2] State the symbol of an element with largest atomic size.

3] State the symbol of best oxidizing element.

4] Write down the symbol of an element whose carbonate can be found along with calcium carbonate in nature.

5] The formula for magnesium chloride is $MgCl_2$. Use this information and the periodic table to write down the formula of calcium fluoride.

6] Four different elements are given below. Using the periodic table, state which element will donate electrons, which element will accept electrons, which will share electrons, and which will be inert.

a) Potassium (K)

b) Argon (Ar)

c) Carbon (C)

d) Chlorine (Cl)

7] State which of the following oxides is alkaline, which is acidic and which is amphoteric.

a) Aluminium oxide -

b) Sulphur di oxide -

c) Sodium oxide -

8] Certain Properties of elements from IIA are stated below. Using this information, state the properties of element - Calcium (Ca) which is placed in same group.

Element	Metal/Non - metal	Formula of an oxide	Formula of chlorine	Nature of an oxide
Magnesium (Mg)	Metal	MgO	$MgCl_2$	alkaline
Beryllium (Be)	Metal	BeO	$BeCl_2$	alkaline
Calcium (Ca)				

होमी भाभा विज्ञान शिक्षण केंद्र

रसायन

नाव : --

सोबत दिलेल्या आवर्तसारणीच्या आधारे खालील प्रश्नांची उत्तरे द्या.

1) खाली काही मूलद्रव्ये दिलेली आहेत. या मूलद्रव्यांची नावे दिलेली नाहीत पण त्यांचे अणुक्रमांक दिलेले आहेत. दिलेल्या अणुक्रमांकाच्या आधारे वरील आकृतीत या मूलद्रव्यांना त्यांच्या योग्य स्थानी दाखवा.

मूलद्रव्य	अणुक्रमांक
क	10
ख	15
ग	25
घ	4

2) वरील आवर्तसारणीतील ज्या मूलद्रव्याचा अणू आकाराने सर्वात मोठा असेल त्यांची संज्ञा लिहा.

----

3) दिलेल्या आवर्तसारणीतील सर्वात उत्तम ऑक्सिडीकारक मूलद्रव्याची संज्ञा लिहा.

----

4) निसर्गात सापडणा-या कॅल्शियम कार्बोनेट बरोबर ज्या मूलद्रव्याचे कार्बोनेट बरोबर ज्या मूलद्रव्याचे कार्बोनेट सापडण्याची शक्यता आहे त्यांची संज्ञा लिहा.

----

5) मॅग्नेशियम क्लोराईडचे सूत्र $MgCl_2$ आहे. याचा व दिलेल्या आवर्तसारणीचा उपयोग करून कॅल्शियम फ्लुराईडचे सूत्र लिहा.

----

6) सोबत दिलेल्या आवर्तसारणीत चार मूलद्रव्ये खाली दिलेली आहेत. आवर्तसारणीतील त्यांच्या स्थानाच्या आधारे यापैकी कोणते मूलद्रव्य रासायनिक क्रियेत इलेक्ट्रॉन देईल, कोणते इलेक्ट्रॉन घेईल, कोणते इलेक्ट्रॉनची भागीदारी करेल व कोणते मूलद्रव्य रासायनिक क्रियेत भाग घेणार नाही ते त्या त्या मूलद्रव्यांच्या समोर लिहा.

पोटॅशिअम	(K)
अरगॉन	(Ar)
कार्बन	(C)
क्लोरीन	(Cl)

7) खाली दिलेल्या ऑक्साईडपैकी कोणते आम्लधर्मी, कोणते अल्कधर्मी व कोणते उभयधर्मी असेल ते सांगा.

ॲल्युमिनिअम ऑक्साईड

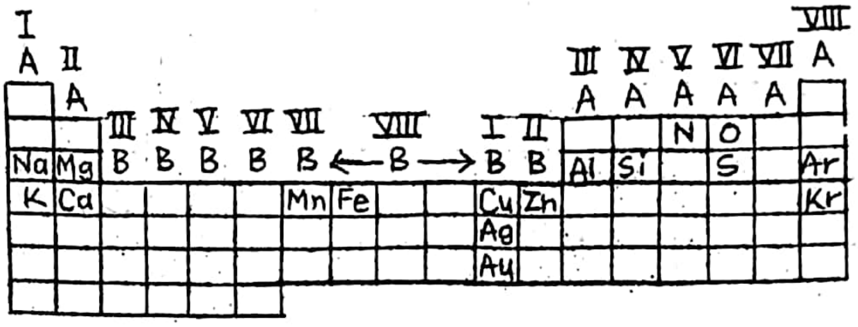
सल्फरडाय ऑक्साईड

सोडिअम ऑक्साईड

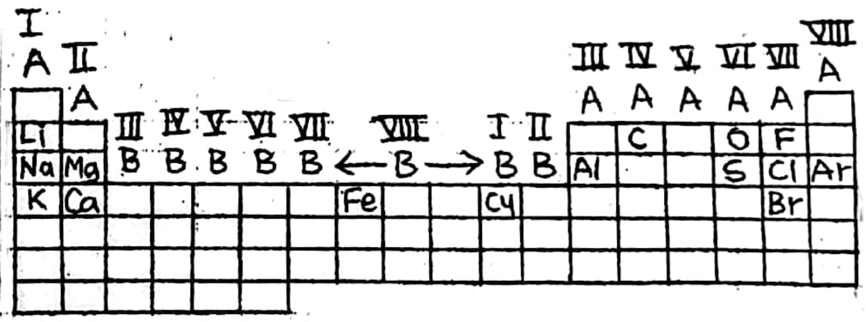
8) खाली **II A** या गणातील मूलद्रव्याचे काही गुणधर्म दिलेले आहेत. यावरून त्यात गणात येणा-या कॅल्शिअम **(Ca)** या मूलद्रव्याचे गुणधर्म लिहा.

		धातू/अधातू	ऑक्साईडचे सूत्र	क्लोराईडचे सूत्र	ऑक्साईड आम्लधर्मी अल्कधर्मी
मॅग्नेशियम	(Mg)	धातू	MgO	$MgCl_2$	अल्कधर्मी
बेरेलिअम	(Be)	धातू	BeO	$BeCl_2$	अल्कधर्मी
कॅल्शियम	(Ca)				

लडगे/मिमस्तकार



Periodic table for test given in appendix 5.03



Periodic table for test given in appendix 5.04

APPENDIX 5.05

NAME :---

SCHOOL NAME :---

AGE :---

Using the given periodic table, answer the following questions.

1] State symbols of two elemets from the same period.

2] State the group number for elements having $3e^-$ in outermost shell.

3] State the symbol of an element with lowest atomic weight.

4] State the symbol of an element with highest atomic number.

5] Give example for each given below. (write only the symbols of the elements).

Transition elements :-

Metals :-

Representative elements :-

Alkali metal :-

6] Write down the symbols of two elements which will have same number of electrons in the outermost shell.

7] The electronic configuration of Na magnessium is 2,8,1. Using this information and given periodic table write down the electronic configuration for Aluminium (Al) and Argon (Ar).

होमी भाभा विज्ञान शिक्षण केंद्र

रसायन

नाव :---

शाळेचे नाव :---

वय:-------------

सोबत दिलेल्या आवर्तसारणीच्या आधारे खालील प्रश्नांची उत्तरे द्या.

1) एकाच आवर्तनात येणा-या दोन मूलद्रव्यांच्या संज्ञा लिहा.

----

2) ज्या गणातील मूलद्रव्यांच्या बाह्यतम कक्षेत तीन इलेक्ट्रॉन कक्षेत तीन इलेक्ट्रॉन असतील त्याचा गणक्रमांक लिहा.

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3) आवर्तसारणीत दाखविलेल्या मूलद्रव्यांपैकी सर्वात कमी वजन असलेल्या मूलद्रव्याची संज्ञा लिहा.

----

4) आवर्तसारणीत दाखविलेल्या मूलद्रव्यांपैकी सर्वात जास्त अणुक्रमांक असलेल्या मूलद्रव्याची संज्ञा लिहा.

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5) खालीलपैकी प्रत्येकाचे एक उदाहरण द्या. (मूलद्रव्यांच्या फक्त संज्ञा लिहा).

1) धातू

2) संक्रमक मूलद्रव्य

3) अल्कली धातू

4) प्रातिनिधीक मूलद्रव्य

6) ज्या मूलद्रव्यांच्या बाह्यतम कक्षेत सारखेच इलेक्ट्रॉन आहेत अशा दोन मूलद्रव्यांच्या संज्ञा लिहा.

----

7) सोडिअम **(Na)** या मूलद्रव्याचे इलेक्ट्रॉन संरुपण 2, 8, 1 असे आहे. याचा व दिलेल्या आवर्तसारणीचा उपयोग करून ॲल्युमिनिअम **(Al)** व अरगॉन **(Ar)** या मूलद्रव्यांचे इलेक्ट्रॉन संरुपण लिहा.

APPENDIX 5.06

NAME:____

Answer the following questions with the help of given periodic table.

1] Certain elements along with their atomic numbers are given below. Place these elements at their proper places in the given periodic table.

Elements	Atomic Number
A	7
B	14
C	31
D	2

2] State the symbol of an element with smallest atomic size.

3] State the symbol of the best reducing element.

4] Write down the symbol of an element whose carbonate can be found along with sodium carbonate in nature.

5] The formula for sodium oxide is Na_2O. Use this information and the periodic table to write down the formula of Potassium sulphide.

6] Four different elements are given below. Using the periodic table state which element will donate electrons, which element will accept electrons, which will share electrons and which will be inert element.

a) Sodium (Na)

b) Neon (Ne)

c) Carbon (C)

d) Bromine (Br)

7] State which of the following oxides is alkaline, acide and amphoteric.

a) Calcium oxide -

b) Sulphur di oxide -

c) Zinc oxide -

8] Certain Properties of elements from IA are stated below. Using this state the properties of element - Rubidium (Rb) which is placed in same group.

Element	Formula of an oxide	Formula of chlorine	Nature of an oxide	Metal/Non-metal
Lithium (Li)	Li_2O	LiCl	alkaline	metal
Sodium (Na)	Na_2O	NaCl	alkaline	metal
Rubidium (Rb)				

होमी भाभा विज्ञान शिक्षण केंद्र

रसायन

नाव : ---

सोबत दिलेल्या आवर्तसारणीच्या आधारे खालील प्रश्नांची उत्तरे द्या.

1) खाली काही मूलद्रव्ये दिलेली आहेत. या मूलद्रव्यांची नावे दिलेली नाहीत पण त्यांचे अणुक्रमांक दिलेले आहेत. दिलेल्या अणुक्रमांकाच्या आधारे वरील आकृतीत या मूलद्रव्यांना त्यांच्या योग्य स्थानी दाखवा.

मूलद्रव्य	अ	ब	क	ड
अणुक्रमांक	7	14	31	2

2) वरील आवर्तसारणीतील ज्या मूलद्रव्याचा अणू आकाराने सर्वात लहान असेल त्यांची संज्ञा लिहा.

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3) दिलेल्या आवर्तसारणीतील सर्वात उत्तम क्षपणक असलेल्या मूलद्रव्यांची संज्ञा लिहा.

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4) निसर्गात सापडणा-या सोडिअम कार्बोनेट बरोबर ज्या मूलद्रव्याचे कार्बोनेट सापडण्याची शक्यता आहे त्यांची संज्ञा लिहा.

----

5) सोडिअम ऑक्साईडचे सूत्र Na_2O असे आहे. याचा व दिलेल्या आवर्तसारणीचा उपयोग करून पोटॅशियम सल्फाईडचे सूत्र लिहा.

----

6) सोबत दिलेल्या आवर्तसारणीतील चार मूलद्रव्ये खाली दिलेली आहेत. आवर्तसारणीतील त्यांच्या स्थानांच्या आधारे यापैकी कोणते मूलद्रव्य रासायनिक क्रियेत इलेक्ट्रॉन देईल, कोणते इलेक्ट्रॉन घेईल, कोणते इलेक्ट्रॉनची भागीदारी करेल व कोणते मूलद्रव्य रासायनिक क्रियेत भाग घेणार नाही ते त्या त्या मूलद्रव्यांच्या समोर लिहा.

सोडिअम (Na)

निऑन (Ne)

कार्बन (C)

ब्रोमीन (Br)

.....2.

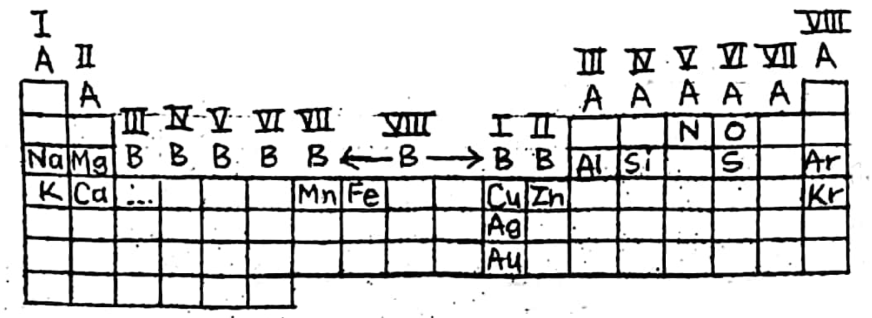
7) खाली दिलेल्या ऑक्साईडपैकी कोणते आम्लधर्मी, कोणते अल्कधर्मी व कोणते उभयधर्मी असेल ते सांगा

1) कॅल्शिअम ऑक्साईड -
2) सल्फरडाय ऑक्साईड -
3) झिंक ऑक्साईड -

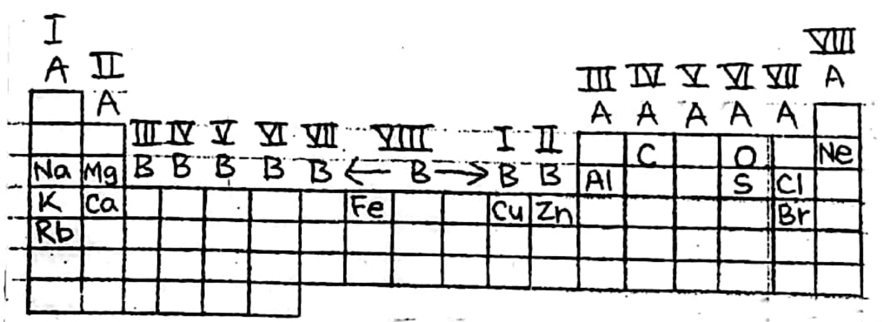
8) खाली IA या गणातील मूलद्रव्यांचे काही गुणधर्म दिलेले आहेत. यावरुन त्याच गणात येणा-या रुबिडिअम (Rb) या मूलद्रव्याचे गुणधर्म लिहा.

		ऑक्साईडचे सूत्र	क्लोराईडचे सूत्र	ऑक्साईडचे स्वरुप	धातू/अधातू
लिथियम	(Li)	Li_2O	LiCl	अल्कधर्मी	धातू
सोडिअम	(Na)	Na_2O	NaCl	अल्कधर्मी	धातू
रुबिडिअम	(Rb)	Rb_2O	RbCl		

लडगे/ममस्तकार



Periodic table for test given in appendix 5.05



Periodic table for test given in appendix 5.06

APPENDIX 5.07

NAME :______________________________

SCHOOL NAME :______________________________

DIV :__________ AGE : ______________

Some properties of iron are given below. State which of these properties are chemical properties and which are physical properties.

1) Iron occurs in solid state.

2) Iron is a metal.

3) Corrosion of iron takes place in air.

4) Iron displaces copper from the solution of copper sulphate.

5) Iron sulphide is obtained by heating iron and sulphur together.

6) Iron melts at about 1500° C.

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : ---

शाळेचे नाव : ---

इयत्ता : --------------- तुकडी : -------------

खाली लोखंडाचे गुणधर्म दिलेले आहेत. त्यापैकी भौतिक गुणधर्म कोणते व रासायनिक गुणधर्म कोणते ते सांगा.

1) लोखंड घनरुप अवस्थेत असतो.

2) लोखंड हा धातू आहे.

3) लोखंड हवेत गंजते.

4) लोखंड मोरचुदाच्या (कॉपर सल्फेटच्या) द्रावणातून तांबे विस्थापित करते.

5) लोखंड व गंधक एकत्र तापवले तर लोखंडाचे सल्फाईड तयार होते.

6) लोखंड सुमारे **1500^{0}C** तापमानाला वितळते.

लडगे/मिमस्तकार

APPENDIX 5.07A

NAME : ____________________________

SCHOOL NAME : ____________________________

DIV : __________ AGE : ________________

Some properties of sulphur are given below. State which of these are chemical properties and which are physical properties.

1) Sulphur occurs in solid state.

2) The boiling point of sulphur is 450°C.

3) Gaseous sulphur dioxide is obtained when sulphur is burnt in air.

4) Sulphur is a non-metal.

5) Iron sulphide is obtained by heating iron and sulphur together.

6) Sulphur dissolves in carbon-di-sulphide.

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : ---------------------------------------

इयत्ता : ------------ तुकडी : ---------------

खाली गंधक (सल्फर) या मूलद्रव्याचे काही गुणधर्म दिलेले आहेत. त्यापैकी भौतिक गुणधर्म कोणते व रासायनिक गुणधर्म कोणते ते सांगा.

1) गंधक घनरुप अवस्थेत असतो.

2) गंधकाची सुमारे 450^0C तापमानाला वाफ होते.

3) गंधक हवेत जाळले की सल्फरडाय ऑक्साईड वायू तयार होतो.

4) गंधक अधातू आहे.

5) लोखंड व गंधक एकत्र तापवले तर लोखंडाचे सल्फाईड तयार होते.

6) गंधक कार्बनडाय सल्फाईडमध्ये विरघळते.

लडगे/मेमस्तकार

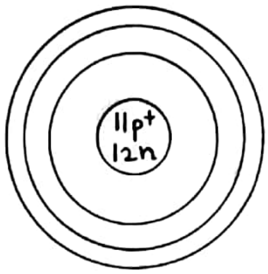
APPENDIX 5.08

NAME : ______________________________

SCHOOL NAME : ______________________________

STD : ______ DIV : ______ AGE : ______

The diagram for Sodium (Na) atom is given below. With the help of this diagram, answer the following questions.



1) Show the nucleus in the above diagram.
2) How many shells are shown in the diagram?
3) Show the outermost shell in the given diagram.
4) State the atomic number of a given atom.
5) State the number of electrons in this atom.
6) State the number of electrons in the 1st orbit.
7) State the number of electrons in the 2nd orbit.
8) State the number of electrons in the 3rd orbit.
9) Show the arrangement of electrons in above diagram.
10) What is the charge on given atom?
11) What is the charge on the nucleus of given atom?

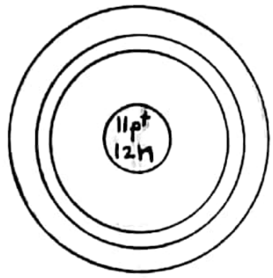
होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : --------------- तुकडी : --------------

खाली सोडिअमच्या अणूचे चित्र दिलेले आहे. त्यावरुन विचारलेल्या प्रश्नांची उत्तरे द्या.



1) दिलेल्या चित्रातील अणुकेंद्र दाखवा.
2) दिलेल्या चित्रात एकूण किती कक्षा दाखवलेल्या आहेत.
3) चित्रातील बाह्यतम कक्षा दाखवा.
4) दिलेल्या अणूचा अणुक्रमांक सांगा.
5) या अणूत एकूण किती इलेक्ट्रॉन असतील ते सांगा.
6) पहिल्या कक्षेत किती इलेक्ट्रॉन असतील ते सांगा.
7) दुस-या कक्षेत किती इलेक्ट्रॉन असतील ते सांगा.
8) तिस-या कक्षेत किती इलेक्ट्रॉन असतील ते सांगा.
9) इलेक्ट्रॉनची मांडणी वरील चित्रात दाखवा.
10) या अणूवर किती प्रभार आहे ते सांगा.
11) दिलेल्या अणूच्या अणूच्या अणुकेंद्रकावर किती प्रभार आहे ते सांगा.

लडगे/मेमस्तकार

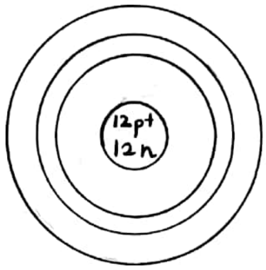
APPENDIX 5.08A

NAME :______________________________

SCHOOL NAME :______________________________

STD : _________ DIV : _________ AGE : _______

Given below, is the diagram of Magnessium (Mg) atom. With the help of this picture, answer the given questions.



1) Show the nucleus in the diagram.
2) How many shells are shown in the diagram.
3) Show the outermost shell in the above digram.
4) State the atomic number of a given atom.
5) State how many electrons will be present in the given atom.
6) State the number of electrons in the 1st orbit.
7) State the number of electrons in the 2nd orbit.
8) State the number of electrons in the 3rd orbit.
9) Show the arrangement of electrons in above diagram.
10) What is the charge on the given atom.
11) What is the charge on the nucleus of the given atom.

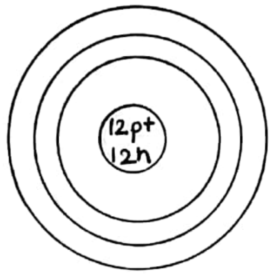
होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ---------- तुकडी ----------

खाली मॅग्नेशिअमच्या **(Mg)** अणूचे चित्र दिलेले आहे. त्यावरुन विचारलेल्या प्रश्नांची उत्तरे द्या.



1) दिलेल्या चित्रातील अणुकेंद्रक दाखवा.
2) दिलेल्या चित्रात एकूण किती कक्षा दाखवलेल्या आहेत ?
3) चित्रातील बाह्यतम कक्षा दाखवा.
4) दिलेल्या अणूचा अणुक्रमांक सांगा.
5) या अणूत एकूण किती इलेक्ट्रॉन असतील ते सांगा.
6) पहिल्या कक्षेत किती इलेक्ट्रॉन असतील ते सांगा.
7) दुस-या कक्षेत किती इलेक्ट्रॉन असतील ते सांगा.
8) तिस-या कक्षेत किती इलेक्ट्रॉन असतील ते सांगा.
9) इलेक्ट्रॉनची मांडणी वरील चित्रात दाखवा.
10) या अणूवर किती प्रभार आहे ते सांगा.
11) दिलेल्या अणूच्या अणुकेंद्रकावर किती प्रभार आहे ते सांगा.

लडगे/ममस्तकार

APPENDIX 5.09

NAME : ______________________________

SCHOOL NAME : ______________________________

STD : ________ DIV: ________ AGE: ________

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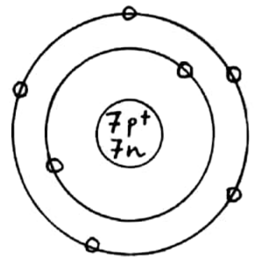
1) The number of electrons in the elements is given below. Write down the electronic configurations for these elements.

1) 7 ______ 2) 13 ______

3) 21 ______

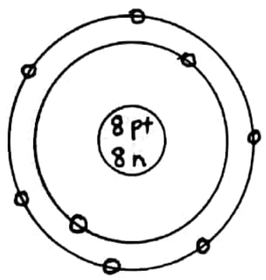
2) The electronic configuration of Nitrogen (N) is shown below diagramatically.



Please state the meanings of the following symbols and by using the above diagram, draw the electronic configuration for these symbols.

1) N^{-3} 2) N^{+5}

3) The electronic configuration of Oxygen atom (O) is given below. Draw a diagram for Oxygen molecules (O_2).



होमी भाभा विज्ञान शिक्षण केंद्र

नाव : ---

शाळेचे नाव : --

इयत्ता : ----------- तुकडी : -----------

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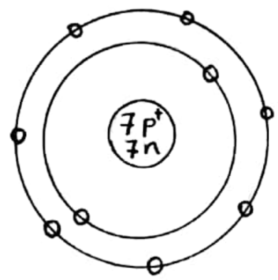
1) खाली काही मूलद्रव्यातील इलेक्ट्रॉनची संख्या दिलेली आहे. त्या मूलद्रव्यांचे इलेक्ट्रॉन संरुपण द्या.

1) 7 ----
2) 13 -----
3) 21 -----

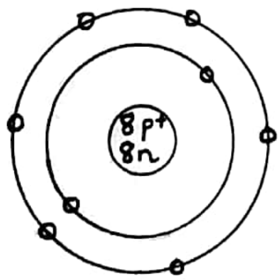
2) नायट्रोजन **(N)** या मूलद्रव्याचे इलेक्ट्रॉन संरुपण खालील आकृतीत दाखवलेले आहे.



यावरुन खालील संज्ञाचे अर्थ सांगा व त्यांचे इलेक्ट्रॉन संरुपण काढून दाखवा.

1) N^{-3} **2)** N^{+5}

3) ऑक्सिजनच्या अणूचे (0) इलेक्ट्रॉन संरुपण खाली दिलेले आहे तर ऑक्सिजनच्या रेणूचे (0_2) चित्र काढा.



ऑक्सिजनचा अणू ऑक्सिजनचा रेणू

लडगे/ममस्तकार

APPENDIX 5.09A

NAME :______________________________

SCHOOL NAME :______________________________

STD : __________ DIV : __________ AGE : ________

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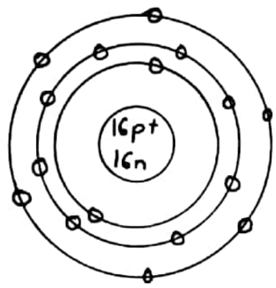
1) The numbers of electrons for some elements are given below. Write down the electronic configuration for these elements.

1) 8 ______ 2) 14 ______

3) 22 ______

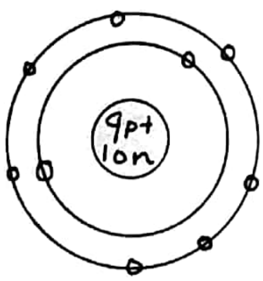
2) The electronic configuration of Sulphur (S) is shown below diagramatically.



Explain the meanings of the following symbols and by using above diagram, draw the electronic configuration for these symbols.

1) S^{-2} 2) S^{+6}

3) The electronic configuration of Fluorine atom (F) is given below. Draw a diagram for Fluorine molecules (F_2).



होमी भाभा विज्ञान शिक्षण केंद्र

नाव : ---

शाळेचे नाव : ---------------------------------------

इयत्ता : ---

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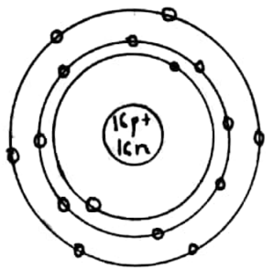
1) खाली काही मूलद्रव्यातील इलेक्ट्रॉनची संख्या दिलेली आहे. त्या मूलद्रव्यांचे इलेक्ट्रॉन संरुपण द्या.

1) 8 ----

2) 14 ------

3) 22 ----------

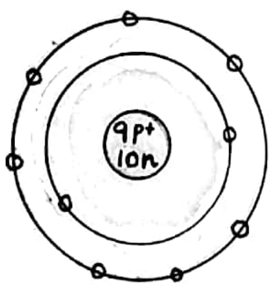
2) सल्फर (**S**) या मूलद्रव्याचे इलेक्ट्रॉन संरुपण खालील आकृतीत दाखवलेले आहे.



यावरुन खालील संज्ञांचे अर्थ सांगा व त्यांचे इलेक्ट्रॉन संरुपण काढून दाखवा.

1) S^{-2} **2)** S^{+6}

3) फ्लेरीन अणूचे (**F**) इलेक्ट्रॉन संरुपण खाली दिलेले आहे. त्यावरुन फ्लेरीनच्या रेणूचे (F_2) चित्र काढून दाखवा.



फ्लोरीनचा अणू

फ्लोरीनचा रेणू

लडगे/ममस्तकार

APPENDIX 5.10

NAME : ______________________________

SCHOOL NAME : ______________________________

STD : ________ DIV : ________ AGE : ________

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1) What is 'Valency' ?

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2) The elements along wtih their electronic configuration are given below. State the valencies of these elements from the given electronic configuration.

Elements	**Li**	**B**	**O**	**Ne**	**F**	**C**	**Be**	**N**
Electronic Configuration	**2,1**	**2,3**	**2,6**	**2,8**	**2,7**	**2,4**	**2,2**	**2,5**
Valency								

a) Which of the above element will be inert ? why ?

b) State whether element 'Be' will be inert ? Justify your answer.

c) Write down the symbols of the elements with lowest valency (apart from inert gas).

d) State the symbol of an element with highest valency.

e) State the symbols of the most reactive element and give reason for their reactivity.

f) State the symbols of those elements which will donate electrons in chemical reaction.

g) Similar to above state the symbols of those elements which will accept electrons in the chemical reactions.

h) State symbol of an element which will share electrons in chemical reaction.

3) If the valencies of calcium and barium are same, then what can you say about chemical properties ?

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ------------ तुकडी : -------------

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1) 'संयुजा' म्हणजे काय ?

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2) खाली काही मूलद्रव्ये व त्यांचे इलेक्ट्रॉन संरुपण दिले आहे. त्यावरुन त्यांच्या 'संयुजा' काढा.

मूलद्रव्ये	Li	B	O	Ne	F	C	Be	N
इलेक्ट्रॉन संरुपण	2,1	2,3	2,6	2,8	2,7	2,4	2,2	2, 5
संयुजा								

अ) वरीलपैकी कोणते मूलद्रव्य निष्क्रिय असेल व का ?

आ) "Be" हे मूलद्रव्य निष्क्रिय आहे का ? असल्यास का व नसल्यास का नाही ?

इ) वरीलपैकी सगळयात कमी संयुजा असणा-या मूलद्रव्यांच्या संज्ञा लिहा.

ई) वरीलपैकी सगळयात जास्त संयुजा असलेल्या मूलद्रव्याची संज्ञा लिहा.

उ) वरीलपैकी सगळयात जास्त क्रियाशील असलेल्या मूलद्रव्यांच्या संज्ञा लिहा व तसेच ती मूलद्रव्य जास्त क्रियाशील का आहेत ते सांगा.

ऊ) वरीलपैकी जी मूलद्रव्ये रासायनिक क्रियेत इलेक्ट्रॉन देतील त्यांच्या संज्ञा लिहा.

ए) वरीलपैकी जी मूलद्रव्ये रासायनिक क्रियेत इलेक्ट्रॉन घेतील त्यांच्या संज्ञा लिहा.

ऐ) वरीलपैकी कोणते मूलद्रव्य इलेक्ट्रॉनची भागीदारी करेल ?

3) समजा, कॅल्शिअम व बेरिअम यांची संयुजा सारखीच आहे, तर त्या मूलद्रव्यांच्या रासायनिक गुणधर्माबाबत तुम्हाला काय सांगता येईल ?

APPENDIX 5.10A

NAME : ______________________________

SCHOOL NAME : ______________________________

STD :__________ DIV :__________ AGE :____________

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1) What is 'Valency' ?

----

2) The elements along wtih their electronic configuration are given below. State the valencies of these elements from given electronic configuration.

Elements	Na	Al	S	Ar	Cl	Si	Mg	P
Electronic Configuration	2,8,1	2,8,3	2,8,6	2,8,8	2,8,7	2,8,4	2,8,2	2,8,5
Valency								

a) Which of the above element will be inert ? why ?

b) State whether element 'Mg' will be inert ? Justify your answer.

c) Write down the symbols of the elements with lowest valency (apart from inert gas).

d) State the symbol of an element with highest valency.

e) State the symbols of the most reactive elements and give reason for their reactivity.

f) State the symbols of those elements which will donate electrons in chemical reaction.

g) State the symbols of those elements which will accept electrons in the chemical reactions.

h) State symbol of an element which will share electrons in chemical reaction.

3) If the valencies of magnesium and calcium are same, then what can you say about chemical properties ?

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ----------- तुकडी : -------------

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1) 'संयुजा' म्हणजे काय ?

----

2) खाली काही मूलद्रव्ये व त्यांचे इलेक्ट्रॉन संरुपण दिलेले आहे. त्यावरुन त्यांच्या संयुजा काढा.

मूलद्रव्ये	Na	Al	S	Ar	Cl	Si	Mg	P
इलेक्ट्रॉन संरुपण	2.8,1	2,8,3	2,8,6	2,8,8	2,8,7	2,8,4	2,8,2	2.8,5
संयुजा								

अ) वरीलपैकी कोणते मूलद्रव्य निष्क्रिय असेल व का ?

ब) 'Mg' हे मूलद्रव्य निष्क्रिय आहे का ? असल्यास का व नसल्यास का नाही ?

क) वरीलपैकी सगळयात कमी संयुजा असणा-या मूलद्रव्यांच्या संज्ञा लिहा. (निष्क्रिय वायू सोडून)

ड) वरीलपैकी सगळयात जास्त संयुजा असलेल्या मूलद्रव्यांची संज्ञा लिहा.

इ) वरीलपैकी सगळयात जास्त क्रियाशील असलेल्या मूलद्रव्यांच्या संज्ञा लिहा व तसेच ती मूलद्रव्ये जास्त क्रियाशील का आहेत ते सांगा.

फ) वरीलपैकी जी मूलद्रव्ये रासायनिक क्रियेत इलेक्ट्रॉन देतील त्यांच्या संज्ञा लिहा.

ग) वरीलपैकी जी मूलद्रव्ये रासायनिक क्रियेत इलेक्ट्रॉन घेतील त्यांच्या संज्ञा लिहा.

म) वरीलपैकी कोणते मूलद्रव्य इलेक्ट्रॉनची भागीदारी करेल ?

3) समजा, मॅग्नेशिअम व कॅल्शिअम या मूलद्रव्यांच्या संयुजा सारख्याच आहेत, तर त्या मूलद्रव्यांच्या रासायनिक गुणधर्माबाबत तुम्हाला काय सांगता येईल ?

APPENDIX 5.11

NAME : ________________________________

SCHOOL NAME: ________________________________

STD : __________ DIV : __________ AGE : __________

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1) The valencies of some elements are given below. Using these valencies write down the formulae for given compounds.

Potassium	(K)	=	1	Magnesium	(Mg)	=2
Oxygen	(O)	=	2	Carbon	(C)	=4
Chlorine	(Cl)	=	1	Phosphorus	(P)	=3
Aluminium	(Al)	=	3			

1) Potassium oxide
2) Magnesium chloride
3) Carbon di-oxide
4) Phosphorus tri chloride
5) Aluminium chloride
6) Aluminium oxide

2) If the valencies of lithium (Li) and potassium (K) are same, then what will be the formula of lithium oxide ?

3) If sulphur (S) and oxygen (O) have similar valencies then what will be the formula of potassium sulphide ?

4) Write down the formula for lithium sulphide.

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता :------------ तुकडी : ---------------

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1) खाली काही मूलद्रव्यांच्या संयुजा दिलेल्या आहेत. त्यावरुन विचारलेल्या संयुगांची सूत्रे लिहा.

पोटॅशिअम	(K) = 1		मॅग्नेशिअम	(Mg)	= 2
ऑक्सिजन	(O) = 2		कार्बन	(C)	= 4
क्लोरीन	(Cl) = 1		फॉस्फरस	(P)	= 3
ॲल्युमिनिअम	(Al) = 3				

1) पोटॅशिअम ऑक्साईड
2) मॅग्नेशिअम क्लोराईड
3) कार्बन डाय ऑक्साईड
4) फॉस्फरस ट्राय क्लोराईड
5) ॲल्युमिनिअम ऑक्साईड
6) ॲल्युमिनिअम क्लोराईड

2) समजा, लिथिअम (Li) या मूलद्रव्याची संयुजा पोटॅशिअम (K) या मूलद्रव्याइतकी आहे, तर लिथिअम ऑक्साईडचे सूत्र काय होईल ?

3) समजा, सल्फर (S) या मूलद्रव्याची संयुजा ऑक्सिजन (O) इतकी आहे. तर पोटॅशिअम सल्फाईडचे सूत्र काय होईल ?

4) लिथिअम सल्फाईडचे रासायनिक सूत्र काय असेल ?

लडगे/मिमस्तकार

APPENDIX 5.11A

NAME : ______________________________

SCHOOL NAME : ______________________________

STD : __________ DIV : __________ AGE : ____________

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1) The valencies of some elements are given below. Using these valencies, write down the formulae for given compounds.

Sodium	(Na)	=	1	Calcium	(Ca)	=	2
Oxygen	(O)	=	2	Silicon	(Si)	=	4
Flourine	(F)	=	1	Phosphorus	(P)	=	3
Aluminium	(Al)	=	3				

1) Sodium oxide -

2) Calcium fluoride -

3) Silicon di-oxide -

4) Phosphorus tri oxide -

5) Aluminium oxide -

6) Aluminium fluoride -

2) If the valencies of lithium (Li) and sodium (Na) are same, then what will be the formula of lithium oxide ?

3) If sulphur (S) and oxygen (O) have similar valencies then what will be the formula of sodium sulphide ?

4) Write down the formula for lithium sulphide.

होमी भाभा विज्ञान शिक्षण केंद्र

नाव : --

शाळेचे नाव : --

इयत्ता : ------------- तुकडी : ---------------

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1) खाली काही मूलद्रव्यांच्या संयुजा दिलेल्या आहेत. त्यावरुन विचारलेल्या संयुगांची सूत्र लिहा.

सोडिअम	(Na) = 1		कॅल्शिअम	(Ca) = 2
ऑक्सिजन	(O) = 2		सिलिकॉन	(Si) = 4
फ्लोरीन	(F) = 1		फॉस्फरस	(P) = 3
ॲल्युमिनिअम	(Al) = 3			

1) सोडिअम ऑक्साईड
2) कॅल्शिअम फ्लोराईड
3) सिलिकॉन -डायऑक्साईड
4) फॉस्फरस ट्रायऑक्साईड
5) ॲल्युमिनिअम ऑक्साईड
6) ॲल्युमिनिअम फ्लोराईड

2) समजा, लिथिअम (Li) व सोडिअम (Na) या मूलद्रव्यांच्या संयुजा सारख्याच आहेत,तर लिथिअम ऑक्साईडच सूत्र काय होईल ?

3) समजा, सल्फर (S) व ऑक्सिजन (O) या मूलद्रव्यांच्या संयुजा सारख्याच आहेत, तर सोडिअम सल्फाईडचे सूत्र काय होईल ?

4) लिथिअम सल्फाईडचे सूत्र काय असेल ?

लडगे/मेमस्तकार

APPENDIX 5.12

NAME :--

SCHOOL NAME :--

STD :--------------- AGE :-----------------

1] Explain what you mean by ' symbols'.

2] Write the name for elements whose symbols are given below.

1) Na

2) I

3) Cu

4) Fe

5) K

3] Give symbols for following elements

1) Carbon

2) Calcium

3) Chlorine

4] Four students from a class have written the symbols of Aluminium in following manner. State which is the correct answer and why it is correct ?

1) AL 2) al 3) Al 4) aL

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नाव : --

शाळेचे नाव : --

इयत्ता --------------------- वय :---------------------

-------------- - -----------------------------------

1) 'संज्ञा' म्हणजे काय हे तुमच्या शब्दात सांगा.

----

2) खालील संज्ञा कोणत्या मूलद्रव्यांच्या आहेत त्यांची नावे लिहा.

1) Na -

2) I -

3) Cu -

4) Fe -

5) K -

3) खालील मूलद्रव्यांच्या संज्ञा लिहा.

1) कार्बन **(Carbon) -**

2) कॅल्शिअम **(Calcium) -**

3) क्लोरीन **(Chlorine) -**

4) एका वर्गातील चार मुलांनी ॲल्युमिनिअमची संज्ञा खालील पध्दतीनी लिहिली. यापैकी कोणते उत्तर बरोबर आहे ? का ?

1) अ - **AL** 2) ब - **al** 3) क - **Al** 4) ड - **al**

APPENDIX 5.13

NAME : ____

SCHOOL NAME : ____

STD : __________ DIV : __________ AGE : __________

A table of elements is provided to you. Only some elements are shown in the table at their appropriate places. Answer the following questions with the help of given table (tick the correct answer).

1) Which of the following elements will have maximum atomic number?

   1) Na 2) Au 3) Kr 4) Mn

2) Which of the following elements will have maximum atomic weight ?

   1) Mn 2) Fe 3) N 4) Au

3) Which of the following elements will have same number of electrons in their outermost shell ?

   1) Na & Mg 2) Mn & Fe 3) Ar & Kr 4) N & S

4) If the electronic configuration of 'Al' is 2,8,3 then what will be electronic configuration of 'S'?

   1) 2,8,4 2) 2,6,8 3) 2,8,6 4) 2,8,8

5) Which of the following elements will have simmilar chemical properties ?

   1) Cu & Zn 2) Mg & Ca 3) Al & S 4) Mg & K

6) Which of the following element will be inert ?

1) K 2) Au 3) Kr 4) N

7) Which of the given elements will be most reactive ?

1) K 2) Au 3) Kr 4) N

8) Which of the elements will be electron donar ?

1) Ca 2) Ar 3) O 4) Si

9) Which of the following elements will be electron acceptor ?

1) Na 2) Al 3) Ca 4) O

10) After chemical reaction, what type of chemical bond will be formed between following elements.

1) Na & O --------

2) N & O --------

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नाव : --

शाळेचे नाव : --

इयत्ता : -------------- तुकडी : --------------

सोबत दिलेल्या आकृतीत तुम्हाला मूलद्रव्याचे टेबल दिलेले आहे. या टेबलामध्ये सगळया मूलद्रव्यांच्या संज्ञा न देता काही ठराविक मूलद्रव्यांच्या संज्ञा त्याच्या योग्य त्या स्थानी दाखवलेल्या आहेत. या टेबलाच्या आधारे खालील प्रश्नांची उत्तरे द्या. (बरोबर उत्तरावर ✓ अशी खूण करा).

1) खालीलपैकी कोणत्या मूलद्रव्यांचा अणुक्रमांक सगळयात जास्त असेल ?

1) Na 2) Au 3) Kr 4) Mn

2) खालीलपैकी कोणत्या मूलद्रव्यांचे वजन सगळयात जास्त असेल ?

1) Mn 2) Fe 3) N 4) Au

3) खालीलपैकी कोणत्या मूलद्रव्यांच्या बाह्यतम कक्षेत सारखेच इलेक्ट्रॉन असतील ?

1) Na व Mg 2) Mn व Fe 3) Ar व Kr 4) N व S

4) 'Al' या मूलद्रव्याचे इलेक्ट्रॉन संरुपण 2,8,3 असे आहे, तर 'S' या मूलद्रव्याचे इलेक्ट्रॉन संरुपण काय असेल ?

1) 2,8,4 2) 2,6,8 3) 2,8,6 4) 2,8,8

5) खालीलपैकी कोणत्या मूलद्रव्याचे रासायनिक गुणधर्म सारखे असतील ?

1) Cu व Zn 2) Mg व Ca 3) Al व S 4) Mg व K

6) खालीलपैकी कोणते मूलद्रव्य निष्क्रिय असेल ?

1) K 2) Au 3) Kr 4) N

7) खालीलपैकी कोणते मूलद्रव्य सगळयात जास्त क्रियाशील असेल ?

1) K 2) Au 3) Kr 4) N

8) खालीलपैकी कोणते मूलद्रव्य रासायनिक क्रियेत इलेक्ट्रॉन देईल ?

1) Ca 2) Ar 3) O 4) Si

9) खालीलपैकी कोणते मूलद्रव्य रासायनिक क्रियेत इलेक्ट्रॉन घेईल ?

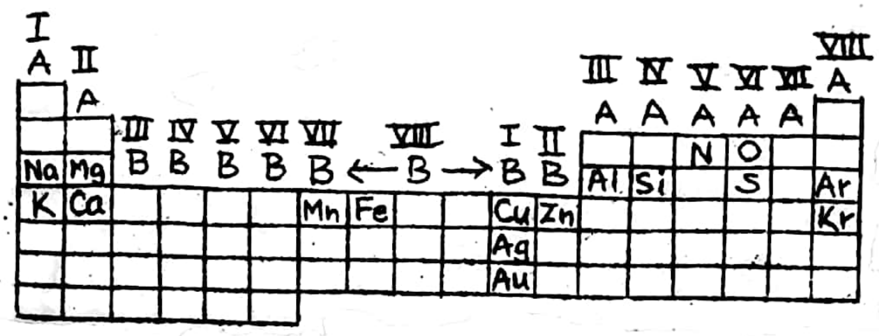
1) Na 2) Al 3) Ca 4) O

10) खालील मूलद्रव्यात रासायनिक क्रिया झाल्यावर कोणता बंध तयार होईल ते सांगा.

1) Na व O -------

2) N व O -------

लडगे/मेमस्तकार



Periodic table for test given in appendix 5.13

APPENDIX 5 - I.1.

INTERVIEWS ON THE PERIODIC TABLE

(Brief outline of the questions asked in the interviews)

While studying science, you study chemistry. I am doing research on students' difficulties in understanding the periodic table. I am going to ask you some questions related to this topic. This interview is not your examination. I want to know about your understanding of the topic and so, answer the questions in your own words. If you don't know the answers to some questions, it does not matter. The information given by you will be used only for my study.

1) You have studied the topic of the periodic table. This periodic table refers to the modern periodic table given in your textbook. Describe the displayed information given in the table.

2) Explain the terms 'group/group number'.

3) What is meant by the term 'period'?

4) How is the periodic table should be read?

5) What is the basis for arrangement of elements in the periodic table?

6) While studying the topic of the periodic table, you have come across some terms. These terms are given below. Explain them.

    1) Periodic event (give examples)
    2) Period
    3) Periodic function.

7) Why the periodic table is called 'the periodic table'?

8) Explain the terms 'element, mixture and compound' with examples.

9) While studying elements, you study physical and chemical properties. Give some physical and chemical properties of any element known to you.

10) What do the terms atomic number and atomic weight of an given element indicate?

11) What is meant by valency?

Calculate valency from the given electronic configuration and chemical formulae.

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आवर्तसारणीवरील मुलाखतीत विचारलेल्या प्रश्नांची ढोबळ रूपरेखा

तुम्ही सायन्सचा अभ्यास करताना रसायनशास्त्र हा विषय शिकता. मी रसायनशास्त्रात खास करून आवर्तसारणीबद्दलच्या मुलांच्या काय अडचणी आहेत याचा अभ्यास करत आहे. यासाठी मी तुम्हाला आवर्तसारणीबद्दल थोडे प्रश्न विचारणार आहे. ही मुलाखत म्हणजे तुमची परीक्षा नाही, त्यामुळे विचारलेल्या प्रश्नांची उत्तरे तुम्ही तुमच्या भाषेत द्या. तुम्हाला जे समजलेले आहे ते मला समजावून घ्यायचे आहे. एखाद्या प्रश्नाचे उत्तर माहीत नसले तरी हरकत नाही. तुम्ही दिलेली माहिती मला माझ्या अभ्यासासाठी उपयोगी पडेल व फक्त माझ्या अभ्यासासाठीच वापरली जाईल.

1) तुम्ही आवर्तसारणीचा अभ्यास केलेला आहे. ही तुमच्या पुस्तकात दाखविलेली आधुनिक आवर्तसारणी आहे. या सारणीमध्ये काय माहिती दाखविलेली आहे ते सांगा..

----

2) गण व गणक्रमांक कशाला म्हणायचे ?

----

3) आवर्तन कशाला म्हणायचे ?

----

4) आवर्तसारणी कोणत्या क्रमाने वाचायची ?

----

5) आवर्तसारणीत मूलद्रव्याची मांडणी कशाच्या आधारे केलेली आहे ?

----

6) तुमच्या पुस्तकातील आवर्तसारणीच्या धडयामध्ये काही शब्द आहेत ते शब्द खाली दिले आहेत. त्यांचा अर्थ सांगा.

आवर्ती घटना (काही उदाहरणे द्या.)

आवर्तन

आवृत्तीफळ

7) आवर्तसारणीला 'आवर्तसारणी' असे का म्हणण्यात येते ?

----

8) मूलद्रव्य, मिश्रण व संयुग या शब्दांचे अर्थ उदाहरणासहित सांगा.

----

9) मूलद्रव्यांचा अभ्यास करताना तुम्ही भौतिक व रासायनिक गुणधर्मांचा अभ्यास करता. तुम्हाला माहित असलेल्या कोणत्याही एका मूलद्रव्यांचे भौतिक व रासायनिक गुणधर्म सांगा.

----

10) एखाद्या मूलद्रव्याचा 'अणुक्रमांक' व 'अणुभारांक' काय दाखवतात.

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11) संयुजा म्हणजे काय ?

दिलेल्या इलेक्ट्रॉन संरूपणावरून त्या मूलद्रव्यांची संयुजा काढा.

दिलेल्या रासायनिक सूत्रांवरून विचारलेल्या मूलद्रव्यांची संयुजा सांगा.

APPENDIX 5 - I.2.

INTERVIEWS ON ELEMENTS, COMPOUNDS AND MIXTURES.

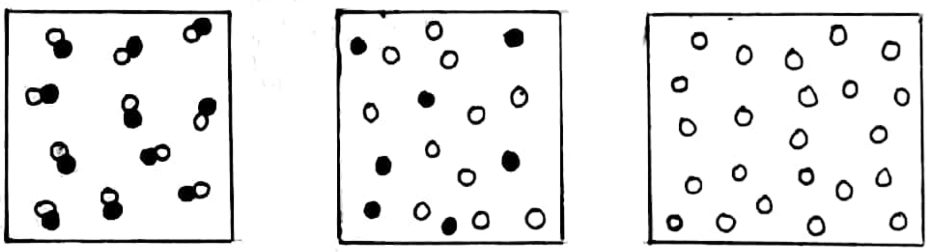
(Brief outline of the questions asked in the interviews)

You study chemistry as a branch of science. I am doing research on students' difficulties in understanding elements, compounds and mixtures. I am going to ask some questions related to this topic. This interview is not your examination. I want to know about your understanding of the topic and so answer the questions in your own words. If you don't know the answers to some questions, it does not matter. The information given by you will be used only for my study.

1) You have studied 'elements, compounds and mixtures'. Explain these terms with examples.

2) In chemistry, you use terms 'atoms and molecules'. Explain both these terms. Are atoms/molecules visible to a naked eye or through the microscope used in your laboratory.

3) Identify element, compound and mixture from the given diagrams. Explain you answer with reasons.



4) Explain what is meant by valency.

होमी भाभा विज्ञान शिक्षण केंद्र

मूलद्रव्ये, संयुगे व मिश्रणे
मुलाखतीत विचारलेल्या प्रश्नांची ढोबळ रूपरेखा

तुम्ही सायन्सचा अभ्यास करताना रसायनशास्त्र हा विषय शिकता. मी रसायनशास्त्रात खास करून मूलद्रव्ये, संयुगे व मिश्रणे याबद्दलच्या मुलांच्या काय अडचणी आहेत याचा अभ्यास करत आहे. यासाठी मी तुम्हाला मूलद्रव्ये, संयुगे व मिश्रणे याबद्दल थोडे प्रश्न विचारणार आहे. ही मुलाखत म्हणजे तुमची परीक्षा नाही, त्यामुळे विचारलेल्या प्रश्नांची उत्तरे तुम्ही तुमच्या भाषेत द्या. तुम्हाला जे समजलेले आहे ते मला समजावून घ्यायचे आहे. एखाद्या प्रश्नाचे उत्तर माहीत नसले तरी हरकत नाही. तुम्ही दिलेली माहिती मला माझ्या अभ्यासासाठी उपयोगी पडेल व फक्त माझ्या अभ्यासासाठीच वापरली जाईल.

1) तुम्ही मूलद्रव्ये, संयुगे व मिश्रणे याचा अभ्यास केलेला आहे.

अ) मूलद्रव्य म्हणजे काय ? (उदाहरणे द्या.)

ब) संयुग म्हणजे काय ? (उदाहरणे द्या.)

क) मिश्रण म्हणजे काय ? (उदाहरणे द्या.)

2) मूलद्रव्य, संयुग, मिश्रणाप्रमाणे अणू व रेणू हे शब्द रसायनशास्त्रात खूपदा वापरले जातात. अणू व रेणू म्हणजे काय ते स्पष्ट करा. अणू/रेणू नुसत्या डोळ्याला अथवा तुम्ही प्रयोगशाळेत वापरता त्या सूक्ष्मदर्शकातून दिसतात काय ?

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3) खाली काही आकृत्या दिलेल्या आहेत. त्यापैकी कोणती आकृती मूलद्रव्य दाखवते, कोणती आकृती संयुग दाखवते व कोणती आकृती मिश्रण दाखवते ते सांगा. तुमच्या उत्तराचे कारण स्पष्ट करा.

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4) संयुजा म्हणजे काय ते सांगा.

Appendix 1

The Periodic Table : A Preliminary Study Of Students' Understanding And Difficulties

SAVITA LADAGE,
Homi Bhabha Centre For Science Education, TIFR, Bombay - 400005.

Abstract

The periodic table of elements is an important classification in chemistry. It reveals the interconnections between the atomic structure and properties of elements. For students of chemistry, such an understanding is of considerable importance. However, in the current chemistry syllabus at the secondary school level, the topics such as atomic structure, valency, chemical formulae and equations are introduced at class IX level whereas the topic of periodic table is introduced in isolation, a year later (that is, at S.S.C.). Even at S.S.C., the weightage allotted to this topic is considerably low. Due to all these reasons, the topic of periodic table is considered as an unimportant topic at the secondary school level.

A model of the periodic table was developed at Homi Bhabha Centre For Science Education to present this topic in an interactive manner, while teaching. This paper describes a pilot study conducted using the model. An attempt was also made to study the difficulties of students regarding the periodic table.

Introduction

At the elementary level, students of chemistry mainly study the properties of elements and compounds. Such a study is of considerable importance, since uses of various materials are linked to their properties. It is more important, however, that the students of chemistry should be exposed to the relation between chemical properties of elements and the atomic/molecular structure of materials. Indeed, it is this relation that elevates medieval alchemy to modern chemistry. In other words, such an exposure helps students to understand why a particular element or a compound has to have certain characteristic properties. The concept that forms the very basis for such an understanding, is the Periodic Table of Elements.[1] The periodic table not only displays the interconnections of properties and the atomic structure, but also reveals how the periodicity in the electronic shell structure leads to the periodicity of properties of elements. It would be natural, therefore, to expect that attempts at instruction in chemistry at the secondary school level (that is, an understanding of properties, chemical formulae and equations etc) would be built around the periodic table. However, in the current chemistry syllabus of Maharashtra State the topic of the periodic table is introduced at standard X (that is, at S.S.C.), while the topics of atomic structure, valency, chemical equations are introduced at the standard IX. In fact, if the topic of the periodic table is introduced soon after the topics, atomic structure and valency, it will help students understand the basis of classification of elements, the regular variations in valencies of elements in the periodic table and the connections between atomic structure, properties of elements and valencies. The periodic table can also be used effectively in understanding the chemical formulae of different compounds. Students of Standard IX also study properties of some elements and compounds in considerable details. Unfortunately, no inter-connections between these topics and the periodic table can be revealed to the students as the periodic table is introduced a year later. Even at the S.S.C. examination, the topic of periodic table is introduced as an independent topic of considerably low weightage in terms of examination, carrying only 3 marks out of 40. All these factors reduce the topic of periodic table to an unimportant, unconnected piece of information.

The periodic table of elements, that is, the long form of the periodic table which is introduced in standard X, as a two dimensional array of elements displays symbols, atomic weights and atomic numbers of elements. This information reveals neither the periodic patterns nor the interconnection between structure and properties.[2] Thus, students find it difficult to understand the significance of the periodic table. If the relevance of the periodic table is to be brought out, its information content must be chosen properly and exhibited in a manner suitable for highlighting the periodic nature of properties and their relation to atomic structure.[3] Apart from this difficulty, the periodic table is generally taught using charts usually hung high on the walls which makes it difficult for students to read the information being displayed.[4] These charts also do not provide any opportunity for students to play with the given information, or to seek more relevant information. In other words, wall charts of the periodic table do not provide an opportunity for students to construct their own periodic table filling the required information. Charts ,therefore, are not the best teaching–learning aid, with reference to the periodic table.

To present information in an interactive mode and to overcome the shortcomings of the conventional, two dimensional periodic table of elements, an attempt has made to develop, a model of the periodic table, at the Homi Bhabha Centre For Science Education (HBCSE). The general features of this model are described in the appendix.

Pilot Study

A pilot study using the model was conducted by the researcher, so as to understand how and to what extent the model could be used in a classroom. For this study, a class of standard X was selected from a Bombay Municipal school (The medium of instruction was Marathi and most of the students were average or below average in performance). As the chapter on the periodic table was already taught in the classroom, two tests on the periodic table were given to the students as pre-tests. After the tests, some students were interviewed to get a feel for their understanding of the topic. The students were then divided into experimental and control group using the systematic sampling procedure (Since it was a pilot study, both the groups were small in size containing 17 and 21 students respectively). The intervention was conducted with the experimental group using the model for three days (about 1.5 hrs/day).No intervention and exposure to the model was conducted with the control group. The earlier two tests were readministered as post-tests to both the groups to learn about significant differences between the two groups, if any.

Intervention

The intervention consisted of three sessions of 1.5 hours each. An attempt was made to make all the sessions interactive so that the students handled the model. In the first session, the face revealing the name, the symbol, and atomic weight was introduced and the students were asked to describe the information. They checked whether the elements were arranged on the basis of the increasing order of the atomic weights. Students were then provided with blank cards on which they were asked to write either the name or the atomic weight of an element. The cards were then handed over to the other students who were supposed to place them at their proper places. The students were asked to classify the cards for few elements provided to them (on each card some properties of an element were written). This activity was performed to facilitate their understanding of groups in the periodic table.

The second session began with students conducting a revision of concepts covered in the first session. Then the students were introduced to the second face of the box, showing the atomic number and symbol of elements to initiate discussion on this aspect. Throughout the session, atomic number remained the focal point of discussion. Initially, the atomic structure was discussed in brief, and the term, atomic number was explained to them. Students used the model to check how the atomic number varied in the periodic table. They were asked to guess the number of electrons in a given atom from its atomic number. Students then drew the electronic configuration of the element on the cards provided to them. They placed these cards at their proper places in the model and studied how electronic configuration varied in the table. Attention was drawn to the group number and number of electrons in the outermost shell. They were asked to guess whether an element would be an electron donor or accepter or sharer on the basis of number of electrons in the outermost shell. This activity led to a discussion related to oxidizing and reducing properties of elements. They were asked to calculate the difference between the atomic numbers of successive elements in the group and to see how these differences vary from one group to another.

The third session was devoted to the concept of valency. Each student was called to the blackboard and was asked to write down the atomic number, the number of electrons, electronic configuration and the expected valencies of any one element. This activity was performed for all the elements in the 3^{rd} row. Students also wrote down the formulae of the oxides of the 3^{rd} row elements. They were then given other elements from different groups and were asked to write down the formulae of their oxides, for example, once they wrote Na_2O, they were asked to write down the formula of potassium oxide. Another element from oxygen group, that is, sulphur was selected and students were asked to write down the formulae of sulphides of different elements. At this stage, discussion was focused on the variation of properties of oxides in the table. At the end of the session, revision of concepts in all the three sessions was conducted.

Analysis of the Experiment

The statistical analysis (that is, t-test) revealed that the two groups did not differ significantly on the pre-tests. However, similar analysis of the post-tests indicated that the performance of the experimental group was significantly better than that of the control group. Comparison within the group (that is, the performance in pre/post test) showed that in case of experimental group, there was significant improvement on almost 50% of the questions. The control group did not show any improvement for any of the given tests. This analysis indicates that the use of model and the intervention helped students in the experimental group in understanding the topic of periodic table when compared to the control group.

Discussion

It will be useful to discuss the nature of the difficulties of the students and also the details regarding the improvement observed in the experimental group after the intervention. As said before, two tests and interviews were used to assess the difficulties of the students. The tests mainly aimed at the understanding of periodic variations of different properties. The interviews were mainly aimed at students' knowledge of a) prerequisites (that is, atomic weight, atomic number, valency and physical and chemical properties of elements b) the periodic table (meaning of the information filled in the periodic table chart shown in the text-book, and the basis for the arrangement of elements and c) meanings of newly introduced words related to the periodic table such as period, periodic event, periodic function (30 students from the class were interviewed.

As discussed before, the curriculum expects that students have understanding of the properties of the elements, the atomic structure and valency before they learn the periodic table. It was observed that most of the students were able to distinguish between the physical and chemical properties of the elements (colour, smell, state were some of the physical properties mentioned by the students). However, it was observed that the understanding of the atomic structure especially that of valency was poor. Nearly 50% of the students failed to explain the terms atomic number and atomic weight. Some of the students interpreted atomic number as number of electrons in the outermost shell or number given on the basis of discovery of elements or number given on the basis of the places of elements in the periodic table. It was also observed that students were confused between the terms atomic number, atomic weight and mass number. One probable reason for this confusion could be that all these terms (and some other terms) are introduced in quick succession at standard IX in the topic of the atomic structure and the equivalent technical terms in Marathi are very similar to one another for example, atomic number- *anukramank*, atomic weight–*anubharank*, mass number – *anuwastumanank*.

The concept of valency appeared to be the most difficult for students to understand. Most of the students failed to give a definition of the term 'valency'. A common misconcept was the equating of the number of electrons in the outermost shell to valency. Students also failed to calculate the valencies from the given chemical formulae. The understanding of valency requires the knowledge of a number of subconcepts such as atomic number, electronic configuration, the concept of stability of a filled shell. To calculate valency from the configuration, one should see how many electrons (that is, number of electrons an element can accept, donate or share) are required to complete the outermost shell. Probably the multi–parametric nature of this concept makes it difficult for the students to understand. Another probable reason for the students' difficulties with the concept of valency could be that all these concepts are taught to the students in a short span of time without giving sufficient time to assimilate them. It is, therefore, essential that these concepts should be revised and referred to constantly while studying other related topics such as properties of different elements and compounds. Thus, it will be useful to devote some time to revise these prerequisites before teaching the periodic table at standard X.

Regarding the periodic table, analysis of the interviews and pretests showed that the understanding of the periodic table and the periodic variations of properties was poor in general. Nearly 40% of the students were unaware of the basis of arrangement of the element in the periodic table. Hydrogen was stated to be the first element, Helium the second and Neon the next element. (Some of the students who were interviewed recently as a continuation of this research work, stated Hydrogen to be the first element followed by Lithium and so on . After Francium, that is, the last element of the first group, they stated Beryllium to be the next element). Nearly, 40-60% of the students could not explain the numbers given in the periodic table. Some students interpreted the upper number (that is, the atomic number) as number of molecules or atoms in the given element or the number of electrons in the outermost shell. Regarding the arrangement of the elements in the periodic table, some students thought that the elements were arranged on the basis of the sequence in which they were discovered or on the basis of valency.

Most of the students failed to explain the meanings of the newly introduced words related to the periodic table. A few students interpreted the new words differently, for example, period was interpreted as 'horizontal line' or as 'belonging to the periodic table'. One student connected this term to reflection. The probable reason for such connection could be the similarities in the equivalent Marathi technical terms (period-*avartan*, reflection-*paravartan*). Most of the students were unable to explain the meaning of the periodic law because they had not understood the word 'periodic function'. When asked to give examples of periodic events from the daily life, some students gave examples such as accidents, fights or quarrels. These students were reluctant to accept the sunrise-sunset or going to school every day (or other such examples) as examples of periodic event. They interpreted word 'event' mainly as horrifying incidents such as accidents or quarrels. Thus, it is essential to explain the meanings of the newly introduced words, in absence of which wrong interpretations of words and terms would hamper the understanding of any topic.

As stated earlier, the performance of the experimental group had improved significantly on the post-tests. It was observed after the intervention that the questions which required scanning of one single property like atomic weight or atomic number or electronic configuration showed significant improvement. However, the questions which required selecting the strongest oxidising element or to write down the chemical formula of a compound, showed that the performance on these had not improved significantly. Such questions require understanding of a number of sub-concepts and their interconnections with one another. The performance on such questions did not improve even after intervention. It appears that more attention and emphasis and possibly more time should be given to concepts involving multi - parametric thinking.

Conclusion

This preliminary study suggests that the periodic table is a complex construct involving many concepts. Students, especially the low achievers in chemistry, have many difficulties regarding the periodic table as discussed earlier. This study also shows that the use of periodic table model and intervention helped the students of the experimental group in understanding the topic better. The model and other activities provided for the experimental group give these students more opportunities for the interactive learning which helped in better understanding of the topic. However, it should be noted here that no intervention was attempted with the control group. In order to test the effectiveness of the model conclusively it is necessary to teach both control group (with the charts) and experimental group (with the model). A detailed study is being planned and will be undertaken soon.

Acknowledgements

I am grateful to Prof.V.G. Kulkarni who provided guidance at all stages of this study. Thanks are due to my colleagues, Dr.H.C. Pradhan, Mr.R.M. Bhagwat and Ms.S.I. Chunawala for their critical discussions. It is not possible to express my gratitude to the teachers and students without whose co-operation this work would have been impossible.

Appendix

Periodic Table Model

The model was prepared using transparent cubic plastic boxes. Different types of information about an element were displayed on the four different faces of the box. For example, face one showed the name, symbol and the atomic weight of an element. The second face showed the symbol along with the atomic number, and other information such as whether the element is solid, liquid or gas at room temperature and whether it is a metal, a nonmetal or a metalloid. The third face displayed the electronic configuration whereas the fourth face showed some properties of the element (See figure 1). The displayed information can be changed any time just by removing the inserted cards from the boxes. For example, in case of the elements predicted by Mendeleev one of the surfaces could purposely be kept blank. The students could then be asked to guess the properties of these missing elements from the properties of other elements belonging to the same group. This activity would help students understand the importance of Mendeleev's work.

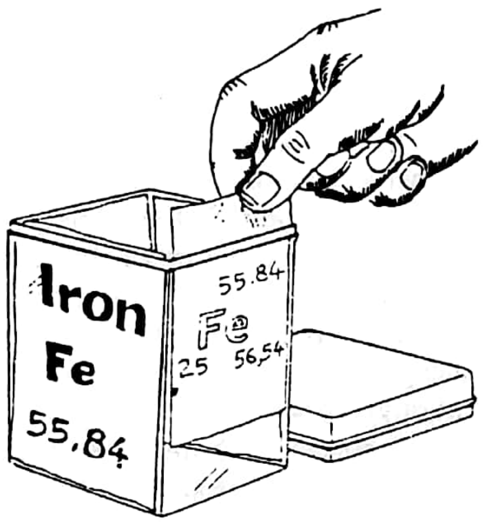

Fig. 1

Such boxes were prepared for every element. A steel rod was passed through the holes and the boxes were arranged into groups. A simple aluminium frame was used to support the columns of the boxes. The distance between the two columns was adjusted in such a manner that each box could freely rotate around its own axis. Small rubber pieces were inserted to reduce friction. In case of lanthanides and actinides, two bunches of 14 cards of each were prepared and were tied at their appropriate places in the model (See figure 2). Each card included the name, symbol, the atomic weight and the atomic number of the corresponding element.

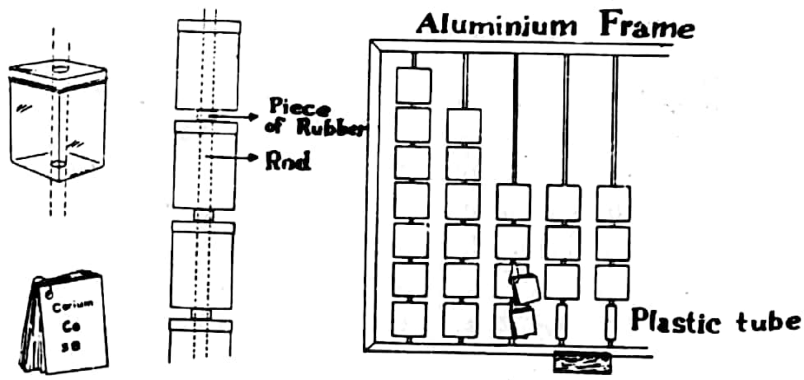

Fig. 2

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Study of Students' Difficulties in Balancing Chemical Equations

SAVITA LADAGE
Tata Institute of Fundamental Research, Mankhurd, Bombay - 400 088.

Abstract

Chemical formulae and equations express symbolically all the necessary information regarding chemical reactions. Students of chemistry must understand this symbolic language of chemistry to understand the described chemical change. As a pre-requisite, they should be able to express a chemical equation correctly, for which balancing chemical equations becomes important. However, students' difficulties in balancing chemical equations, remain unremedied. A study was conducted to understand students' difficulties in balancing chemical equations. It is observed that these difficulties are mostly due to the lack of the understanding of different chemical concepts though lack of numerical skills also play their part. The current paper describes details of this study.

The primary purpose of chemistry is to explain and describe chemical changes on the basis of which we understand how one substance is converted into another. Chemical changes are expressed in a symbolic language, that is, in the language of chemical formulae and chemical equations. In other words, chemical equations are the means to describe in precise symbolic language, all the necessary information such as the composition of reactants and products, the state and proportion of reactants and products, the energy changes. It is, therefore, necessary for students of chemistry to be well-acquainted with this symbolic language of chemistry. For interpreting a given equation, it is essential that the equation be expressed in a correct *balanced* form. Thus, ability to balance the chemical equation is a fundamental requirement in chemistry[1]. However, acquiring this basic skill seems to cause considerable difficulties for the students of chemistry [2,3,4,5,6]. A survey conducted by the researcher herself revealed that the topic of 'chemical formulae and chemical equations' is perceived as one of the most difficult topics at the school level, both by students and teachers[7].

To balance any chemical equation and to understand whether the given equation is correctly expressed, knowledge of number of sub-concepts is essential since the absence of this knowledge leads to misunderstanding of the described chemical change. L.G. Savoy[8] has described the different concepts required for understanding of chemical equations along with their hierarchy. Figure 1 represents the different concepts and their hierarchy as described by him.

This above diagram needs to be modified further by the addition of a few more sub-concepts such as familiarity with chemical symbols, identification of elements, compounds and mixtures, and understanding of chemical and physical change (These additional sub-concepts are presented in italics in Fig.1).

In the syllabus of chemistry, currently prescribed in the state of Maharashtra, topics such as classification of matter, physical and chemical change and atoms and molecules including their chemical symbols, are introduced at class VIII while topics of atomic structure, valency, chemical formulae and equations are introduced at class IX. Unfortunately, periodic table which reveals the interconnections between the atomic structure, electronic configuration, valency and bonding is introduced only at class X as an isolated topic. In other words, the periodic table introduced at the fag end of the course constitutes a few more facts to be remembered, instead of being introduced at an early stage as a tool for understanding the logical basis for chemical changes.

It is important that students understand the concepts such as elements and compounds, chemical change and chemical reaction in terms of atoms and atomic struc-

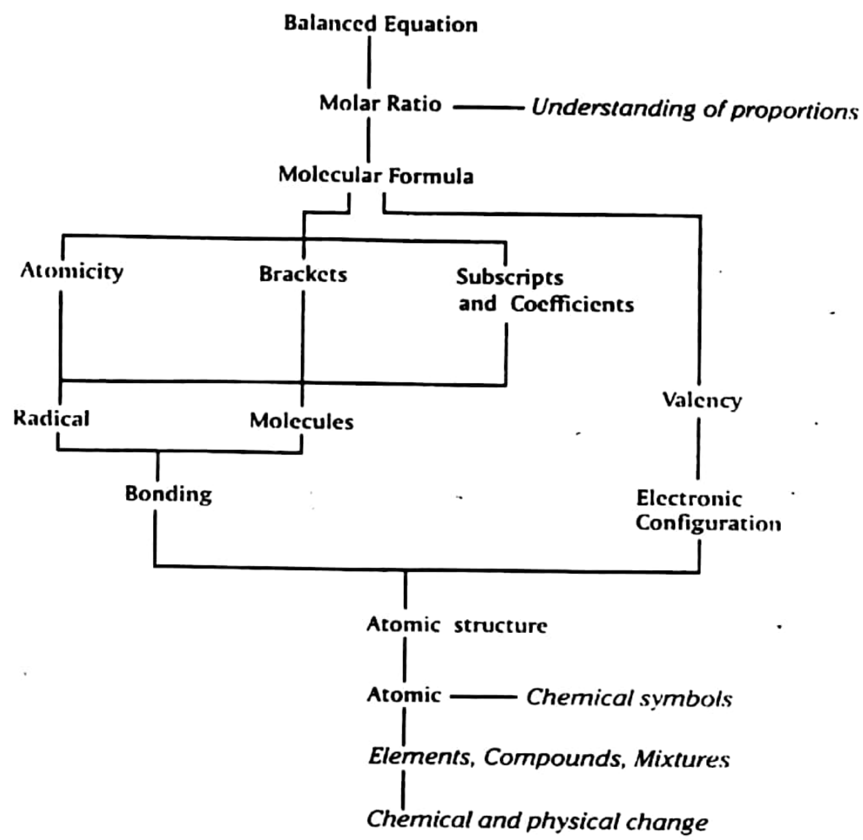

Fig. 1 : A hierarchy of concepts needed to balance chemical equations.

ture. It is, therefore, essential that students be exposed to the necessary interconnections between these topics. Thus, a study was conducted in order to understand students' conception of chemical equations and their difficulties in balancing them.

Methodology

(i) Sample

The study was conducted at two different schools, one in the city of Bombay and the other in the city of Solapur (Maharashtra). The total sample consisted of 73 students of class X (38-Bombay, 35- Solapur). The students from the school in Bombay were described by their teacher as average in their scholastic performance in chemistry whereas the students of the Solapur school were described by their teacher scholastically as a shade above the average. The researcher's interaction with both the groups of students led to an impression which more or less tallied with the teachers' opinion.

(ii) Tests

Two tests on chemical equations were administered to the students. The first test consisted of seven equations which they were asked to balance. The second test was administered to the same students. It consisted of five equations, in which students were expected to spot and correct the errors and then balance the equations. The tests were administered in Solapur at the beginning of the school second term. In Bombay, these tests were administered almost at the end of the second term. The two tests were administered with a gap of a day at Bombay whereas at Solapur, the gap was of five days. The average time taken for both the tests was about 25-30 minutes (The tests are given in the appendix).

Analysis of the tests

The analysis of the first test revealed that even after learning and using the chemical equations for more than a year, students had difficulties in balancing the given equations. The following table shows the number and percentage of successful, partly successful and unsuccessful students on the test. Discriminating indices (D.I.) for different equations are also given in the table. The D.I. is calculated as follows:

D.I. = No. of successful students in top 25% of student — No. of successful students in bottom 25% of students

TABLE 1

Performance of students on test 1 (N=73)

Eq. No	Number and % of successful students	partly successful students	unsuccess-ful students	D.I.
1.	58 (80%)	5 (7 %)	10 (14%)	3
2.	44 (60%)	17 (23%)	12 (16%)	11
3.	31 (43%)	13 (18%)	29 (40%)	16
4.	38 (52%)	12 (16%)	23 (32%)	17
5.	40 (55%)	12 (16%)	21 (29%)	16
6.	25 (34%)	29 (74%)	19 (26%)	17
7.	23 (32%)	8 (11%)	42 (58%)	17

The discriminating indices indicate that almost all the equations (except equation 1) are able to discriminate between the performance of successful and unsuccessful students to almost the same extent. It is also clear from the above table that equations 3, 6 and 7 were the most difficult equations for the group whereas equation 1 was the easiest one.

Similar analysis was conducted for the second test. Initially, the correlation coefficient (r) between the marks obtained for the two tests was calculated. The correlation observed for the whole group was positive and significant ($r = 0.499$). The performance of students, that is, number and percentages of successful, partly successful and unsuccessful students is displayed in Table 2.

TABLE 2

Performance of students on test 2 (N=73)

Eq. No.	Number and % of successful students	partly unsuccessful students	unsucessful students
1.	3 (4 %)	59 (81%)	11 (15%)
2.	9 (12%)	57 (78%)	7 (7 %)
3.	28 (38%)	37 (51%)	8 (11%)
4.	3 (4 %)	55 (75%)	15 (21%)
5.	4 (6 %)	18 (25%)	51 (70%)

The table indicates that few students (about 4-10%) were successful in balancing the equations after locating and correcting the given errors. Due to this reason, the discriminating indices (D.I.) were not calculated for this test. Also, the performance of most of the students in the partly successful category was hardly more than that of the unsuccessful students. Most often, these students had corrected only one particular error.

As mentioned earlier, in the second test the equations contained errors. The following table displays students' performance in identifying and correcting these errors. The numbers and percentages given in the table are calculated for the total group of students (both Solapur and Bombay). The students' responses to the errors can be classified in four categories - (i)

TABLE 3

Performance of students in identification and correction of errors (N=73)

Errors	0	1	2	4
K2*	52 (71%)	15 (21%)	1 (1 %)	4 (9 %)
$2NaSO_4$	49 (67%)	20 (27%)	2 (3 %)	2 (3 %)
2HO	5 (9 %)	64 (88%)	2 (3 %)	2 (3 %)
HO_2	2 (3 %)	66 (90%)	-	5 (7 %)
$ZnOH_2$	24 (33%)	32 (43%)	12 (16%)	5 (7 %)
2O	10 (14%)	54 (74%)	-	9 (12%)
Al_3O_2	43 (59%)	18 (25%)	3 (4 %)	9 (12%)
$Al_3(SO_4)_2$	44 (60%)	11 (15%)	10 (14%)	8 (11%)
$NaSO_4$	31 (43%)	18 (25%)	16 (22%)	8 (11%)

*The correct representation is 2K.

(i) not identified and hence not corrected (code- 0), (ii) identified and corrected (code- 1), (iii) identified but corrected wrongly (code - 2), and (iv) not answered (code - 4).

The table indicates clearly that the percentage of students who identified and corrected the errors for the formula of water or for molecular formula of oxygen was high (about 80%). However, for other errors this percentage was small and varied between 15% to 28%.

Discussion

Table 1 indicates that even the simplest equation, that is, equation 1 was not balanced by all the students. While the success rate of 80% seems high in comparison with that for other equations, failure of nearly 20% on so simple task does not augur well for the eventual progress of the class and therefore, deserves attention. In the case of other equations, more than 50% of the students have failed to balance them. In general, the wrong responses in balancing the equations can be classified into four different categories - (i) balancing of only one or two elements (12% - 24%), (ii) balancing by changing the subscripts or by adding new products (7% - 21%), (iii) wrong numerical balancing (especially for equations 6 and 7 - 33% and 26%), and (iv) not answered (5% - 8%).

Table 1 indicates that equation 7 was the most difficult equation to solve. There could be two possible reasons for the students' difficulties - (i) the element oxygen occurs in all the reactants and in all the products; a situation which is probably more complicated than one in which all atoms of a given element are lumped in one substance, (ii) the total number of oxygen atoms on the reactant side is odd whereas that on the product side is even which defies the familiar trick of finding a simple multiplier to balance the equation. In case of this equation, students (mainly from Bombay school) changed the product NO to NO_2. Equation 3 was also difficult for the students, once again probably due to the fact that the number of oxygen atoms in reactant is even whereas it is odd in the product. In case of this equation, students concentrated on aluminium ignoring oxygen and tried to balance it by adding a coefficient 2 on the reactant side. Some students balanced it as $2Al + 3O_2 \rightarrow Al_2O_3$ (that is, paying attention to subscripts of products and adding same numbers as coefficients on the reactant side). Attempts were also made to balance it by changing the reactant Al to Al_2, Al_3 or by changing O_2 to O_3, O_6 (similar errors were committed in equation 5, that is, changing Zn to Zn_2 or Zn_3 or Al to Al_2). Sometimes students tried to balance the equations by matching the product to reactant or vice versa, for example, in equation 4 the product $AlCl_3$ was converted to Al_2Cl_3 or the product H_2O was changed to H_2O_3 (similar to the reactant Al_2O_3). Such attempts were also made for equation 5 by a few students (changing $ZnSO_4$ to $Zn(SO)_3$ which resembles the product $Al_2(SO_4)_3$).

The above analysis reveals that students try to balance chemical equations in a mechanical manner, that is, they try to equalize the number of 'atoms' in reactants and products by adjusting numerical subscripts, disregarding the sanctity of molecular formulae. Another example illustrating this point was provided by a student who balanced the equation 6, $C_3H_8 + 2O_2 \rightarrow CO_2 + H_2O$, by adding a new product $(CH_3)_2O$. The student simply counted the number of atoms of all elements which were excess on L.H.S. and added them on R.H.S. as a new product. Such responses indicate that students consider chemical equations as a numerical exercise in balancing atoms on both sides and do not understand 'symbolic language'. It is worthwhile investigating if current instruction fails to zoom in on the 'symbolic language' part of chemistry. The concern for balancing equations correctly needs to be based on understanding chemical concepts and hence the chemical language.

It is also clear from the above discussion that the wrong/inadequate responses of the students are only partly due to errors in numerical calculations. Lack of understanding of chemical concepts and chemical language is even more important. The precise meaning of a subscript in a molecular formula and coefficient applied to the entire formula constitute an important aspect of chemical language. Balancing equations by writing Al_3 instead of 3Al and similar other errors mentioned above indicate that students fail to distinguish between subscripts and coefficients. Such responses also reveal that students have poor understanding regarding the elemental or molecular nature of elements. The change of chemical formulae such as NO_2 (for NO), H_2O_3 (for H_2O), Al_2Cl_3 (for $AlCl_3$), $Zn(SO_4)_3$ (for $ZnSO_4$) illustrates how students over-concerned by the need to balance the number of atoms disregard valencies of elements and radicals even though they have been exposed to these concepts.

The discussion so far has concentrated on the errors committed by the students on the first test. The analysis of the second test confirms the points among others. Table 3 indicates that the percentages of students who failed to identify and correct the errors was very high in general. Nearly, 71% of the students failed to identify the errors K_2. Almost 24% of the students have either not been able to identify the difference between 2O and O_2. Similar errors were also created by the students in attempting to balance equations, for example, Br or Br_3 for Br_2, Al_3 or Al_2 for 3Al and 2Al. It once again indicates that atomic and molecular nature of different elements as well as the significance of subscripts and coefficients are not understood by the students. The wrong chemical formula $2NaSO_4$ in equation 2 was not identified or corrected by almost 67% of the students. For the same error in equation 5, about 22% of students have made wrong corrections such as $Na(SO_4)_2$ or $Na_2(SO_4)_3$ or $Na_2(SO_4)_2$. For the same equation, 60% of the students have either failed to identify and to correct the error $Al_3(SO_4)_2$. Some students tried to correct it as Al_3SO_4 or $Al_2(SO_4)_2$ or $Al_3(SO_4)_3$. All these changes in formulae of sodium sulphate and aluminium oxide were essentially made simply to balance the number of atoms in the given equation. In case of equation 4, the wrong formula of aluminium oxide (Al_3O_2) was neither identified nor corrected by about 59% of the students. Most of the students did not make any attempt to balance this as the given equation itself appeared to be balanced ($3Al + 2O \rightarrow Al_3O_2$). In case of equation 3, 33% of the students failed to identify and to correct the error $ZnOH_2$. Nearly, 16% of the students have tried to correct it as $Zn+(OH)_2$, ZnO_2+H_2, ZnH_2O or as $ZnOH_2 + H_2O$. Thus, it becomes clear from these responses that the understanding of valencies is poor and that importance of brackets as well as the concept of radicals are not clear to the students. All these responses also raise doubts whether classroom exposure to chemical reactions has led to an understanding of the concept of compound and hence its symbolic representation. The responses such as $Zn + (OH)_2$, $ZnO_2 + H_2$ indicate that $Zn(OH)_2$ is not viewed as an entity. Such responses also raise doubts regarding students' understanding of the interactive aspect of chemical reaction (that is, bond breaking and bond formation).

As said earlier, the performance of those students (18 in number) who successfully balanced almost all the equations from the first test was analyzed in detail. Generally, one would like to assume that these students would exhibit deeper understanding of the necessary sub-concepts as compared to other students. However, the analysis of their performance on the second test reveals that most of these students also possess poor knowledge of the necessary chemical concepts in general. Out of these 18 students, only one student (from Bombay school) has identified and corrected all the errors. He has also correctly balanced all these equations. There were four other students (from Bombay) who have identified and corrected almost all the errors but failed to balance the equations. However, the performance of all other students (that is, 13 students) was poor in general. Most of the students have failed to identify the different given errors. A few (four in number) students have created additional new errors such as H_4O_2, Al_3SO_4, $Na(SO_4)_2$. One such student, while correcting the error 2HO, has reasoned that the given molecular formula of water, 2HO which means H_2O_2, is wrong. This reasoning clearly indicates that the student thinks that when the subscript is common, it is written as coefficient as it would be in algebra class. Thus, most of the successful students who could successfully balance equations on test 1, owe their success to rote memory or to some numerical skill rather than to an understanding of chemistry.

Conclusion

The study indicates that even after using the chemical equations for more than a year, students commit many errors while balancing the chemical equations. Poor mathematical manipulation is not the only cause of such errors. In fact, many errors are created due to the lack of understanding of appropriate chemical sub-concepts and of language of chemistry such as subscripts, coefficients, use of brackets, radicals, valencies of elements and its representation in chemical formulae, besides the knowledge of atomic and molecular nature of elements. Unfortunately, the study also reveals that even those students who seem to be good at balancing the equations, exhibit poor understanding of these chemical sub-concepts. The study throws doubt on the diagnostic capability of routine tests of balancing familiar chemical equations. In fact, balancing equations containing errors can be a better diagnostic tool for conceptual understanding along with the numerical one. In the teaching of chemical equations, numerical calculations should not be allowed to overshadow conceptual understanding.

Acknowledgements

I am grateful to Prof. V.G. Kulkarni who provided guidance at all stages of this study. Thanks are due to my colleagues, Mr. R.M. Bhagwat and Ms. S.I. Chunawala for their critical discussions. I also express my gratitude to the teachers and students without whose co-operation this work would not have been possible.

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Appendix

Test 1

1. $KI + Br_2 \rightarrow KBr + I_2$.
2. $NaOH + H_2SO_4 \rightarrow Na_2SO_4$.
3. $Al + O_2 \rightarrow Al_2O_3$.
4. $Al_2O_3 + HCl \rightarrow AlCl_3 + H_2O$.
5. $ZnSO_4 + Al \rightarrow Al_2(SO_4)_3 + Zn$.
6. $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$.
7. $NO_2 + H_2O \rightarrow HNO_3 + NO$.

Test 2

Five chemical equations are given below. Each equation contains some errors. Identify the errors, correct them and then balance the equation.

1. $KBr \rightarrow K_2 + Br_2$

KBr	K_2	Br_2
Potassium bromide	Potassium	Bromine

2. $NaOH + H_2SO_4 \rightarrow 2NaSO_4 + HO_2$

$NaOH$	H_2SO_4	$2NaSO_4$	HO_2
Sodium sulphate	Sulphuric acid	Sodium sulphate	Water

3. $ZnO + 2HO \rightarrow ZnOH_2$

ZnO	$2HO$	$ZnOH_2$
Zinc oxide	Water	Zinc hydroxide

4. $3Al + 2O \rightarrow Al_3O_2$

$3Al$	$2O$	Al_3O_2
Aluminium	Oxygen	Aluminium oxide

5. $Al_3(SO_4)_2 + Na \rightarrow NaSO_4 + Al$

$Al_3(SO_4)_2$	Na	$NaSO_4$	Al
Aluminium sulphate	Sodium	Sodium sulphate	Aluminium

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Every scientific advance is an advance in method. The invention of a specialized laboratory procedure brings about rapid conquests in new fields of science and technology : finally it exhausts itself and is replaced by a still more practical method.

(Source L. Zechmeister and L. Von Cholnoky *Principle and Practice of Chromatography*.)

CONTENTS

INTRODUCTION

Chemistry is a fascinating subject. Even at the elementary level, where one studies the simple properties and composition of some familiar substances, chemistry begins to reveal the beautiful patterns of 'Nature's Architecture'. Indeed, it is at the elementary level that we must pause to understand and admire this brilliant architecture. The purpose of this book is to introduce you to this fascinating world.

While studying the fundamentals of chemistry, we are introduced to various basic concepts and principles. One such important concept in chemistry is the systematic classification of elements based on their properties. This classification is amazingly fruitful. It reveals the periodic nature of the properties of elements and shows clearly how properties are related to the structure of atoms. The arrangement of elements according to their properties gave rise to the *Periodic Table* of elements. As students of chemistry you are familiar with this Table in its widely used form. You also know that the major credit for the discovery of the periodic table and the periodic law goes to the Russian chemist, Dmitry Mendeleev.

Though the discovery of the periodic table is attributed to Mendeleev, several scientists, from the ancient Greek philosophers and alchemists of the middle ages to modern scientists working in well-equipped laboratories, have contributed significantly to its development. In fact, this is how science grows. The work of a large number of scientists accumulates until some exceptionally gifted scientist sees a pattern in the mass of information and explains its 'meaning'. The story of the periodic table illustrates this point perfectly.

The desire to find patterns in nature has been an important aspect of scientific investigation, since ancient times. The Greek philosophers tried to explain all matter on the basis of four natural or basic 'elements'. However, the steady progress of chemistry led to the discovery of elements as we know them today. By 1860 there were 60 known elements. This story in itself is interesting, but we shall not spend too much time on it here. We need cover only the important points which will enable us to understand how the *periodic table of elements* evolved.

It took several centuries of intelligent hard work together with flashes of genius for humankind to acquire the understanding that is presented in this book. Now, you can read all about it in a few days. But, apart from learning about and understanding the scientific theories of today, it is also useful to study the historical development of various concepts and theories of science. Louis Pasteur (1822–1895), the famous scientist, once wrote a report 'on the usefulness of the historical methods in teaching science'. According to him, the teaching method involving historical developments 'evokes the individual efforts of the most important inventors, adopts preferably their own terms, indicates their essentially simple procedures and tries to transport the audience mentally into the period when the discovery was made'(1).

According to Spencer Weart, Manager of the Centre for History of Physics at the American Institute of Physics, New York, 'The history of science is the story of a community of people with ordinary human flaws

Recognizing Patterns

Collection of a heap of information does not by itself lead to knowledge. It is only when a law or a pattern in which pieces of information fit is discovered, that one gains insight or understanding. Let us consider a few examples:

1. *It is easy to observe that the sun rises in the east and sets in the west. The moon and the planets do the same. This information is certainly useful. However, it is only when we realize that the earth spins on its axis once every 24 hours from west to east, that the information about the rising and setting of heavenly bodies acquires a meaning. We then understand that, because of the earth's rotation, all heavenly bodies would appear to rise in the east and set in the west.*

2. *We know that any object thrown up will eventually fall down. We know that if we wish to move an object faster, we have to push harder. However, once we learn Newton's laws of motion, all these experiences become understandable and predictable. Newton's laws provide a framework into which all our mechanical experiences fit.*

3. *As you study chemistry, you will learn that some elements like sodium, potassium and oxygen are very active, and that they form compounds with other elements rather easily. On the other hand, there are some other elements like neon, argon and helium that just do not react with other elements. In the absence of a pattern you will have to remember this information for each individual element. However, the periodic table of elements presents you with a useful pattern in which elements of the same group have similar properties.*

who fumble their way to new ideas and then verify them, aided chiefly by hard work and intellectual honesty. Without some knowledge of the history of science, students naturally imagine that science is the story of a few great men who somehow came upon their truths in a flash of genius. . . the work of getting more familiar with history is rewarding — even fun. To the austere world of scientific facts, history brings what one eminent scholar called "the smell of human flesh". Authentic history replaces the old, sterile marble statues of scientists with real men and women. One can watch these people, still vividly alive to the informed mind, struggling with new ideas with all the confusion of the most ignorant student. It is only where such real people are found that real science can be found'.(2)

Human progress in science began in the prehistoric era. The very first observations about trees, animals and different events happening in nature must have prompted human beings to keep records of these things. When such observations became numerous they began to classify them. Thus *classification* first evolved in biology (the living world), before enriching other branches of science.

The periodic table is the result of such attempts at classification in chemistry. All the known properties of chemical elements were systematically studied and organized to see if a pattern emerged. Eventually, when such a pattern did emerge, it was really successful. It fitted in with all the known information. Besides, it helped predict elements not yet discovered and also acted as a corrective device in some cases.

The periodic table of elements has several distinctions to its credit. It withstood major crises created by discoveries of new elements such as the inert gases, rare earths and radioactive elements. The most amazing fact about the periodic table is that it achieved its final form even before the discovery of atomic structure which eventually and correctly provided the basis for the periodic table.

It will be interesting to read the story of the periodic table. In our book we have taken care to use facts and concepts which will be easily understood by secondary/higher secondary students. Where we have to use concepts or skills somewhat above this level, we have explained them in considerable detail in boxes alongside the main text. Interesting facts about scientists mentioned in the text are also provided in boxes. The six chapters of this book tell you the history of the periodic table. In the appendices you will find some additional useful and interesting information. When there is a quotation in the text you can look up the number in the list of references to find its source.

1. THE CONCEPT OF ELEMENTS

The word *element* has a variety of meanings. The Oxford dictionary gives several meanings for the word, depending on the context in which it is used. For example, an element is (1) one of the simplest parts into which something can be divided, (2) something which is present in small quantities in a larger whole, (3) one of the basic parts of a branch of knowledge, such as the elements of mathematics, (4) a natural element, like wind or water, or (5) in mathematics, a member of a set!

Even in the context of chemistry, the word element has two distinct meanings:

1. the elements of chemistry—the basic principles of chemistry;
2. the chemical elements—the basic substances which are fundamental units of complex materials.

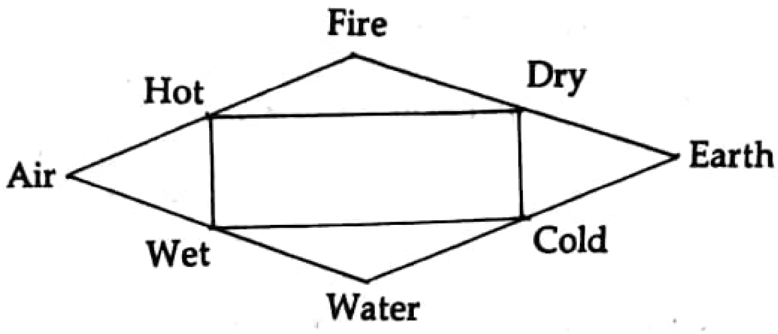
In this book the word 'element' is used in the second context.

While observing the enormous variety of living and non-living objects in nature, thinkers began to wonder whether this complexity could be built up of just a limited number of basic units. This thinking was probably based on their experiences; for example, a variety of words could be produced using a limited number of letters of the alphabet, a few ingredients in the kitchen could produce different dishes, three basic colours could produce a whole variety of shades, etc. The concept of matter being made up of chemical elements probably developed along the same line of thought.

Various attempts were made to identify these 'elements'. The Greek philosophers of ancient times (around 500 BC) tried to identify different substances as elements. Thales (624–546 BC) thought of water as the fundamental substance. Anaximenes (about 570–500 BC) suggested that it was air, whereas Heraclitus (about 540–475 BC) thought it to be fire. Empedocles (around 490–430 BC) suggested that there were four basic elements, namely water, air, fire and earth. To this list Aristotle (384–322 BC) added a fifth—ether, the element of the heavens. However, for centuries the four elements (air, water, fire and earth) were accepted as the elements or building blocks that made the universe.

Other philosophers from different countries (mainly China and India) also suggested similar substances as elements. The number of elements listed rarely exceeded five.

The pioneering attempt at classification of elements (we could call it the first table of elements) was represented as follows:



Hot + Dry = Fire
Dry + Cold = Earth
Cold + Wet = Water
Wet + Hot = Air

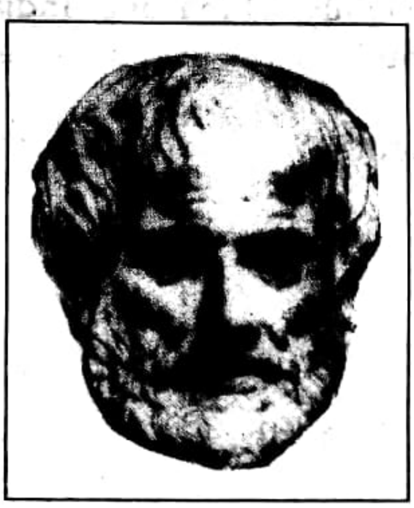
Based on this model, Aristotle explained certain phenomena and certain reactions. For example,

1. Hot or cold was explained on the basis of presence or absence of fire.
2. Solids were substances devoid of water.
3. It was concluded that wood is made of earth and fire, as on burning it gives ash and heat.

The apparent reasonableness of such explanations and the overall respect commanded by Greek philosophers, and especially by Aristotle, gave credibility to this model which prevailed for centuries to come.

Even later, when people began the study of alchemy, false views prevailed with respect to certain elements. One such myth surrounded the element gold. Gold occurs in nature in the elemental or native form. That is, gold is usually found as gold nuggets, and not as an ore from which the metal has to be extracted. Gold was, in fact, one of the first metals to attract man's attention, mainly because of its sparkling yellow colour. It is a beautiful metal, soft, ductile and malleable, easily worked upon and cast. It is, therefore, suitable for artistic work. In ancient times, it was indeed used mainly for ornamental or artistic objects. With the progress of civilization, the exchange and transport of various materials and goods (that is, trade and commerce) gained importance. Soon there was need for a medium of exchange to replace the barter system. Gold, along with silver

Aristotle (384–322 BC)



Aristotle was a Greek philosopher who achieved great fame and influenced the thinking of scholars for several centuries. His father was a physician attached to the court of Macedonia and is said to have introduced Aristotle to the natural sciences. At the age of 17, Aristotle went to Athens where he attended the school of Plato (another great Greek philosopher) for twenty years. He left Athens when Plato died in 347 BC and tried to establish his own school. Soon, Philip II of Macedonia invited him to teach his son who became the conqueror, Alexander the Great. When Philip II died in 335 BC Aristotle returned to Athens and founded his school called the Lyceum. The building had a large covered court where Aristotle taught his students, walking as he spoke, as some of your teachers may do in the classroom. After the death of Alexander the Great, there was an anti-Macedonian wave, and Aristotle was forced to flee. He died in exile at Chalcis in 322 BC.

Aristotle was a great teacher and a prolific writer. He wrote exhaustively on many subjects, but most of his writings are lost. For example, his 'Popular Writings' which were in dialogue form, and his 'Memoranda' which was an encyclopedia of known facts, are both lost. However, many of his treatises on philosophy and natural sciences were saved by the Arab philosophers. These books cover an astonishingly wide spectrum from the science of poetry and literature to ethics, morality, political science, and natural sciences.

The influence of Aristotle continued for centuries. His views were accepted as gospel truth and were not questioned. Unfortunately, experimental science was not yet born and some of Aristotle's views were not checked experimentally. Do you know that Aristotle once stated that women have fewer teeth then men, and no one even bothered to verify his statement? His influence was so great that even today, a person who shows off or acts too smart is rebuked: 'Who do you think you are—Aristotle?'

Before you criticize Aristotle for his mistakes, remember that he was the pioneer of organized research. At one time, with the support of Alexander the Great, he had nearly one thousand people working for him in Greece and Asia, collecting material for his 'natural history'. As H.G. Wells observed, ' . . . nothing of the kind had ever been attempted, had even been thought of, as far as we know, before his time. . . . The students of the Lyceum under his direction made an analysis of 158 political constitutions.'(3) Endowed with a remarkable intellect combined with strong common sense and various organizational skills, Aristotle pioneered efforts in the western world to acquire and systematize information.

and copper, became the main medium of exchange. Gold thus gained further value and importance. Efforts were, therefore, made to search for natural gold and also to convert other baser metals like iron and copper into gold. In the middle ages, alchemists (the forerunners of modern chemist) began to search for the mythological *Philosophers' Stone* which they believed could change base metals into gold.

Around AD 800, an Arabian alchemist, Jabir, suggested that all the metals were made of sulphur and mercury. This theory does not seem all that absurd when one remembers that many metals occur in nature as sulphides and that heating these sulphides produces sulphurous fumes and, often, free molten metal which resembles mercury.

Gold

The element gold was among the first few metals known to man. Gold has always been synonymous with beauty, wealth and power. Gold is truly 'noble'. It does not get corroded and can be preserved easily. It was, therefore, considered a symbol of immortality. Unlike other metals which have to be extracted from their ores, often using complex and expensive processes, gold is found in pure form. All one has to do is to collect small particles of gold mixed with soil. Simply wash away the soil and you get gold, or collect gold nuggets if you are lucky. For these reasons, ancient people, especially the rich and powerful collected huge quantities of this element. The following story will give you some idea about the quantities of gold collected by ancient peoples.

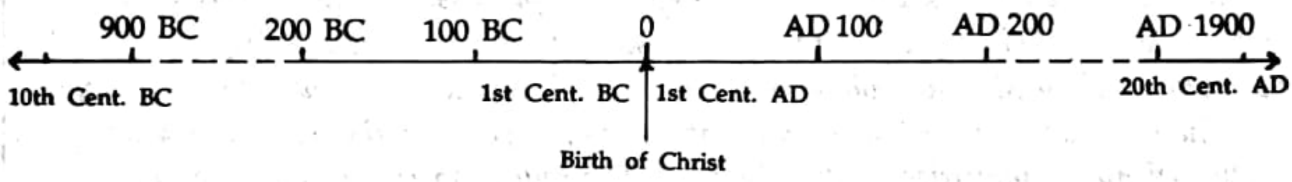
On 6 November 1922, Howard Crater, a British archaeologist, discovered an Egyptian tomb. It was that of Tutankhamun, the boy Pharaoh who died in his eighteenth year, around 1350 BC. He was also known as king Tut, the foremost cultural ambassador of ancient Egypt.

The weight of Tutankhamun's coffin (well over one ton) puzzled Crater. When it was opened, it revealed another coffin decorated with gold leaves and inlaid with a mosaic of multicoloured glass. Inside the second coffin was a third one, made of solid gold. This innermost coffin weighed 1100 kg. (If we take a price of Rs 3000 per 10 g, the approximate value of 1100 kg of gold works out to Rs 33 crores!) Inside the solid gold coffin, lay the mummy of Tutankhamun; this too was covered with a solid gold funerary mask.

Gold has also served as medium of exchange. In ancient times gold was used as currency in international trade. It is interesting to note that even though India never produced much gold, her flourishing trade ensured that gold flowed in from all parts of the world. It is only after the Industrial Revolution in Europe, that the trade began to reverse its direction.

Along with the quest for the Philosophers' Stone, chemistry gained importance as a result of the need for medicines. The growing concern for health and its maintenance generated various views about the elements. People who undertook this search for medicines were referred to as *iatrochemists*. Paracelsus, the famous iatrochemist of the 16th century, suggested that all matter was composed of mercury, sulphur and salt. He considered these substances to be the principles of matter and elevated them to the status of elements.

The 17th century saw the birth of experimental science. It also saw the evolution of the *scientific method*. Natural philosophers (scientists) started performing experiments in laboratories to identify causes of phenomena observed in nature. Robert Boyle (1627–1691), a noted experimental scientist, gave a new definition of an element, which was indeed close to the modern concept. He defined an element as a substance which cannot be broken down into simpler constituents. He stated further that an element combines with other elements to give a compound (which he referred to as a mixture), but it cannot combine with itself to produce a compound (which he referred to as a texture).



How are centuries counted?

Sir Isaac Newton was born in December 1642. In which century was he born? A common mistake is to regard 1642 as being in the 16th century. However, the correct answer is that the year 1642 belongs to the 17th century. If you are perplexed, consider the following example:

Suppose Sunil Gavaskar is batting with (say) 162. Which century is he making? Obviously, the 2nd. Remember the same when you refer to the 17th or 18th century. With this method of counting centuries, it is obvious that we are living in the 20th century and looking forward to the 21st century.

Here's another point to remember: The years of modern calendar are associated with Christ. Periods before Christ are referred to as BC. *Thus, the fifth century* BC *refers to an earlier period than the third century* BC. *That is why, in the case of people who lived in an era before Christ, the year of birth is larger number than the year of death. For example, Alexander the Great was born in 356* BC *and died in 323* BC.

The basis for chemical equations

The work of alchemists had established that in the process of experiments with chemical compounds one could end up with new ones. What exactly was happening in the process? Were new atoms being created? Was matter 'conserved' or was it created or destroyed? This question bothered the chemists of the 18th century.

The conclusive answer came soon after Joseph Priestley discovered oxygen in 1774. Antoine Laurent Lavoisier repeated and modified these experiments to prepare oxygen and to test its properties. He also conducted a series of experiments to settle the conservation issue. Remember that Lavoisier, a true scientist, did not jump to any conclusion on the basis of a single experiment. He conducted a large number of experiments which all pointed to the same conclusion.

Lavoisier took mercury in a sealed glass vessel and weighed it accurately. The vessel was then heated in an oven for 14 days. The mercury in the vessel reacted with the oxygen in the air trapped in the vessel to form red oxide of mercury. Slow heating over 14 days ensured that all the mercury was converted into its oxide. He then allowed the vessel to cool and weighed it accurately. The two weights were exactly the same. No mass had been created or lost. It was also noticed that when the seal of the vessel was broken (carefully to preserve the tiny glass fragments) air hissed through. Obviously, air rushed in to replace the oxygen used in the reaction. Lavoisier carefully weighed the vessel (with the broken glass fragments) to determine the weight of the air that had entered the vessel.

You know that red oxide of mercury heated to high temperature decomposes to liberate oxygen leaving behind only mercury. This Lavoisier achieved by focusing sunlight on the red oxide using a convex lens. The oxygen liberated in the reaction was collected carefully and weighed. It was found that the weight of the oxygen collected was precisely equal to that of the air that had entered the vessel in the first part of the experiment. In other words, mass was conserved in chemical reactions. The experiments of Lavoisier are often mentioned in the context of preparing oxygen. However, the real importance of these experiments lay in providing conclusive evidence for the conservation of mass. In fact, they provided the justification for writing a chemical equation.

These experiments were the first major blow to Aristotle's choice of elements which had gone unchallenged for almost 2000 years. Science no longer depended on written arguments and suppositions. These had to stand the crucial test of experimental verification.

Unfortunately for the science of chemistry, Lavoisier fell an innocent victim to the French Revolution. He died on the guillotine at the age of 50.

In the year 1776, while studying the reactions of an acid on a metal plate, Henry Cavendish (1731–1810) discovered a highly inflammable gas. He collected the gas over mercury and tested its properties. Another scientist, Joseph Priestley (1733–1804), had discovered in 1774 a gas obtained by heating mercuric oxide, in which substances burned more brightly than in air. Antoine Lavoisier (1743–1794), the French chemist, showed that by burning together the inflammable gas discovered by Cavendish and the gas discovered by Priestley, water was produced. Its weight was equal to the sum of the weights of the two gases. Lavoisier named the inflammable gas hydrogen and the other gas oxygen. Thus, supporting Boyle's theory, he concluded that water was a compound of the elements hydrogen and oxygen.

Scientific method

A large number of events occur around us. A stone thrown up first rises and then falls. Sugar dissolves in a cup of tea. Visibility improves after a sharp shower.

What causes such events? We now know, thanks to the efforts of several brilliant scientists, that events such as these occur because of natural forces and properties. It is possible to understand and describe these forces and properties. In other words, we can describe and explain most of events occurring around us. We can also predict some events.

Many thinkers say that this process of generating descriptive and explanatory frameworks is the essence of science. Does that mean that we can know everything? Not at all. For instance, while we generally know why earthquakes occur, we still cannot predict earthquakes. We are also only beginning to learn to predict weather. On the earth and in space, there are still natural events and phenomena which haven't yet been thoroughly understood and explained.

It is scientific method which is the key to these unsolved problems. We should always keep an open mind and be ready to change our descriptive and explanatory frameworks if new information demands such a change. In this book you will come across many examples of scientists changing their views in the light of new information. Remember, this is a continuous process.

What we have said above applies also to social sciences. Why do prices of commodities rise or fall? Why are some nations rich and others poor? Why do groups in a society feel angry and dissatisfied? Why do people go to war? We are just beginning to learn about social forces and understand social behaviour.

Discovery of new elements

The efforts of alchemists and iatrochemists indirectly led to the discovery of several new substances, mainly acids and alkalis. It also helped in the development of various types of apparatus essential for experiments, and in improving experimental skills. The work of Robert Boyle and Lavoisier in the 17th and 18th centuries clarified the nature of elements. With better understanding of the concept of elements and with better equipped laboratories, scientists began to concentrate on discovering new elements.

In the last decade of the 18th century and in the first decade of the 19th century (from 1794 to 1804), the elements chromium, vanadium, niobium, tantalum, cerium, palladium, rhodium, iridium and osmium were discovered. An important invention which enhanced the rate of discovery of elements was Volta's cell. Alessandro Volta (1745–1827) constructed this cell by piling alternate discs of copper and zinc, each pair separately by a piece of cloth soaked in brine (salt water). This cell provided a steady and reliable source of electricity, and placed in the hands of chemists a new and powerful tool for separating elements. Using the cell, it was possible to pull apart positive and negative ions and to deposit them on *electrodes*. In later chapters of this book you will come across more examples of how new inventions and techniques have served basic scientific research.

The English chemist, Sir Humphry Davy (1778–1829), working at the Royal Institute, London, isolated extremely active metals using Volta's cell. In 1807, he isolated sodium and potassium by passing an electric current through molten sodium hydroxide and potassium hydroxide, respectively. He used this technique effectively with compounds of other metals and within a year he was able to isolate calcium, strontium, barium and magnesium. The discovery of sodium and potassium was vital as both these elements are powerful reducing agents. These elements thus enriched substantially the tools of chemists who could use them to reduce several elements from their compounds. Jons Jakob Berzelius (1779–1848) discovered selenium, silicon, zirconium, titanium and thorium, all with the help of potassium as a reducing agent. All these elements, along with boron, lithium, cadmium, aluminium and vanadium, were discovered by 1830.

Who discovered chemical elements?

The history of the discovery of elements is an instructive story that began during prehistoric times when man discovered fire and noticed the carbon from burnt wood left in the forests. Actually, some substances like the seven metals—silver, gold, copper, lead, iron, tin and mercury, and two non-metals—sulphur and carbon, were known from biblical times and even before. But they were not recognized as elements. It is only relatively recently that scientists realized that these substances were elements. All these elements occur either in the free state in nature or in the form of ores composed of compounds that can be decomposed easily using primitive techniques like simple heating or heating in the presence of carbon.

Between the 12th and 15th centuries, that is, in the middle ages, the work of alchemists led to the discovery of elements like arsenic, antimony and bismuth.

Little is known about the individuals who discovered these elements. The first fortunate man to be credited with discovery of a chemical element was German alchemist, Henning Brand (1630–) who in 1669 succeeded in isolating a substance which he named phosphorus. This discovery was an important event in the history of chemistry, as it marked the beginning of a new era, when people started keeping detailed records of their experiments.*

(The year of Brand's death is not known).*

Chemical symbols

From ancient times man has used symbols to denote objects, actions and events, and chemical elements are no exception. The first symbols assigned to elements were pictorial. The simplest ones were those used to represent the four basic elements of ancient times:

Fire	🜂	Air	🜁
Water	🜄	Earth	🜃

In the case of the seven elements known to the ancients, each one of them was paired with a heavenly body and its symbol was fixed accordingly. For example,

Gold (Sun) ○ (Solar disc)

Silver (moon) ☾ (Crescent moon)

Copper (Venus) ♀ (Mirror of Venus)

New symbols were added from time to time. In 1787, J.H. Hassenfratz and P.A. Adet presented new and simplified symbols. For example, in the case of non-metals, simple geometric characters were used:

Oxygen	—	Nitrogen	/
Sulphur	◡	Phosphorus	◠

Circles containing simple abbreviations were used to represent the metals. For example:

Copper	Ⓒ	Iron	(Fe)

Around 1805, John Dalton (1776-1844) used circles with different internal markings as symbols of elements. For example:

Oxygen	○	Sulphur	⊕
Hydrogen	⊙	Nitrogen	⦶

The ultimate credit for developing the symbols used today goes to J.J. Berzelius (1779–1848). He suggested in 1813 that abbreviations of names of elements could be used as their symbols. This simple and powerful idea was soon accepted widely. He suggested certain rules regarding the selection of symbols:

1. In the case of non-metals, the initial letter could be used as the symbol for that element. For example, carbon—C, oxygen—O, hydrogen—H.

2. In the case of elements whose names start with the same alphabets, the symbols should be formulated using the first two letters of the word. For example, silicon—Si and selenium—Se.

3. If the first two letters are found to be common, then the initial letter along with the first consonant which is not common should be used for one of the elements. For example, calcium—Ca and cadmium—Cd.

Even today, many symbols given by Berzelius are in use. Obviously, there has to be a uniformity in the use of symbols. This is now looked after by the International Union of Pure and Applied Chemistry (IUPAC). It has given English names to all the elements but has retained some symbols which originated from the Latin names of those elements. An appreciation of the origin of chemical names of elements is useful in developing familiarity with the shorthand language of chemistry. For example, Antimony—Sb (from the Latin name Stibium). Similarly, Copper—Cu (from the Latin name Cuprum), Gold—Au (from the Latin name Aurum) and Iron—Fe (from the Latin name Ferrum).

The language of symbols

Chemical elements are represented by symbols. For example, phosphorus—P, silver—Ag, sodium—Na. Many of you may wonder whether these symbols are really useful, but if you think about it you'll see that we use symbols not only in chemistry but in several other disciplines; in fact in everyday life. These symbols make our life easier.

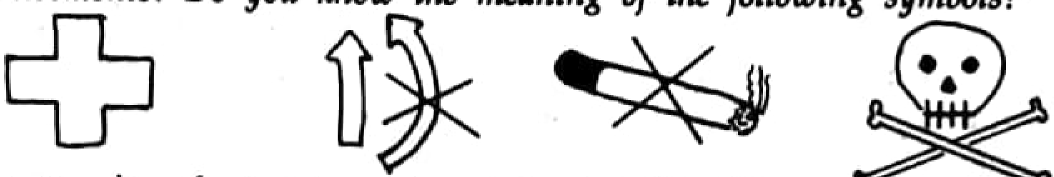
Consider the following statements:

Ram has a few oranges. If you double the number of his oranges, add four to it and multiply the result by three, you get thirty-six. Can you remember this statement? Now, let us put it in symbolic language.

$$3(2x + 4) = 36$$

Is it not a better way of expressing the same statement?

You will notice symbols almost everywhere, on roads, in hospitals and even in advertisements. Do you know the meaning of the following symbols?



However, in order to ensure that a given symbol conveys the same meaning to everyone, it is necessary to agree to some universal convention. What a mess it would be if you wrote Na for sodium while your friend preferred to write So and few others chose Sd!

2. DALTON'S ATOMIC THEORY

While the credit for proposing the first atomic theory goes to the ancient Greek philosophers of the 5th century BC, these ideas were essentially philosophical. Ideas relating to issues such as the nature of matter and the discontinuity versus continuity of matter, were speculative in nature and were debated on the basis of pure logic.

The Atomic School, originated by the Greek philosopher Leucippus (about 400 BC–?) and his student Democritus (about 470—380 BC) thought that matter was discontinuous and the subdivision of matter could ultimately yield an atom, the ultimate indivisible particle. However, this concept was rejected by Aristotle, and his followers supported the continuous nature of matter. In 1650, that is almost 2000 years later, a French philosopher Pierre Gassendi, reconsidered the concept of atom in the context of the behaviour of gases. Both Robert Boyle (in his book *The Sceptical Chemist* in 1661) and Sir Isaac Newton (in his book *Principia Mathematica* in 1687) supported the concept of atoms.

In the early years of the 19th century, John Dalton revived the concept of atoms in his famous atomic theory and supported it with experimental evidence available to him. Dalton's atomic theory is an important milestone in the history of chemistry. John Dalton had before him laws of chemical combinations which were extracted from data collected over the years by alchemists, and which were also based on precise quantitative measurements made by physicists and chemists. All this mass of information made sense only if one assumed that elements are composed of small indivisible particles called atoms (*a*—not, *tomio*—to divide) which participate in a chemical reaction. The genius of John Dalton realized this, and expressed it clearly in three principles:

1. Elements are composed of extremely small indivisible particles called atoms. All atoms of an element are identical with respect to their mass, size and properties.
2. Atoms of different elements have different properties. In the course of chemical reactions, no atom of one element disappears or is changed into an atom of another element.

John Dalton (1766–1844)

John Dalton, an English scientist, was the son of a poor weaver. His formal education was very limited and he was essentially a self-made man. For most of his life he worked as a teacher.

Dalton had varied interests. He began his scientific work in the field of meteorology, keeping systematic weather records every day for almost 46 years, and wrote a book on weather. He was one of the first scientists to study colour-blindness, a subject of considerable personal interest since he himself was colour-blind. But John Dalton is best known for his important contribution to chemistry. He revived the concept of atomicity of matter and put forward his famous atomic theory. There is, however, an important difference between Dalton's theory and the philosophical views of the ancient Greek thinkers. Dalton's theory of atoms 'explained' the laws of conservation of mass. Also, the law of definite proportions followed as a logical consequence of Dalton's theory. It stood yet another crucial test. It was able to predict the law of multiple proportions.

During the years in which Dalton was carrying out his researches in England, the soldiers of the British East India Company were busy extending and strengthening their hold on our country. The armies of a number of Indian kingdoms, including those of the powerful Maratha Empire, were reeling back in the face of superior offensive weapons and military organization. When tracing the history of science, it is interesting to occasionally consider what was happening in our country while major scientific developments were taking place elsewhere. Try and do this in some other cases and think about what the comparisons show.

3. A compound is formed when atoms of more than one element combine. In a given compound, the relative number of atoms present will be definite and constant. These relative numbers can be expressed as integers.

Dalton's theory offered a simple explanation for the basic laws of chemistry known earlier.

1. Law of conservation of mass

The law of conservation of mass was put forward by Antoine Lavoisier (1743–1794) in 1785. It states that there is no detectable change in mass in the course of a chemical reaction. Postulate 2 of Dalton's theory explained this law. As atoms are conserved in chemical reaction, mass also is conserved. (Lavoisier designed direct and convincing experiments to demonstrate conservation of mass. See the box, 'The basis for chemical equations', on page 9.)

2. Law of constant proportion

In 1799 it was suggested by Joseph Proust (1754–1826) that a compound, regardless of its origin or method of preparation, contains the same elements in the same proportion of their masses. If the ratio of atoms in a given compound is constant (postulate 3 of the theory), their proportion by mass must be fixed, since all atoms of one element have to be identical.

The importance of a theory depends upon its ability to fit in with and explain all the available data, and even more importantly on its ability to predict new observations. Dalton's theory stood both these tests and at the same time was simple and elegant. It explained the law of conservation of mass and the law of constant proportion. Dalton used this theory to predict the law of multiple proportion which states that, when two elements combine to form more than one compound, the masses of one element which combine with a fixed mass of the other element are in a simple ratio of small whole numbers.

This law can be illustrated with the help of two compounds of carbon and oxygen, namely, carbon monoxide (CO) and carbon dioxide (CO_2).

The elemental analysis of 1 g of CO shows that it consists of 0.57 g of oxygen and 0.43 g of carbon.

Ratio of oxygen of carbon in CO

$$= \frac{0.57}{0.43} = 1.33$$

That is, 1.33 g of oxygen combines with 1 g of carbon to form CO.

Similar analysis of 1 g of CO_2 shows that it consists of 0.73 g of oxygen and 0.27 g of carbon.
Ratio of oxygen to carbon in CO_2

$$= \frac{0.73}{0.27} = 2.67$$

That is, 2.67 g of oxygen combines with 1 g of carbon to give CO_2.

Thus, in these two compounds the ratio of masses of oxygen that react with 1 g of carbon = 2.67 : 1.33 = 2 : 1 which is a simple integral ratio, supporting Dalton's law of multiple proportion. Dalton assumed that, in the case of carbon monoxide, one atom of oxygen combines with one atom of carbon, while in carbon dioxide, two atoms of oxygen combine with one atom of carbon. That is why we can write carbon monoxide as CO, and carbon dioxide as CO_2.

This law was found to be valid for analytical data obtained by other workers. Another example of the law of multiple proportion is given below:

Compound	*Mass of nitrogen (g)*	*Mass of oxygen (g)*
Nitrous oxide (N_2O)	28	16
Nitric oxide (NO)	28	32
Nitrogen trioxide (N_2O_3)	28	48
Nitrogen dioxide (NO_2)	28	64

Thus the ratio of masses of oxygen that react with 28 g of nitrogen in the case of above compounds is 16 : 32 : 48 : 64. That is 1 : 2 : 3 : 4 which is an integral ratio. This law is of great importance as it firmly supports the theory of the atomic nature of matter.

In retrospect Dalton's atomic theory seems very simple and convincing. However, it had to face two hurdles in its time. Measurements in those days were few and not as accurate and reliable as those of today. The inaccuracies and uncertainties in experiments concerning the law of multiple proportion led to some scepticism. Moreover, atoms could not be seen. The abstract concept of atoms was so far removed from natural 'real' experiences that several decades had to elapse before this concept was accepted. It is interesting to know that a similar fate awaited relativity and quantum theories.

We have seen that Dalton's theory satisfied two conditions. It explained known facts, and it also predicted something new, that is, the law of multiple proportions. Dalton's theory has one more important facet: it stated that all atoms of the same element are identical in size, mass and properties. This statement indicates that *atomic mass* is a clear signature of the element. Quite obviously, size is not immediately useful since atoms are too small to be seen without powerful instruments. But mass can be measured readily. Thus, apart from their chemical properties, elements had one distinguishing property: their atomic mass. It is not surprising, therefore, that John Dalton was the first person to try to determine atomic weights.

3. ATOMIC WEIGHT DETERMINATION

As described earlier, atomic weight became the signature or identification mark of an element. Various people made efforts to determine the atomic weights of elements. Before describing their efforts, it is essential to understand the difficulties involved.

How can one determine the weight of one atom? In daily life, if we wished to determine the weight of (say) one grain of rice or wheat we would simply count one hundred or one thousand grains and weigh them. The rest would be easy. However, the problem of determining atomic weight was not so simple. How does one count atoms? In spite of this hurdle, the scientists of the nineteenth century devised indirect ways of determining atomic weights. Let us study some of their attempts.

Even to compare atomic weights of different elements, it is necessary to know:

(1) the correct formula of a chemical compound, and

(2) the combining weight of an element.

By the early nineteenth century chemists knew how to determine the combining weight of an element by elemental analysis of its compound. However, the correct formulae of compounds were not known. This was a major problem because the concept of the valence of an element was not yet properly understood.

In the absence of knowledge of valence, chemists started working on atomic weight determination by assuming some simple formulae for compounds. While reading about these efforts, it is important to remember that these chemists were groping their way in complete darkness. Credit must be given to them because it was their sustained efforts that ultimately clarified the picture.

Dalton

Dalton was the first person to determine the atomic weights of different elements. He calculated atomic weights on a comparative basis. He chose hydrogen, the lightest known element, and assumed its weight to be one.

Two methods to determine the atomic weights of other elements relative to hydrogen seemed possible:

1. Comparing the weights of an equal number of hydrogen and (say) oxygen atoms. However, Dalton did not know how to take the same number of atoms for two elements.

2. Determining the combining weight of an element with hydrogen.

Dalton used the second method. To find the atomic weight of oxygen relative to hydrogen he used water. It had been established by electrolysis of water that the mass ratio of hydrogen and oxygen in water is 1:8. To start with, Dalton considered two situations:

1. In the first situation Dalton assumed that whenever two elements combine to form a compound they do so in a simple ratio, 1 : 1. Applying this rule to water he assumed the formula of water to be 'HO'.

$$\text{Mass Ratio} = \frac{1}{8} = \frac{\textit{Number of atoms of hydrogen} \times \textit{weight of one hydrogen atom}}{\textit{Number of atoms of oxygen} \times \textit{weight of one oxygen atom}}$$

When one atom of hydrogen combines with one atom of oxygen, number of hydrogen atoms = number of oxygen atoms. So

$$\frac{1}{8} = \frac{\textit{Weight of one hydrogen atom}}{\textit{Weight of one oxygen atom}}$$

Thus, if the atomic weight of hydrogen is one, then according to Dalton, the atomic weight of oxygen is 8.

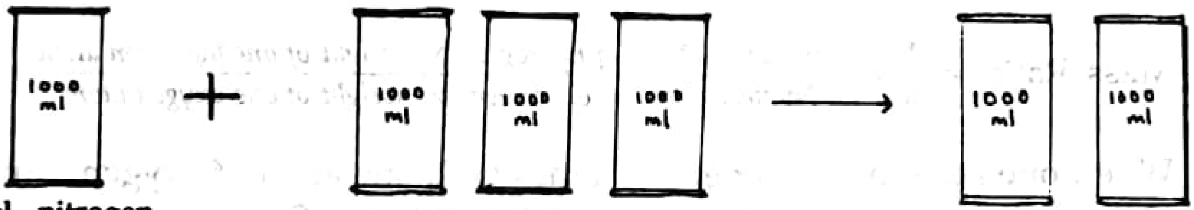
2. Dalton also considered complex situations where two elements A and B combine to form more than one compound. Dalton assumed that nature was simple. The compounds would be of the type AB, AB_2 or A_2B, and not (for example) $A_{13}B_{41}$. Using this procedure he calculated the atomic weights of elements by analysing their compounds.

Dalton was a good theoretical chemist. However, he was not equally skilled in performing experiments (4). Many of his atomic weights had to be modified later. In spite of this shortcoming, Dalton's contribution is regarded (and rightly so) as a milestone in chemistry. It was Dalton who elevated speculative concepts regarding the atomic nature of matter, to the status of a theory. He also gave a method for comparing atomic weights.

Gay-Lussac

While studying chemical reactions in the gaseous phase, Joseph Gay-Lussac noticed that 1000 ml of oxygen gas requires 2000 ml of hydrogen gas to give 2000 ml of water in gaseous form. He further observed that 1000 ml of hydrogen chloride gas reacted with exactly 1000 ml of ammonia gas to give 1000 ml of ammonium chloride gas, whereas 1000 ml of carbon monoxide gas combined with 500 ml of oxygen gas to form 1000 ml of carbon dioxide gas.

On the basis of these observations, in 1808, he formulated the 'law of combining volumes of gases'. It states that the volumes of gases that react with one another, or are produced in chemical reactions, are in the ratios of small integers, provided the volumes are measured under the same conditions of temperature and pressure. In other words, Gay-Lussac would expect,

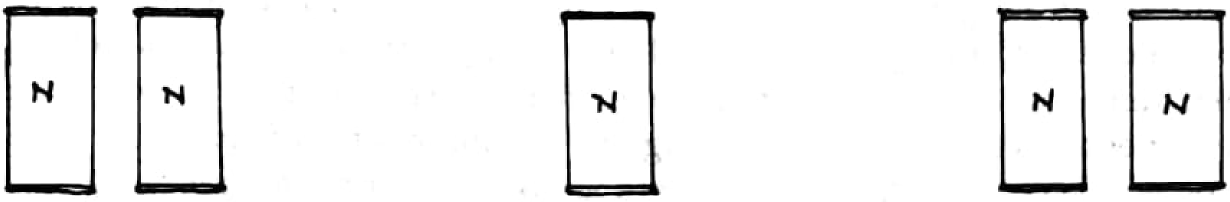


1 vol. nitrogen 3 vol. hydrogen 2 vol. ammonia

But not, for example,

31 vol. nitrogen + 43 vol. hydrogen → 41 vol. ammonia.

We have seen before that mass is conserved in chemical reactions. It is clear from the above reactions that volumes do not obey the conservation law. For example, how do we interpret the process 2 vol. hydrogen + 1 vol. oxygen → 2 vol. water vapour? If one supposes that equal volumes of all gases under equal temperature and pressure contain the same number of atoms, then this picture becomes somewhat clearer. Let us assume 1000 ml of any gas contain (say) *N* atoms. One can therefore, write the reaction of formation of water vapour as follows:



2000 ml (2*N* atoms) of hydrogen + 1000 ml (*N* atoms) of oxygen → 2000 ml of water vapour (made up of 2*N* atoms of H, *N* atoms of O)

Gay-Lussac (1788–1850)

Joseph Louis Gay-Lussac was a French chemist. Like most scientists of his day, Gay-Lussac was interested in a variety of subjects. One of his interests was studying the composition of the atmosphere. In 1804, he launched a hot air balloon which rose to a height of 23,000 feet (7000 m), a record that remained unsurpassed for 50 years. Remember, there were no remote sensing electronic gadgets in those days. Gay-Lussac himself travelled in a basket attached to the balloon, to collect data.

Gay-Lussac's most important contributions were in chemistry. He studied chemical reactions in the gaseous state, and discovered the famous law of combining volumes of gases. What is so great about this law? It is important to realize that Gay-Lussac pointed out that in cases of gases, volumes (at standard temperature and pressure, of course) are as important as mass! This insight paved the way for the discovery of molecules and Avogadro's hypothesis.*

* *Standard temperature and pressure (STP): 76 cm of mercury and 273°Kelvin*

However, the answer is not all that simple. Even if we suppose that one atom of oxygen combines with two atoms of hydrogen, that is, the formula of water is H_2O, how can we produce two volumes of water vapour? If we have

$$2H + O \rightarrow H_2O$$

then shouldn't we have

2 vol. hydrogen + 1 vol. oxygen → 1 vol. water vapour?

If one oxygen atom had to produce two units of vapour, the oxygen atom would have to split into two. Dalton would not allow this. Nor could he ignore Gay-Lussac's law as it was based on experimental observations. This conceptual difficulty led Dalton to propose that Gay-Lussac's experiments with gases were perhaps not accurate enough.

Avogadro

It was Avogadro who provided the missing link in 1811. Without splitting atoms, he clarified the conflict between Gay-Lussac's observation and Dalton's atomic theory.

Amedeo Avogadro suggested that gas does not exist in the natural state as single atoms. Two or more atoms group together to form a particle which Avogadro called an *elementary particle*. If during a chemical reaction such a particle were to split releasing individual atoms, Dalton's and Gay-Lussac's theories could both be satisfied. Today, we know that Avogadro was referring to *molecules*. Thus, to avoid confusion, we shall refer to Avogadro's 'elementary particles' as molecules. Along with the concept of molecules, he put forward an important hypothesis, now called Avogadro's hypothesis.

Avogadro (1776–1856)

Amedeo Avogadro, an Italian physicist, was born just a few days before the American Colonies declared their independence from Great Britain. Like Dalton, Avogadro worked as a teacher throughout his life. While he taught physics, Avogadro, like his contemporaries, never hesitated to tackle any problem that caught his attention, whatever branch of science it involved.

He excelled in quantitative thinking and used his knowledge of mathematics in his scientific investigations.

Based on Gay Lussac's observations, Avogadro put forward the important concept of molecules. He also proposed a hypothesis which eventually acquired great importance in physics and chemistry. This hypothesis, which is now called Avogadro's hypothesis, states, 'Equal volumes of all gases contain an equal number of molecules under the same conditions of temperature and pressure.'

Avogadro's hypothesis ultimately enabled chemists to establish the correct relative atomic weights of various elements. Unfortunately, Avogadro's hypothesis was so far ahead of its time that he did not receive any credit for this outstanding work in his lifetime.

Today you know that a gram molecular weight of any element or compound contains the same number of molecules, namely, 6.023×10^{23}, a number known as Avogadro's number.

Avogadro's hypothesis states that equal volumes of all gases under the same conditions of temperature and pressure contain an equal number of molecules. That is, if one volume of gas contains *N* molecules under the same conditions of temperature and pressure, the reaction of hydrogen and oxygen to form water vapour can be written as:

2*N* molecules of hydrogen + *N* molecules of oxygen = 2*N* molecules of water

Avogadro suggested that each molecule of oxygen must contain two atoms. This diatomic molecule undergoes splitting and then reacts with hydrogen to form water. Thus,

$$2H_2 + O_2 \rightarrow 2H_2O$$

Do you realize the importance of Avogadro's hypothesis? It solves the difficulty of 'counting' atoms or molecules. Remember the difficulty scientists faced in trying to compare atomic masses. They could not count atoms/molecules since they could not see them. So there was no way of taking an equal number of atoms/molecules of two different elements.

Was Avogadro crazy?

Avogadro's hypothesis is indeed a remarkable example of human brilliance. Remember, our daily experience is very different. Bags of equal size will NOT contain an equal number of grapes, potatoes or pumpkins. Was Avogadro crazy? Not at all. Note that Avogadro was talking of gases. Now, we know that 22.4 litres of any gas at normal pressure and temperature will have exactly 6.023 $\times 10^{23}$ molecules. What is the actual volume of all these molecules?

A typical small molecule has a radius of approximately 1Å (Angstrom, a unit of length, 10^{-10} m or 10^{-8} cm). The approximate volume of one typical molecule (assuming it to be more or less spherical)

$$\frac{4\pi}{3} r^3 \approx 4 \times 10^{-8} \times 10^{-8} \times 10^{-8} \, ml = 4 \times 10^{-24}$$

[The value of π ($\approx$ 3.14) cancels with 3.]

Thus, the physical volume of 6.02×10^{23} molecules will be $6.02 \times 10^{23} \times 4 \times 10^{-24}$ ml, which is approximately equal to 2.4 ml. This is just about a spoonful. The molecules are spread over the entire 22.4 litres at STP because they are in a gaseous state—they are darting around at high speed, colliding among themselves and with the walls of the container. They are not idle.

Going further than Avogadro's hypothesis, we now know that one gram mole of any substance in any form will have 6.023×10^{23} molecules. However, if we wish to take the same number of (say) sugar or salt molecules, we cannot go by volume. We have to go by weight.

Avogadro solved this problem for gases. Equal volumes of any two gases under identical conditions of temperature and pressure have the same number of molecules. This discovery was, therefore, very useful in determining atomic weights.

According to Avogadro, Gay-Lussac's observation was correct and the molecular formula of water should be H_2O. The atomic weight of oxygen, therefore, comes out to be 16 on the basis of Avogadro's hypothesis, and not 8, as calculated by Dalton.

Unfortunately, Avogadro's hypothesis met the same fate as that of Gay-Lussac, and practically nobody paid much attention to it until it was revived by Stanislao Cannizzaro (1826–1910) and was used effectively for atomic weight determination.

Berzelius

Let us come back to the story of determining atomic weights. Berzelius's contributions to chemistry, namely the discovery of a number of elements and the development of symbols for chemical elements, have been discussed earlier. He also made important contributions towards the determination of atomic weights. A comparison of the atomic weights determined by Berzelius with their modern values exhibits the remarkable accuracy of his measurements in most cases.

Berzelius realized the importance of Dalton's atomic theory. He felt that if this theory was confirmed, it would have a great impact on the progress of chemistry. He also realized that accurate determination of the atomic weights of elements would provide a crucial test for this theory. He, therefore, set out to solve the problem of atomic weight determination.

To explain Gay-Lussac's observations, Berzelius assumed that a unit volume of any gas (assuming equal temperature and pressure) contained the same number of atoms or molecules. The same was suggested by Avogadro in 1811, though there is no recorded evidence to show that they knew of each other's work.

Berzelius combined the experimental results of Gay-Lussac with his own ideas and concluded that the molecular formula for water was H_2O. He then inferred that the atomic weight of oxygen was 16. Berzelius used Gay-Lussac's law as a guideline and undertook a study of various compounds of different elements. He used the concept of analogy to assign a formula to a compound and proceeded to determine the atomic weights of various elements. For example, by analogy of sulphides and oxides, he assumed the formula of hydrogen sulphide to be H_2S like H_2O. By extending his studies to selenium and tellurium which indicated their relationships with

Berzelius (1779–1848)

Jöns Jakob Berzelius, a Swedish chemist, made several contributions to the field of chemistry. In fact, he is considered as one of the pioneers of modern chemistry. By meticulous analysis of about 2000 compounds, he obtained accurate atomic weights for most of the known chemical elements. The language of symbols and formulae is based essentially on the system suggested by Berzelius. He also played a major role in the discovery of of several elements and contributed to the development of electrochemistry.

At the age of 29, Berzelius was elected to the Stockholm Academy of Sciences. He was honoured on his wedding day with the title of Baron by the king of Sweden, Charles XIV.

sulphur, he assumed their hydrides to be H_2Se and H_2Te respectively. Berzelius had to work with gases since Gay-Lussac's law is applicable only to gases. He also had to study compounds containing hydrogen (whose weight was taken as the standard).

Choice of hydrogen as the reference element meant that Berzelius's work had to be confined to a few elements that combine with hydrogen to form hydrides. What about the elements that did not form hydrides? Berzelius therefore changed his reference from hydrogen to oxygen, whose atomic weight was already inferred as 16. From the determination ofthe elemental composition of oxides by chemical analysis, one can find the atomic weight of an element provided the formula of its oxide is known. Berzelius assumed certain rules to arrive at the formulae of oxides. Chemists of that era believed that if two elements A and B combined to form a compound, they did so in simple ratios like AB, AB_2 or A_2B. Berzelius extended this list to include AB_3, AB_4 and also A_3B and A_4B, but insisted that either A or B must be one. Thus, Berzelius extended the ideas of his colleagues, but ignored, to begin with, the possibility of combinations like A_2B_3.

Subsequently, Berzelius filled this lacuna. After 1818 he made an exhaustive study of oxides. He prepared oxides of different elements and then analysed them for their oxygen and metal contents. Altogether, he analysed almost 2000 compounds, and each several times. This gives us some idea of the enormous amount of work that he carried out for the careful determination of atomic weights.

In 1819, two important discoveries were made in physical chemistry which were exploited fruitfully by Berzelius for atomic weight determination. These were:

(1) the law of Dulong and Petit, and
(2) the law of isomorphism.

Law of Dulong and Petit

The relationship between the specific heat and the atomic weight of an element is known as the Law of Dulong and Petit. It was published in 1819 by two French scientists, Pierre Dulong (1785–1838) and Alexis Petit (1791–1820).

Dulong and Petit noticed that in the case of elements in the solid state, especially metals, the product of specific heat and atomic weight was a constant. (The specific heat of a substance is defined as the amount of heat required to raise the temperature of one gram of the substance through 1°C.)

The results obtained by Dulong and Petit are shown below:

Element	*Specific heat cal/°C/g*	*Atomic weight O=1g*	*Product of atomic weight and specific heat cal/°C*	*Atomic weight O=16g*	*Product of atomic weight and specific heat cal/°C*
Bismuth	0.0288	13.30	0.3830	209.0	6.0
Lead	0.0293	12.95	0.3794	206.0	6.1
Gold	0.0298	12.43	0.3704	197.0	5.9
Platinum	0.0314	11.16	0.3740	195.0	6.1
Tin	0.0514	7.35	0.3779	119.0	6.1
Silver	0.0557	6.75	0.3759	108.0	6.0
Zinc	0.0927	4.03	0.3736	65.4	6.1
Tellurium	0.0912	4.03	0.3675	128.0	11.7
Copper	0.0949	3.957	0.3755	63.5	6.0
Nickel	0.1035	3.69	0.3819	58.7	6.1
Iron	0.1100	3.392	0.3731	55.8	6.1
Cobalt	0.1498	2.46	0.3685	58.9	8.8
Sulphur	0.1880	2.11	0.3780	32.1	6.0

Note that Dulong and Petit took the atomic weight of oxygen as 1. If, however, they had used the correct atomic weight, that is 16, the product of atomic weight and specific heat would be about 6 cal/°C as shown in the last column. In the above table the products for elements tellurium and cobalt differ from the constant, that is, from 6 cal/°C. This was due to the fact that Dulong and Petit had incorrectly estimated the values of specific heats for these elements.

Even though the law was an empirical one (that is, there was no theoretical proof or explanation available), Dulong and Petit suggested that it could be used for the determination of approximate atomic weights. To determine the atomic weights of the element, it would be enough to know its specific heat.

Berzelius used this law to cross-check the atomic weights he had obtained by chemical methods of analysis. In some cases he noted discrepancies, that is, his value of atomic weight × specific weight did not tally with the table of Dulong and Petit. In such cases, Berzelius changed the formula of oxides of certain metals from XO_2 to XO (X=metal) and obtained the correct atomic weights for metals like gold, zinc, lead, copper, iron and tellurium.

What does the law suggest? The law indicates that the same amount of heat (that is, 6 cal) is required to raise the temperature of one gram atomic weight of an element through 1°C irrespective of whether the element is gold, copper, lead or iron. It means that the heat absorbed depends mainly

Heat capacity and specific heat

Usually the word specific means relative. Thus, density is expressed as weight/volume but specific gravity of any substance is the ratio of its density to the density of water. Since the density of water is 1 g/cm^3, the two numbers, that is, density and speific gravity are the same. However, density is expressed in units, e.g. g/cm^3, while specific gravity is a pure number. Similarly, the heat capacity of a substance is the heat in calories required by one gram of the substance to raise its temperature by 1°C. Specific heat was then defined as ratio of the heat capacity of that substance to the heat capacity of water. Interestingly, the heat capacity of water is the highest, and turns out to be 1. You need 1 calorie of heat to raise the temperature of 1 ml or 1 g of water by 1°C. Once again the two numbers expressing heat capacity and specific heat should be the same, but they would not have the same units. Specific heat would be a pure number. However, these days this difference is dropped and specific heat is defined as heat required to raise temperature of one gram of the material by one degree celsius (cal/g/°C).

on the number of atoms present in one gram atomic weight of the substance and not on the kind of atoms. We now know that one gram molecular weight of any element (that is, one mole) contains the same number of molecules (particles) equal to Avogadro's number, 6.023×10^{23}. We also know that the molecules of metals are monoatomic. That is, in the case of metals, one gram atomic weight will contain 6.023×10^{23} atoms. As the number of particles receiving heat is constant, the product, atomic weight $\times$ specific heat, turns out to be a constant.

Law of Isomorphism

We said at the beginning of this book that chemistry is a fascinating subject. Here is yet another instance where nature reveals its magnificent architecture. You know that several substances crystallize. Diamond is a crystal. Common salt, potassium permanganate, copper sulphate, alum and several other chemicals crystallize. But not all crystals are alike. Some common forms are described in the box on page 32. Do you think that the crystal structure and the nature of the chemical could be related? Why should these two seemingly unrelated things be related? Here is a surprise for you.

Eilhardt Mitscherlich (1794–1863) studied various chemical compounds and their crystalline forms. He found a relationship between crystal forms and chemical composition. From such a study, he inferred the law of isomorphism which states that compounds which form similar types of crystals have similar chemical compositions.

Mitscherlich found that the compounds potassium sulphate (K_2SO_4) and potassium selenate (K_2SeO_4) are isomorphous compounds, that is, they form similar types of crystals (rhombic). He studied the isomorphism between perchlorates and permanganates; arsenates and phosphates, chromates, sulphates and manganates and also among other compounds.

By using this law, it became possible to infer the chemical formula of an unknown compound. For example, suppose we know that potassium perchlorate is isomorphous to another compound which is made of potassium, manganese and oxygen. The chemical formula of potassium perchlorate is known to be $KClO_4$. By using the law of isomorphism, we can infer the chemical formula of the unknown compound to be $KMnO_4$.

This law can also be used for the determination of atomic weights. For example, we want to determine the atomic weight of selenium (Se). The salts potassium sulphate and potassium selenate are found to be isomorphic, that is, they form a similar type of crystal (rhombic). Elemental analysis of these compounds gives the following results:

% of elements	*In Potassium sulphate*	*In Potassium selenate*	
Potassium (K)	44.83%	(K)	35.29%
Oxygen (O)	36.78%	(O)	28.96%
Sulphur (S)	18.39%	Selenium (Se)	35.75%

The total % of weight of potassium and oxygen in potassium sulphate = 44.83 + 36.78 = 81.61.

Similarly, the total % weight of potassium and oxygen in potassium selenate = 35.29 + 28.96 = 64.25.

The law of isomorphism says that isomorphic compounds have similar chemical compositions. In this example, the ratios K:O:Se must be the same. If the proportional weights of sulphur and selenium combining with the same amount of potassium and oxygen are calculated, then it is possible to determine the atomic weight of selenium. We must first of all have the same scale for these ratios.

From the table above, it is clear that 81.61% of potassium and oxygen require 18.39% of sulphur. To calculate the weight of selenium which will combine with the same amount of potassium and oxygen (that is, 81.61%),

$$64.25\ \%\ \text{of}\ (K + O) = 35.75\ \%\ \text{of Se (from he table)}$$

$$\therefore\ 81.61\ \%\ \text{of}\ (K + O) = \frac{81.61 \times 35.75}{64.25} = 45.40\%\ \text{of Se}$$

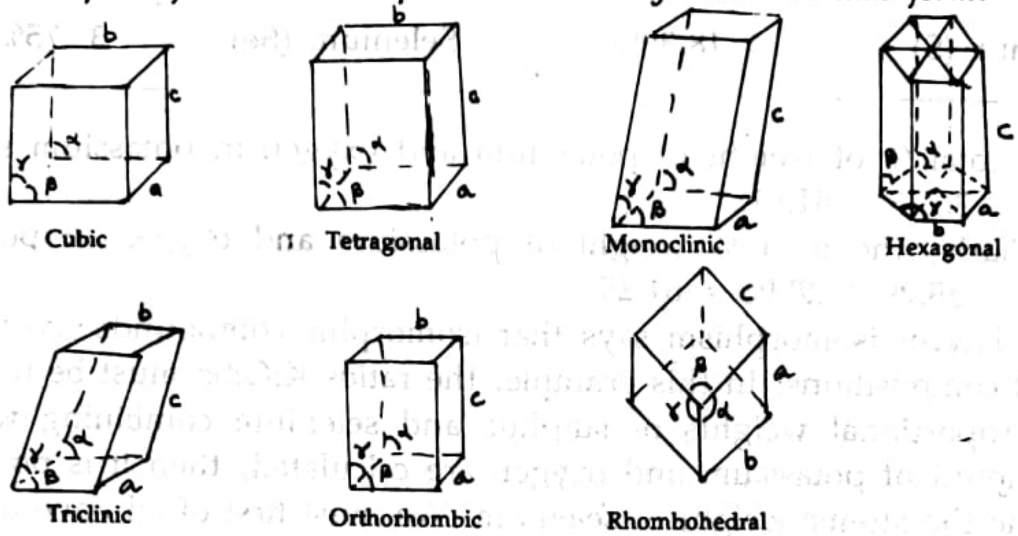
In other words, the ratio of weights of Se and S combining with the same weights of K and O is 45.40/18.40 = 2.47. If we know that the atomic weight of S is 32, we can predict that of Se to be 32 × 2.47 = 79.04.

Remember, in the above calculations, we have not used the actual chemical formulae of the compounds. Do you now realize the importance of the law of isomorphism? With the help of this law, one can calculate the atomic weight of an element without knowing the actual chemical formula of its compound.

Berzelius used this law to correct the chemical formulae of compounds and, hence, the atomic weights of the elements. For example, he observed isomorphism between chromic oxide (Cr_2O_3) and oxides of aluminium, iron and manganese. Using the law of isomorphism, he concluded that the

Common forms of crystals

You are aware that many solids substances like common salt, sugar and potassium permanganate crystallize in different forms. All these different complex crystal forms can be resolved into seven fundamental types of crystals. The following table describes these fundamental forms along with their characteristics. It also gives examples of chemical compounds which crystallize in that form.



Type	Characteristics	Examples
Cubic	a = b = c $\alpha = \beta = \gamma = 90°$	NaCl, KCl
Tetragonal	a = b ≠ c $\alpha = \beta = \gamma = 90°$	MgF_2
Orthorhombic (or rhombic)	a ≠ b ≠ c $\alpha = \beta = \gamma = 90°$	$BaSO_4$ K_2SO_4
Hexagonal	a = b ≠ c $\alpha = \beta = 90°, \gamma = 120°$	$AlCl_3$, graphite
Monoclinic	a ≠ b ≠ c $\alpha = \beta = 90°, \gamma \neq 90°$	Sulphur
Triclinic	a ≠ b ≠ c $\alpha \neq \beta \neq \gamma \neq 90°$	$CuSO_4.5H_2O$
Rhombohedral	a = b = c $\alpha \neq 90°, \beta \neq 90°, \gamma \neq 90°$	Al_2O_3

formulae of the oxides of these elements were Al_2O_3, Fe_2O_3 and Mn_2O_3 respectively. Using these formulae, he recalculated the atomic weights of these elements.

Thus, using Dulong and Petit's law and the law of isomorphism, Berzelius corrected the atomic weights of a number of elements. He published a revised version of the table of atomic weights in 1826. Comparison of this table with the currently accepted atomic weight values reveals the remarkable accuracy of his results. It also reveals the ingenuity of Berzelius, who worked without modern, sophisticated tools and techniques.

As discussed earlier, atomic weight determination used information about the elements that made up a compound as well as the number of atoms of each element in a molecule of the compound, i.e., its molecular formula. From this information, the atomic weight of one element in the compound could be calculated if the atomic weights of the other elements were known.

Dalton calculated the atomic weight of oxygen to be 8 by assuming the molecular formula of water to be HO and the weight of hydrogen to be 1. Further, the work of Gay-Lussac and Avogadro showed that the molecular formula of water was H_2O giving an atomic weight of 16 for oxygen.

The determination of the atomic weight of oxygen was crucial as the weights of many elements could be determined using oxygen as the reference element. This was possible because oxygen forms oxides with almost all the elements. Moreover, unlike hydrides, many of these oxides are stable. By analysing carbon monoxide and carbon dioxide, the atomic weight of carbon was determined. It was found to be 6 if the atomic weight of oxygen was taken as 8, and 12 if the atomic weight of oxygen was taken as 16.

Thus, different assumptions gave different atomic weights for the same element. For these reasons, a chaotic situation existed in the first half of the nineteenth century regarding the atomic weights of the chemical elements.

Cannizzaro

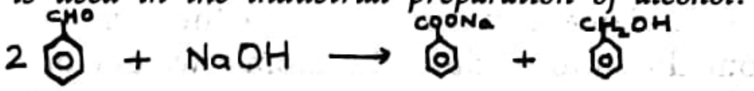
Cannizzaro solved this problem with the help of Avogadro's hypothesis. In 1858, he published a paper which summarized the application of Avogadro's hypothesis for the determination of the molecular weights of gaseous compounds. He also showed how the data on correct molecular weights could be used to calculate the atomic weight of an element present in a compound. Let us see how Cannizzaro utilized Avogadro's hypothesis.

Let us choose equal volumes of the two compounds A and B in gaseous state under the same conditions of temperature and pressure.

Cannizzaro (1826–1910)

Stanislao Cannizzaro, an Italian chemist, made two important contributions to chemistry—one to the field of organic chemistry and the other to the field of atomic science.

He developed a method of decomposing an aldehyde (which is an organic compound) into a mixture of an organic acid and an alcohol. This reaction is today called Cannizzaro's reaction, and is used in the industrial preparation of alcohol.



Benzaldehyde **Sodium benzoate** **Benzyl alcohol**

Cannizzaro was the first person to realize the significance of Avogadro's hypothesis. In 1858, two years after the death of Avogadro, he explained how Avogadro's hypothesis could be used effectively for determining molecular and atomic weights. Cannizzaro's work enabled chemists to determine atomic weights of several elements accurately, which paved the way for later work on the periodic law and periodic table.

In 1891, the Royal Society of Britain recognized his contributions and bestowed the prestigious Copley Medal on him.

. Let M_A = molecular weight of gaseous compound A,
M_B = molecular weight of gaseous compound B,
V = volume of A = volume of B,
N_1 = number of molecules of A present in volume V, and
N_2 = number of molecules of B present in volume V.

Now, the weight of compound A present in volume V is

$$W_A = M_A \times N_1$$

Similarly, the weight of compound B present in volume V is

$$W_B = M_B \times N_2$$

If D_A is the density of A, then

$$D_A = \frac{W_A}{V}$$

Substituting $W_A = M_A \times N_1$

$$D_A = \frac{M_A \times N_1}{V}$$

Similarly,

$$D_B = \frac{M_B \times N_2}{V}$$

Now we can measure the densities and volumes of A and B. M_A can be compared with M_B only if we count N_1 and N_2. But how do you count N_1 and N_2 molecules? You don't need to, if you recall Avogadro's hypothesis. If you take equal volumes, then $N_1 = N_2 = N$ (say).

In the language of algebra,

$$D_A = \frac{M_A \times N}{V} \qquad D_B = \frac{M_B \times N}{V}$$

$$\frac{M_A}{D_A} = \frac{V}{N} \qquad \frac{M_B}{D_B} = \frac{V}{N}$$

$$\frac{M_A}{D_A} = \frac{M_B}{D_B} = K, \text{ where } K = \frac{V}{N}$$

(This is an example of how the use of even elementary mathematics can give us a better insight into a practical problem.)

In other words, the molecular weight of a compound in gaseous phase is proportional to its density.

The constant K can be calculated if the molecular weight and the density of a compound are known. The value of K can be calculated from the data for oxygen, as Avogadro established that oxygen is a diatomic molecule and its atomic weight is 16, that is, its molecular weight is 32.

Cannizzaro observed that one litre of oxygen gas weighs 1.429 g under STP (pressure = 76 cm of Hg, temperature = 273°K), that is, the density of oxygen under STP is 1.429 g/litre. He calculated the value of K.

$$K = \frac{\textit{molecular weight of oxygen}}{\textit{Density of oxygen}}$$

$$= \frac{32}{1.429} = 22.4 \text{ litres}$$

Remember the formula for K was K = V/N where V = volume and N = number of molecules. Hence the constant K should have the same unit as that of volume. Thus, one gram of molecular weight of any gaseous substance occupies a volume of 22.4 litres at STP. This is the most valuable and useful conclusion for the molecular weight determination of gaseous substances. Thus, the molecular weight of any element which vaporizes easily can be found, provided the gaseous density is measured under STP conditions. We noted that the volume of the gas is measured at STP. How do you maintain pressure = 76 cm of mercury and temperature = 273°K in the laboratory? You do not have to. You can conduct your experiment in your laboratory at room temperature and pressure and use the relation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \qquad \begin{array}{l} P = \text{pressure;} \\ T = \text{temperature;} \\ V = \text{volume} \end{array}$$

to convert your measurements to STP. Gases are indeed co-operative!

The density of the compound in gaseous state is then calculated from the weight of the compound taken and the volume in litres calculated under STP conditions. The molecular weight of the compound is found by multiplying the calculated density by 22.4.

Thus, Cannizzaro, first used Avogadro's hypothesis to calculate the molecular weight of an element or a compound which exists in (or can be converted into) a gaseous state. Why are we saying 'exists' or 'can be converted'? There are compounds which will not be in the gaseous phase at room temperature. We can change the temperature and pressure to get them into the gaseous state. Remember, we can use the relation stated above to convert our observations to STP.

For an element which cannot be vaporized easily, Cannizzaro suggested another method for determination of its atomic weight, provided the element forms a number of easily volatilizable compounds. The molecular weights of a number of such compounds are determined by taking their measured densities (g/litre) under STP conditions and multiplying these by 22.4.

According to Cannizzaro, the atomic weight of an element can be determined from the molecular weight of its compound as follows:

An atom is the smallest part of an element which participates in the formation of chemical compounds. The atomic weight, therefore, must be the smallest weight of the element that can be found in the molecular weight of its compound. This is illustrated by the following example:

Suppose we want to calculate the atomic weight of carbon. For this purpose a number of different compounds of carbon which are gaseous or can be vaporized, are selected and their gaseous densities (D) under STP conditions are measured. The compounds chosen are methane, ethane, benzene and chloroform. From their densities under STP conditions, the molecular weights are determined by using the formula $M = KD$, where $K = 22.4$ litres.

Prout's hypothesis

In 1815, William Prout (1785–1850), a British chemist, put forward an important hypothesis which stated that the atomic weights of all the elements were exact multiples of the atomic weight of hydrogen (atomic weight = 1). This hypothesis indicates that Prout probably considered hydrogen to be an integral part of all the elements. The analytical data available at that time were found to support this hypothesis. However, it was essential to determine the atomic weights of elements very accurately in order to test this hypothesis. Prout's hypothesis, therefore, acted as a trigger to intensify the existing efforts aimed at accurate determination of atomic weights.

Jean Stas (1813–1891), a Belgian scientist, started working on this problem around the mid-1850s. He worked for almost a decade and succeeded in determining atomic weights more accurately than any others before him. His work showed that the atomic weights of a number of elements were not integral values. Rejecting Prout's hypothesis, Stas said in 1860, that it was '. . . only an illusion, a pure hypothesis absolutely contradicted by experiments. . . '(5)

Stas's results were accepted as standard for more than fifty years until they were improved upon by Theodore Richards (1868–1928), the first American chemist to win the Nobel Prize in chemistry for his work on atomic weights of chemical elements.

But ultimately, the work done in the beginning of the 20th century showed that the proton, that is, the hydrogen ion H^+, is an integral part of all atoms. Prout had probably guessed correctly and he cannot really be blamed for not distinguishing between the hydrogen atom and the hydrogen ion.

The percentage of carbon is measured by chemical analysis of these compounds and then the weight of carbon per molecular weight is determined. The data obtained are shown in the following table:

Compound	*Density D (g/l) at STP*	*Molecular weight M=22.4×D*	*% of Carbon (C)*	$\frac{\%\,C \times mol.\ wt.}{100}$
Methane	0.715	16.02	74.80	12
Ethane	1.340	30.02	79.80	24
Benzene	3.480	75.95	92.30	72
Chloroform	5.340	119.62	10.05	12

Now in the last column, the weight of carbon present in each molecule of the different compounds is shown. According to Cannizzaro the smallest of all these must be the atomic weight of carbon, and hence 12 is the atomic weight of carbon.

Another example is that for chlorine.

Compound	*Density D (g/l) at STP*	*Molecular weight M= 22.4×D*	*% of Chlorine (Cl)*	$\frac{\%\ Cl \times mol.\ wt.}{100}$
Ethyl chloride	2.88	64.51	55.0	35.48
Carbon tetrachloride	6.38	152.99	92.20	141.05

Reasoning in the same way as above, the atomic weight of chlorine is found to be 35.48.

The knowledge of the atomic weight of an element enables us to calculate the number of atoms of that element present in the molecule of a given compound. For example, ethane will contain 2 atoms of carbon (as the atomic weight of carbon is 12 and the total weight of carbon present is 24), benzene will contain 6 atoms of carbon, and carbon tetrachloride will contain 4 atoms of chlorine (as the atomic weight of chlorine is 35.48 and the total weight of chlorine is 141.05)

In the development of methods for the determination of atomic weights of elements, Cannizaro's contributions are very important. Reliable atomic weights of elements led to further progress in chemistry, as will be discussed in the next chapter.

4. THE KARLSRUHE CONGRESS

The discussion in the previous chapter gave us some idea about the problems which existed with respect to the determination of atomic and molecular weights in the first half of the nineteenth century. We know that two elements, hydrogen and oxygen, were used as reference elements for determination of atomic weights. Oxygen was used more widely as it forms compounds, that is, oxides, with almost all other elements. But unfortunately, different people assigned different atomic weights to oxygen, for example, 8 (Dalton), 16 (Gay Lussac and Avogadro) and 1 (Dulong and Petit.)

As atomic weights of other elements were determined with respect to oxygen, these also varied when different values of the atomic weight of oxygen were assumed. For example, the atomic weight of carbon determined by analysis of its oxides led to two values:

(a) 6, when the atomic weight of oxygen was taken as 8, and

(b) 12, when the atomic weight of oxygen was taken as 16.

Thus, for the same element, different atomic weights were used by different people.

Apart from this confusion in atomic weights, another source of error was the use of the equivalent weight of an element rather than its atomic weight. (This error was a result of the fact that equivalent weight can be found more easily by experiment than atomic weight).

Another problem was the lack of a clear understanding of the valence of an element, hence the molecular formula proposed for a single compound varied widely, so much so that, around 1860, Friedrich Kekule listed 19 different formulae for acetic acid. For example, $C_4H_3O_2 + H_2O$, $C_2O_3 + C_2H_3 + HO$, $C_4H + H_3O_4$. All these problems became critical around the middle of the nineteenth century. It had become essential for chemists to come together to resolve them. This was the main objective of the first International Congress of Chemists which was held at Karlsruhe in Germany on 3 September 1860. Fredrich Kekule, an eminent chemist, was the main spirit behind the Congress. Almost all the renowned chemists of the day, including Stas, Berzelius, Bunsen, Cannizzaro and Dumas, participated in the Congress.

What is a Standard?

In everyday life we use the second, the metre and the kilogram as standard units of time, length and mass, respectively. In this book you have seen how chemists tried several alternatives to provide a standard unit of atomic weight. Why did they have to do this?

An element whose atomic weight could be used as a standard unit had to have several virtues. Firstly, it had to be an active element, forming compounds with several other elements. Secondly, it had to be light enough so that other weights could be expressed as easy multiples. (You cannot use kilograms in goldsmith's shop!) Hydrogen was the lightest element, but not many elements formed hydrides. Oxygen was active and many elements formed oxides, but it was a little too heavy. Carbon, too, formed many compounds. Should they have tried carbon?

Just to get an idea of the problem, you can play the following game. Imagine that you are in a grocer's shop, and that the weighing balance is available but the standard weights are missing. Can you construct standard weights from items in the shop so that you can carry on the business? Here are some hints. You may discover that toothpaste tubes come in three or four sizes and that tubes of the same size weigh about the same. Cardboard boxes containing tea can be used similarly. Do cakes of soap have roughly the same weight?

Maybe you can use these items to run the shop and sell rice, wheat and other commodities by weighing them against toothpaste tubes or soap cakes. But how do you choose a standard weight? Why not try a matchbox or a small piece of toffee? The predicament of chemists in the past was not very different.

During the Congress, Cannizzaro explained and emphasized the effective use of Avogadro's hypothesis for molecular weight and atomic weight determination. A pamphlet setting out the atomic weights of elements derived on the basis of Avogadro's hypothesis was also distributed to all the participants. Even though Cannizzaro's explanation was not approved immediately, it had a great impact on the chemists present at the Congress. Both Lothar Meyer and Mendeleev, who eventually shared the honours for the discovery of the periodic table and the periodic law, were present at the Congress. Lothar Meyer, who was profoundly impressed by Cannizzaro's explanation, described the effect it had: '. . . The scales fell from my eyes, uncertainty vanished and in its place came a feeling of calmest assurance. . . '(6).

Equivalent Weight

The concept of equivalent weight is rather important. Consider, for example, two compounds, NaCl and $MgCl_2$. We can say that 23 g of Na combine with 35.5 g of Cl. Now, if we wish to compare the abilities of Na and Mg to combine with Cl, we will have to note that 24 g of Mg combine with 71 g of Cl. Normalizing with respect to 35.5 g of Cl, the equivalent weight of Mg will be half of 24, that is, 12.

Such a concept of equivalence is not used only in chemistry. It is used also in a variety of other disciplines. For example, you know that the water equivalent of a copper calorimeter is the weight of the calorimeter × 0.1 which is the specific heat of copper. In other words, 100 g of copper will be equivalent to 10 g of water, in that both will need 10 cal to show a temperature rise of 1°C. However, that does not mean that you can buy 100 kg of copper by bartering 10 kg of water! All statements about equivalence are in relation to something specific. Equivalence and equality are very different concepts.

In daily life we use the concept of equivalence. When you are told (look up your text-book on arithmetic) that 10 men, 15 women and 30 children are equivalent, one is referring to their ability to do work. In some other context like rail-fare, an infant would be equivalent to zero, while a ten-year-old child will be equivalent to half and a man or woman will be equivalent to one.

At present, one US dollar is equivalent to about 30 Indian rupees and one British pound sterling is equal to about 50 Indian rupees. How does one get this equivalence? It is arrived at on the basis of trade. If we want to import large quantities of goods from (say) the USA, and we do not export goods to the USA in comparable quantities, then the dollar will become more valuable in terms of rupees. On the other hand, if a country has to buy many goods from us and has nothing to sell to us, the value of our rupee will rise with respect to the currency of that country. Do you think that the value of the rupee will increase substantially if India finds large deposits of oil?

The meaning of the terms 'atomic weight' and 'molecular weight' became clear from Cannizzaro's explanation. Uncertainties regarding the atomic weights of most of the elements vanished. With the availability of accurate molecular weights (from Cannizzaro's work), it also became possible to distinguish between the empirical and the molecular formula of a compound. Thus, the chemists of the nineteenth century came together, exchanged ideas, clarified fundamental concepts like those of molecular and atomic weights and paved the way for further progress in chemistry.

Molecular and empirical formulae

Consider the following example:

Elemental analysis of an unknown compound shows that it contains 40% carbon, 6.67% hydrogen and 53.33% oxygen. The molecular weight of the compound was found to be 180. We also know that the atomic weights of carbon, oxygen and hydrogen are 12, 16 and 1 respectively.

Using this information, we wish to determine the molecular and empirical formulae of the compound.

Let us first calculate the weight in grams of individual elements present in 180 g of this compound.

Grams of carbon present = molecular weight × % of carbon

$$= 180 \times \frac{40}{100} = 72 \text{ g}$$

Grams of oxygen present $= 180 \times \frac{53.33}{100} = 95.99 \text{ g} = 96 \text{ g}$

Grams of hydrogen present $= 180 \times \frac{6.67}{100} = 12 \text{ g}$

To know the number of atoms of carbon present in a molecule of given compound, use the following relation:

$$\text{Number of atoms} = \frac{\text{grams of carbon}}{\text{atomic weight of carbon}} = \frac{72}{12} = 6$$

Similarly, number of oxygen atoms $= \frac{96}{16} = 6$

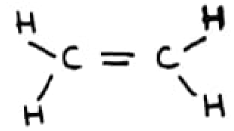
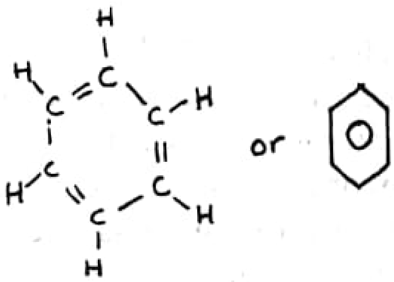
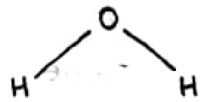
Number of hydrogen atoms $= \frac{12}{1} = 12$

The given compound can now be represented as $C_6H_{12}O_6$.

This formula which shows the number of atoms of different elements present in a molecule of a given compound, is called the molecular formula of the compound.

Now, consider the proportion of different elements in a given compound, that is, the ratio C:H:O = 6:12:6 or 1:2:1. If we are not interested in the molecular weight of the compound and wish to consider only the relative proportion of elements forming the compound, we can say it is of the type CH_2O. *Such a formula is called the empirical formula of the compound. In some cases, the molecular and the empirical formula would be identical (for example* H_2O, CO_2, *HCl). If you are interested in knowing the arrangement of atoms of different elements in the molecule of a given compound, you need yet another formula called the structural formula of the compound.*

Examples of Structural Formulae

Name	*Empirical formula*	*Molecular formula*	*Structural formula*
Acetylene	CH	C_2H_2	
Benzene	CH	C_6H_6	
Water	H_2O	H_2O	

What is the significance of this account of Karlsruhe Congress? It showed that the leading chemists of that era were not only ingenious and hard-working, they also exhibited what is now called a scientific attitude. They came together, exchanged views and settled their differences in opinions and beliefs. In the face of new evidence, they were willing to discard their old theories for newer, more correct ones. The need to question and improve on existing ideas is the basis of all scientific progress.

5. THE PERIODIC TABLE

ATTEMPTS PRIOR TO 1860

By 1860, 60 to 63 chemical elements were known. Moreover, chemists knew with certainty which substances were elements and which were compounds. The atomic weights of elements were also known fairly accurately due to the work of several chemists. While studying the physical and chemical properties of elements and compounds, chemists had also noticed that some elements exhibited similar properties. For example, sodium, potassium and rubidium were all very active, reacted violently with water and formed hydroxides, and were strong reducing agents. Similarly, flourine, chlorine, bromine and iodine were strong oxidizing agents. Moreover, chemists had also noted that elements having similar properties replaced one another rather easily in chemical reactions. For example, calcium, strontium and barium have similar properties and calcium can be replaced easily by strontium.

With the clarification of various concepts like atomic weight and molecular weight and with the settlement of issues like standardization and choice of reference element (oxygen = 16, hydrogen = 1), scientists turned their attention to other unsolved problems in chemistry. One such problem was why some elements had similar properties. As a first step, some scientists thought they could use the tool of classification to get a better insight into the properties of elements.

Even before these issues were resolved, attempts at classifying chemical elements were made as early as 1829, by a scientist called Johann Döbereiner (1780–1849). He identified groups of elements having similar properties. He further noticed that each group had three elements and called them triads. He found that when the elements of the triad were arranged according to increasing atomic weights, the atomic weight of the middle element was approximately the average of the atomic weights of the remaining two elements. Some of his triads were lithium, sodium and potassium; sulphur, selenium and tellurium; chlorine, bromine and iodine. It was also possible to infer the properties of the middle element from the properties of the other two elements. This finding is illustrated by the following example:

Property	*Calcium*	*Barium*	*Strontium*	
			Mean	*Actual*
Atomic Mass	40.00	137.30	88.70	88.60
Density (g/cm^3)	1.60	3.50	2.55	2.60
Melting point (°C)	850	704	777	770
Boiling point (°C)	1490	1638	1564	1370

Döbereiner published his law of triads in 1829. By 1843, ten different triads were found. However, three tetrads and even one pentad—nitrogen, phosphorus, arsenic, antimony and bismuth—were also identified. The concept of grouping elements with similar properties looked promising, though the number three lost its magic.

But all these efforts before 1860 had little success, mainly because the confusion regarding atomic weights of chemical elements was yet to be clarified.

CLASSIFICATION OF ELEMENTS AFTER 1860

Begauyer de Chancourtois

The first post-Karlsruhe Congress attempt to classify chemical elements was made in 1862, just two years after the Congress was held. It is a pleasant surprise that it was made, not by a chemist, but by a geologist called Chancourtois.

In his model, Chancourtois arranged the elements on a line or helix that descended at an angle of 45° from the top of the cylinder. If you draw such a line on a right circular cylinder, you will find that it forms a helix like a winding staircase. In order to place elements on this line, Chancourtois decided to divide the circumference of the cylinder into sixteen parts, since oxygen = 16 was used as a reference element. He expressed the atomic weights of other elements as whole numbers in accordance with Prout's hypothesis.

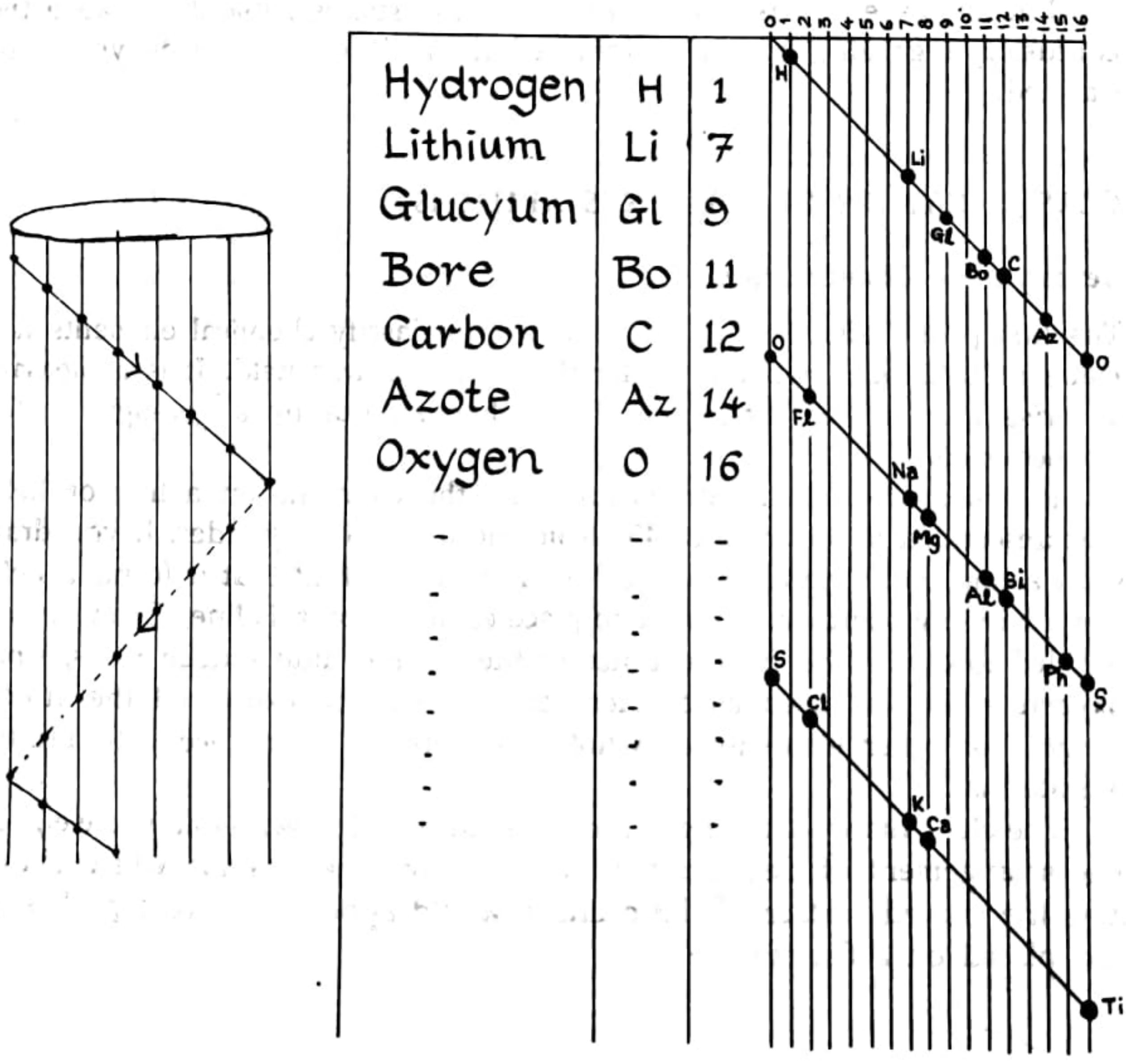
The elements were arranged according to their increasing atomic weights. The arrangement of elements will be clear from the diagram which shows how the curved surface of the cylinder would appear if it were peeled off and placed on a flat surface.

It is clear from the figure that the elements of some triads appeared in one vertical line in the model. But for some other elements the model did not work that well. For example, boron and aluminium were followed by nickel, arsenic, lanthanum and palladium, which did not have similar chemical properties.

Chancourtois called this three-dimensional model the 'Telluric Screw' as the element tellurium was almost at the centre of the model.

The 'Telluric Screw' was a step in the right direction, as it demonstrated the existence of several groups of elements having similar properties. However, it lacked precision as it failed to bring similar elements together in some cases. In other words, Chancourtois had discovered periodicity, but had got the frequency wrong.

When Chancourtois reported his model to the French Academy in 1862, not much attention was paid to it. Thus, his efforts did not gain any contemporary recognition though history now gives him due credit.



Chancourtis's model: cylinder and one-dimensional representation

Chancourtois (1820–1866)

Begauyer de Chancourtois, a geologist, was the first person to try and classify the chemical elements after the Karlsruhe Congress. He had studied classification as a tool, and had applied it to fields such as mineralogy, geology, geography and even philosophy.

Chancourtois was studying the nature and composition of rocks and was looking for a system of simple substances. At that stage his attention was drawn to a book written by one of his colleagues on volcanic and metal-rich rocks. This book discussed the geographical distribution of elements and classified the 59 then known elements according to their electro-positivity. Inspired by this approach, Chancourtois began his work on classification of elements. He systematically collected data for the atomic weights of all 59 elements. He also decided to use whole numbers for these weights in accordance with Prout's hypothesis. Chancourtois then arranged all these elements on the basis of their atomic weights on the curved surface of a cylinder. He called this model a 'Telluric Screw'.

Unfortunately, the contemporary scientific community regarded this Telluric Screw Model merely as an amusing curiosity and did not take it seriously.

John Newlands

John Newlands, a teacher of chemistry and an expert in sugar chemistry, came very close to the crucial understanding of the periodicity of chemical elements.

Newlands presented his paper in March 1866 to the Chemical Society, London. It was promptly rejected by the Society. Dr Olding, the President of the Society stated that they had 'made a rule not to publish a paper of purely theoretical (*speculative*) nature since it was likely to lead to correspondence of controversial character' (7). G.C. Foster, professor of Physics at the University College, London, made a comment ridiculing Newlands and suggested that he might as well try to arrange the elements in alphabetical order (8). If you really try to arrange the periodic table in alphabetical order it will appear as shown in the picture. You can clearly see the futility of such an effort. Suppose Indians had discovered most of the elements and had given them Sanskrit names, the alphabetical order

John Newlands (1838–1898)

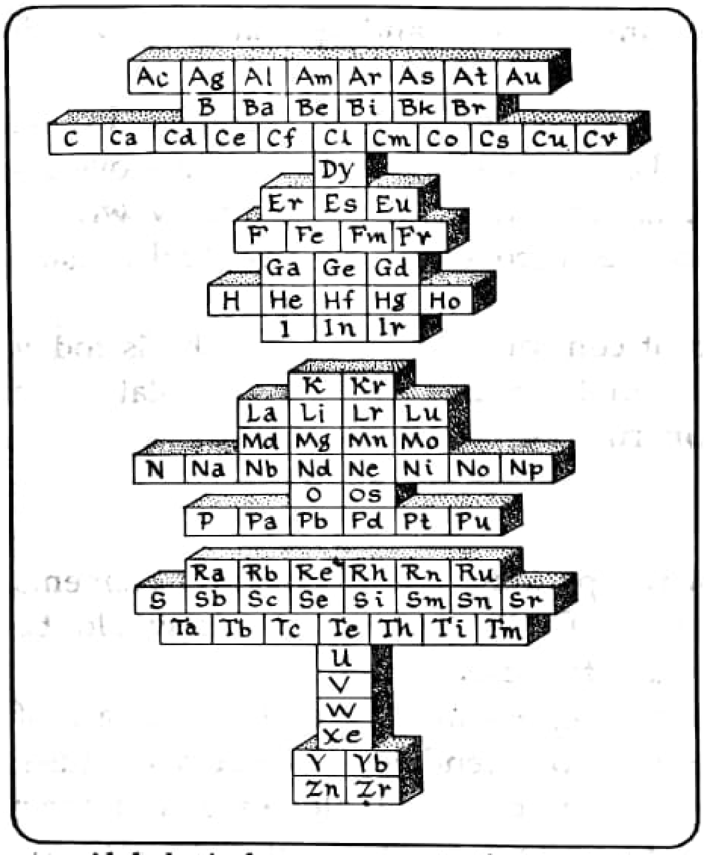
John Alexander Reina Newlands was born in 1838 only a short distance away from Faraday's birthplace (in London). He was educated privately by his father, and developed a love for music from his mother who was of Italian descent. In 1860, he participated in the insurrectionary movement in Italy under Garibaldi. For most of his professional life, he worked as an expert in sugar chemistry.

Even though Newlands did not attend the Karlsruhe Congress, he was among the first people to accept the atomic weights determined by Cannizzaro. He arranged the then known chemical elements on the basis of these atomic weights. In doing so, he observed that the analogous elements differed either by 7, or by multiples of 7. Comparing this relationship with octaves in music, he called it the law of octaves. Newlands thus saw the essential nature of periodicity in the properties of chemical elements even before Mendeleev. However, he could not give his periodic table the necessary finishing touches, like identifying and interpreting the gaps. The history of science is full of examples of brilliant minds who saw the broad outline of a new idea, but who could not give it complete shape. Eventually, the credit goes to the scientist who provides the finishing touches and perfects the theory.

Newlands' contribution to the formation of the periodic table was recognized only 23 years after his first publication. In 1887, he was awarded the prestigious Davy Medal by the Royal Society, London.

would be very different! The classification of chemical elements has to be based on the *properties* of elements, not their names.

Unfortunately, Newlands did not enjoy a high standing among his contemporaries. Discouraged by their attitude he did not pursue his ideas further until Mendeleev's paper appeared in 1869. After the publication of this paper, Newlands staked his claim for credit in the discovery of the periodic law. It was in 1887, almost twenty-two years after Newlands' paper, that his contribution were recognized by the Royal Society which awarded him the prestigious Davy Medal. Similar honours had been bestowed upon Mendeleev and Meyer in recognition of their contributions to the periodic classification of elements five years earlier, in 1882.



Alphabetical arrangement of chemical elements (Source: *Education in Chemistry*, Sept., 1988)

Newlands was among the first to accept the atomic weights suggested by Cannizzaro. He arranged the elements on the basis of these atomic weights. He also numbered these elements and called these numbers ordinal numbers. Newlands noticed that there was a periodicity and that the eighth element exhibited properties similar to the first one. Because of the similarity between the periodicity and octaves in music (which he was fond of), he christened it 'the Law of Octaves'. In August 1865 he published a table of the 62 known elements arranged in eight vertical columns and seven horizontal rows. In 1865-66 he worked on the law of octaves and in March 1866 he published a revised version of the periodic table (see Table 1 on page 59).

Newlands arranged elements in the increasing order of their atomic weights. He placed all his confidence on atomic weights rather than on the elements' physical and chemical properties. His table exhibits several anomalies:

1. Some elements having similar properties are separated from one another. For example, iron is separated from cobalt and nickel and osmium is separated from iridium and platinum.
2. Some elements having different properties fell into the same category. For example, chromium was placed below aluminium, manganese was placed below phosphorus, and tungsten was placed below tin.
3. In addition, incorrect atomic weights for elements like indium (In), cerium (Ce), lanthanum (La), uranium (U), vanadium (V) and gold (Au) resulted in their being put in the wrong place. (Newlands was primarily wrong in the placement of transition elements and rare earths.)

Actually, Newland's earlier table of 1864 showed that he was aware of the existence of certain elements that had yet to be discovered. This table had gaps in it, which Newlands predicted would be filled by newly discovered elements, including scandium, yttrium and germanium, which were actually discovered later.

Unfortunately, Newlands did not pursue this line of thought. In the 1866 table he removed all the gaps. Did he feel that all new discoveries would be fitted into new columns? This, too, did not prove totally wrong, as the inert gases, which were still to be discovered, did eventually make up a separate column.

In any case Newlands' work was of considerable value, and he is today recognized as one of the predecessors of Mendeleev in the formulation of the concept of periodicity in the properties of chemical elements.

DMITRI MENDELEEV

The major credit for the discovery of the periodic law of chemical elements is rightly given to the Russian chemist, Dmitri Mendeleev. It would be interesting to know what Mendeleev did to deserve this credit.

Mendeleev attended the Karlsruhe Congress of 1860 and was aware of the atomic weights suggested by Cannizzaro. Mendeleev began his studies of the chemical and physical properties of chemical elements and their compounds in 1867 when he decided to write a textbook of chemistry. At that time he was a professor of inorganic chemistry at the University of St Petersburg (later and till recently called Leningrad). He decided to group the elements according to their valence with respect to hydrogen (atomic weight 1). In his study of compounds, Mendeleev primarily and very effectively used the law of isomorphism. He grouped the isomorphous compounds together and then inferred their general formula. Such a grouping of isomorphous compounds gave him an idea about analogous elements, that is, elements with similar chemical and physical properties.

Mendeleev was so possessed by these ideas that he prepared 63 different cards, one each for the 63 known chemical elements. He wrote the name, the atomic weight and the chemical and physical properties of each element on a separate card. He shuffled his cards and tried a large number of arrangements which would display the periodicity of elements.

On 17 February 1869, Mendeleev cancelled his visit to a cheese factory (where he was going to investigate the methods used for making cheese) and stayed at home to resolve the problem of the arrangement of chemical elements. On the same day, he succeeded in formulating a system for such an arrangement. The elements were arranged on the basis of increasing atomic weights and the valencies of the elements were represented with respect to the elements oxygen (valence 2) and hydrogen (valence 1). On 1 March, the table was sent for printing, as Mendeleev intended to send copies of it to eminent chemists all around the world. This first table published in 1869 is shown in Table 2. In 1871, Mendeleev published his Periodic Table which is shown in Table 3 (see pages 60–61 for Tables 2 and 3).

Mendeleev stated the Periodic Law: *'Elements placed according to the values of their atomic weights present a clear periodicity of properties.'*

In arranging the elements, Mendeleev utilized two different attributes in two directions, that is, family likeness in the vertical direction and a progression of atomic weights in the horizontal direction. However, he emphasized the family likeness more than atomic weight sequence. Where these two did not match, he openly challenged the existing atomic weights or left vacant spaces in his arrangement. He never sacrificed family likeness for the sake of atomic weights.

He found that the physical and chemical properties of the element indium were similar to those of group III elements. However, the current atomic weight of indium which was 75.6 presented a problem. Mendeleev was confident enough to question the atomic weight which had been calculated assuming the valency of indium to be 2. Mendeleev placed the element indium in Group III. From the available chemical data and by assigning the valency 3 instead of 2, he recalculated the atomic weight of indium to be 113. In retrospect it looks like a very logical decision. After all, atomic weights were being revised all the time, whereas chemical properties were firmly established. But remember, everything looks simple in retrospect! Mendeleev also changed the atomic weights of certain heavy metals. By observing family likenesses, he placed uranium in group VI and thorium in group IV and modified their atomic weights from 116 to 240 and 118 to 231 respectively. Similarly, he placed the element tellurium where it belonged chemically, in the sixth row in group VI, even though this placement caused an anomaly with tellurium (128) coming before iodine (127). To remove this anomaly, he later changed the atomic weight of tellurium from 128 to 125. (See underlined parts of Tables 2 and 3 on pages 60–61).

But what about the vacant spaces? Mendeleev was confident enough to predict that the vacant spaces represented elements yet to be discovered. He even ventured to predict the physical and chemical properties of these absent elements. Sure enough, elements with these predicted properties were eventually discovered.

J. Bronowski in his book, *The Ascent of Man,* brings out the importance of Mendeleev's work in the following words: '. . . The conception of the gaps or missing elements was scientific inspiration. It expressed in practical terms what Francis Bacon proposed in general terms long ago, the belief that new instances of a law of nature can be guessed or induced in advance

Dmitri Mendeleev (1834–1907)

The genius who conceived, nursed and gave the finishing touches to the periodic table was a Russian chemist, Dmitri Mendeleev.

Mendeleev, the youngest child of his parents, was unfortunate enough to lose them in his early childhood. Even so, Mendeleev was greatly influenced by his mother. Later in life, he mentioned the advice she gave him on her deathbed: 'Refrain from illusions, insist on work and not on words. Patiently seek divine and scientific truth.' (9)

Mendeleev followed his mother's advice. After an outstanding academic career, he became a professor of chemistry at St Petersburg University. He soon acquired a reputation as one of the most inspiring teachers in Europe. His book 'Principles of Chemistry', is considered the best Russian chemistry book ever written.

Mendeleev successfully classified the 63 known chemical elements. He emphasized mainly the similarities and differences in chemical and physical properties, and used his outstanding judgement to ignore, where necessary, the atomic weight sequence. His greatest achievements were the decision to leave vacant places in the periodic table for undiscovered elements and to predict their properties. For example, while leaving the gap for gallium, Mendeleev predicted that it would be a metal with a low melting point. His confidence can be judged by the legendary statement attributed to him: 'If I hold it in my hand, it will melt.' Sure enough, gallium is a metal and it melts at 27°C (the temperature of the human body is 37°C). The eventual discovery of these elements and their placement in the very gaps left for them by Mendeleev brings out the fundamental nature of his work. In fact, Mendeleev's periodic table guided chemists in their search for new elements.

The problem that Mendeleev faced was very formidable. It is almost unbelievable that he was able to build the periodic table when atomic structure and the concept of atomic number were yet to be discovered. Try solving the following puzzle and you will appreciate the genius that was Mendeleev:

Once upon a time, a chemistry teacher had a peculiar class of students. There were 30 students in the class. Roll numbers were assigned according to marks scored in a chemistry test in the previous year. Thus, the student with roll number 1 had 95 marks, number 2 had 93 marks, number 3 had 79 marks and so on. It also turned out that roll numbers divisible by 3 belonged to girls, →

while roll numbers divisible by 5 had marks divisible by 10. On the first day only 20 students turned up. The teacher had to seat them according to their roll numbers, leaving appropriate vacant seats for those who had not yet turned up. However, the students did not know their roll numbers. They knew only the marks they had scored and, of course, you could spot the girls. Could the teacher manage to seat them correctly?

This amusing but fictitious puzzle illustrates the nature of the problem that Mendeleev set out to tackle. He had, of course, one advantage. The atomic weights were related to the properties of atoms rather more reasonably than marks were to roll numbers!

from old instances. And Mendeleev's guesses showed that induction is a more subtle process in the hands of a scientist than Bacon and other philosophers supposed. In science, we do not simply march along a linear progression of known instances to unknown ones. Rather, we work as in a crossword puzzle, scanning two separate progressions for the point at which they intersect: that is where the unknown instances should lie in hiding. . . '(10)

Mendeleev provided a perfect example of the above philosophy. For example, according to the then known atomic weight sequence, the element next to calcium was titanium. Mendeleev noticed that titanium had physical and chemical properties similar to those of carbon and silicon. He, therefore, placed titanium below silicon. The place next to calcium was left vacant. Mendeleev interpreted it as the place of an undiscovered element. It represented the first gap in Mendeleev's periodic table. The next two successive gaps were left after the element zinc. Mendeleev was sure that three undiscovered elements with properties similar to those of boron, aluminium and silicon, respectively, would eventually fill the gaps left for them. He was so sure that these elements would exhibit properties similar to boron, aluminium and silicon, that he decided to name them (even before birth) as eka-boron, eka-aluminium and eka-silicon. It is interesting to note that Mendeleev turned to Sanskrit to select the prefix *eka* meaning one. Today we know that eka-boron is scandium, eka-aluminium is gallium and eka-silicon is germanium.

In 1875, Boisbaudran, a French spectroscopist, discovered a new element by emission spectroscopic analysis. He named it gallium. Surprisingly, the properties of this element were found to match exactly those predicted by Mendeleev for the element eka-aluminium, except for density (gallium—4.7 g/cm^3, eka-aluminium—5.9 g/cm^3). But Mendeleev was so confident about his value that he asked Boisbaudran to re-determine the density. Boisbaudran did this and found that value was was actually 5.956 g/cm^3 (see Table 4 on page 61).

Such precise agreement between Mendeleev's predicted properties of eka-aluminium and those of gallium elevated Mendeleev's periodic law and periodic table from a mere laboratory curiosity to the status of a prestigious theory capable of explaining what was known and making verifiable predictions of the unknown. In science, the predictive ability of a hypothesis and subsequent confirmations of such predictions signify real success.

Subsequent discoveries of scandium, (that is, eka-boron) by Nilson in 1879, and of germanium (that is, eka-silicon) by Winkler in 1886, and the agreement between their predicted and actual properties, reinforced the value of the periodic law (see Tables 5 and 6 on page 62).

Mendeleev formulated his periodic table in 1871 when 63 elements had been discovered. New elements discovered subsequently had appropriate places waiting for them. However, at that time, the atom was still undivisible. It was like a billiard ball, with no structure. The concepts of atomic number, the nucleus, the proton and neutron, and hence isotopes, were simply not known. It is thus remarkable that modern understanding of atomic structure led to only marginal changes in Mendeleev's periodic table.

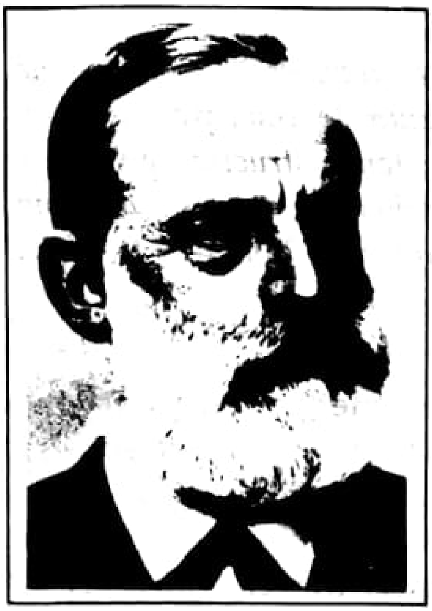
In 1955, tribute was paid to Mendeleev, the father of the periodic table, by naming the 101st element, a man-made one, 'Mendelevium'.

Lothar Meyer

Lothar Meyer, a German professor of chemistry, has also received recognition for the periodic classification of chemical elements as he achieved this independently of Mendeleev.

Like Mendeleev, Meyer too had attended the Karlsruhe Congress in 1860, which prompted him to look for the numerical relationships between the elements. He felt it necessary that a textbook which he was writing should be based on a classification of chemical elements.

In 1864 Meyer published a set of two periodic tables for chemical elements in which the elements were grouped according to their valence. The first table with six columns did not include all the then known elements. For example, Meyer did not include the transition elements like iron, copper, manganese, vanadium and chromium. Meyer's second table which included mainly transition elements was divided into seven groups. He believed that most atoms in the second table were tetravalent (valence = 4), with a few exceptions. The two systems Meyer proposed are shown in Tables 7 and 8 on page 63.



Lothar Meyer (1830–1895)

Lothar Meyer was a German chemist who independently discovered the periodic law and the periodic table. He began his career as a science teacher holding various appointments until he became professor of chemistry. Lothar Meyer tried to arrange the elements on the basis of atomic weights. Interestingly, he took into account (like Mendeleev) the chemical properties of elements, and went one step ahead to study the physical properties of elements. In 1864, he formulated his first periodic table.

The most important feature of Meyer's work is his study of the physical properties of elements. He plotted a graph of atomic volume as a function of atomic weight. The graph (shown later in this section) clearly revealed the periodicity of elements with respect to atomic volume. Meyer also studied physical properties such as compressibility, hardness, and boiling and melting points of analogous compounds as a function of atomic weights.

The Royal Society of London recognized Meyer's contribution to the periodic table and honoured him with the prestigious Davy Medal.

Study of these tables clearly indicates that valence was not the only criterion used for the grouping of elements. Even though Meyer did not make any mention of atomic weight sequence, the elements were arranged according to their increasing atomic weights, as seen in his tables. He also realized that the difference in the atomic weights of analogous elements was either 16 or a multiple of 16.

By 1868, Meyer had prepared a new and consolidated version of the periodic table which incorporated almost all of the then known chemical elements. But unfortunately this was not published until 1895, the year in which Meyer died. This table in which the elements were divided into 15 columns is shown as Table 9 on page 64.

The elements were arranged in increasing order of their atomic weights. The only exceptions to the increasing atomic weight sequence were the elements aluminium, molybdenum, vanadium and tungsten. Actually, Meyer could have placed aluminium (atomic weight 27.3) before silicon or magnesium (see Table 9 on page 64). Why he did not do so is not known.

Transition elements

Transition elements are metals which occur in three rows of the block in the middle of the periodic table we use today, from scandium to zinc, from yttrium to cadmium, and from lanthanum to mercury. Their atomic structure gives rise to their typical properties of variable valency and colour. They are hard and strong, have high melting and boiling points, and are good conductors of heat and electricity.

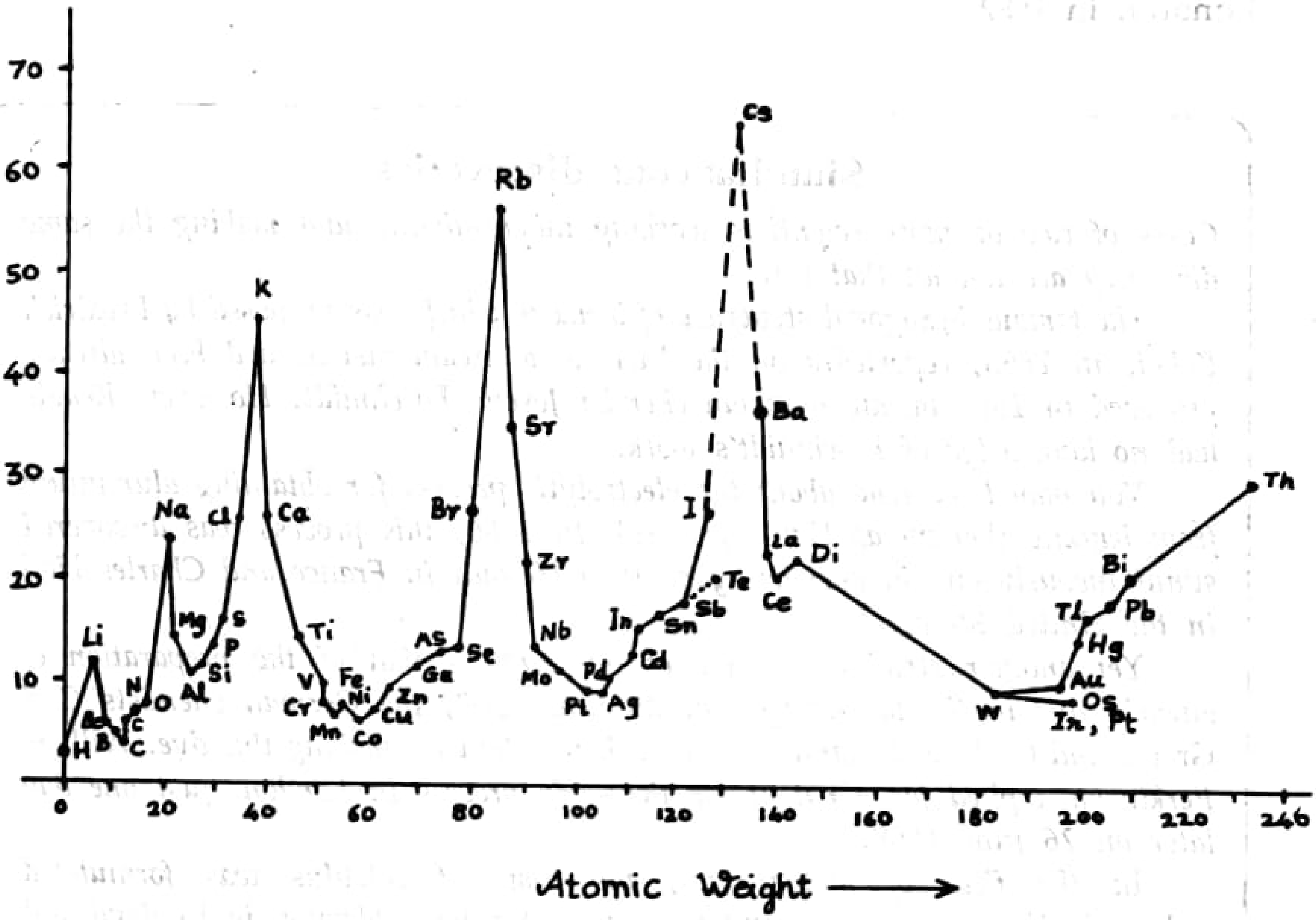
Lothar Meyer published his first article on the periodic system of elements in 1870, that is, one year after the publication of Mendeleev's first periodic table. When he wrote this article, he had already seen a German abstract of Mendeleev's Russian publication. It is, therefore, possible that Meyer may have benefited from Mendeleev's paper. Meyer's own remarks indicated the probability of this. He wrote '. . . The table below is in important aspects, identical to the one given by Mendeleev. . . '(11)

But the fact that Meyer worked independently and that he did not imitate Mendeleev's system can be seen by a comparison of the two tables, that is, Mendeleev's 1869 table and Meyer's 1870 table. (see Tables 2 and 10).

It is clear that both the tables have striking similarities. But unlike Mendeleev, Meyer did not separate the main and sub-group elements. The distinct transition element groups were thus formed in his table. (For example, see Gr. IV or Gr. VI of Table 10 on page 65.) On the other hand, transition elements were placed in various groups by Mendeleev (see Table 2).

Meyer correctly placed the elements mercury and lead as homologues of cadmium and tin, respectively. Mendeleev went wrong in placing these elements as homologues of silver and barium, respectively. Meyer properly placed thallium in the boron group, while it was wrongly placed in the alkaline group by Mendeleev. Meyer changed the atomic weight of indium from 75.6 to 113.4 and placed it in Gr. III. All these differences indicate that Meyer had conceived the periodic table independently of and almost simultaneously with Mendeleev, whose revised version of the periodic table in 1871 does incorporate several positive features of Meyer's table published in 1870. How much they gained from each other will probably never be known. It is best to assume that each arrived at his result independently.

Meyer pointed out that the properties of elements were periodic functions of their atomic weights. He attempted what no chemist had tried so far: plotting a graph of atomic volume vs. atomic weight. The term atomic volume was defined as the ratio of atomic weight and density, using hydrogen as having unit atomic weight and water as having unit density. The periodicity is seen clearly in this graph.



Meyer's plot of atomic volume against atomic weight

Even though Meyer was conservative about changing the atomic weights of elements on the basis of this graph, he did do this in some cases: for example, changing indium from 75.6 to 113. He also studied other physical properties such as specific weight (that is, density), coefficient of expansion, melting point, etc. to show such periodic variations with atomic weights of elements. It is obvious from this discussion that Meyer took both physical and chemical properties into account. In fact, he paid more attention to the physical properties, whereas Mendeleev concentrated on the chemical properties in arranging the elements.

Mendeleev's firm belief in the validity of his periodic law led him to predict unknown elements. Meyer did leave many gaps for undiscovered elements in his table but did not predict chemical and physical properties of these elements. Mendeleev's predictions which came true in a brilliant manner proved the strength of the periodic table and rightly earned him the major credit for the periodic classification of chemical elements.

As independent discoverers of the periodic system, Mendeleev and Meyer were jointly awarded the prestigious Davy Medal by the Royal Society, London, in 1882.

Simultaneous discoveries

Cases of two or more scientists working independently and making the same discovery are not all that rare.

The famous hexagonal structure of benzene which was proposed by Friedrich Kekule in 1865, reportedly on the basis of a dream vision, had been already proposed in 1861 by an Austrian chemist Joseph Loschmidt. However, Kekule had no knowledge of Loschmidt's work.

You may have read about the electrolytic process for obtaining aluminium from bauxite (known as Hall's process). In 1886, this process was discovered simultaneously and independently by Paul Heroult in France and Charles Hall in the United States.

Yet another striking example of this type is that of the preparation of alizarin dye in the laboratory. On 25 June 1869, the German chemists Carl Graebe and Carl Liebermann submitted their patent for making this dye. William Perkinson applied for a patent for the same process in London, just one day later on 26 June 1869.

In the field of mathematics, the basis of calculus was formulated independently and almost simultaneously by Sir Isaac Newton in England and Gottfried Liebnitz in Germany. You perhaps already know that in the 19th century, radio-waves were discovered simultaneously by Sir J.C. Bose and M.G. Marconi, once again independently of each other. When the double helix model of DNA was proposed by Watson and Crick, other scientists like Linus Pauling were about to achieve the same breakthrough.

As chemists gathered valuable information about properties of elements, several scientists attempted to search for a pattern. You can see from examples given in this book that many scientists noted similar patterns simultaneously.

These examples tell you that often a scientist's hard work can remain unknown to the world, and unrewarded by recognition, merely because another scientist happens to publish his or her results earlier. However, a true scientist will be glad to have other scientists working on the same subject, and will not hesitate to share the credit where this is due.

Table 1: Newlands' Periodic Table (1866)

						H^{1} 1
Li^{2} 7	Be^{3} 9	B^{4} 11	C^{5} 12	N^{6} 14	O^{7} 16	F^{8} 19
Na^{9} 23	Mg^{10} 24	Al^{11} 27.5	Si^{12} 28	P^{13} 31	S^{14} 32	Cl^{15} 35.5
K^{16} 39	Ca^{17} 40	Cr^{19} 52.5	Ti^{18} (50)	Mn^{20} 55	Fe^{21} 56	Co,Ni^{22} 58.5
Cu^{23} 63.5	Zn^{25} 65	Y^{24} (64)	In^{26} (72)	As^{27} 75	Se^{28} 79.5	Br^{29} 80
Rb^{30} 85	Sr^{31} 87.5	Ce,La^{33} (92)	Zr^{32} 89.5	Di,Mo^{34} 96	Rh,Ru^{35} 104	Pd^{36} 106.5
Ag^{37} 108	Cd^{38} 112	U^{40} (120)	Sn^{39} 118	Sb^{41} 122	Te^{43} 129	I^{42} 127
Cs^{44} 133	Ba,V^{45} (137)	Ta^{46} (138)	W^{47} 184	Nb^{48} (195)	Au^{49} (196)	Pt,Ir^{50} (197)
Os^{51} (199)	Hg^{52} 200	Tl^{53} 203	Pb^{54} 207	Bi^{55} 210	Th^{56} 238	

Source: *Journal of Chemical Education*, Vol. 26 (1949), pp. 491–96.

Note: It has been mentioned in the 3rd point of discussion on page 49 that incorrect atomic weights of some elements led to the wrong placements in the periodic table. This is especially true for those elements whose atomic weights are given in parentheses (i.e. the atomic weights given in parentheses are incorrect). Why Newlands reversed the order in the case of these elements is not known. Perhaps Newlands might have paid attention to similarities in the properties of elements.

Table 2: System of Mendeleev (1869)

			Ti = 50	Zr = 90	? = 180
			V = 51	Nb = 94	Ta = 182
			Cr = 52	Mo = 96	W = 186
			Mn = 55	Rh = 104.4	Pt = 197.4
			Fe = 56	Ru = 104.4	Ir = 198
			Ni = Co = 59	Pd = 106.6	Os = 199
H = 1			Cu = 63.4	Ag = 108	Hg = 200
	Be = 9.4	Mg = 24	Zn = 65.2	Cd = 112	
	B = 11	Al = 27.4	? = 68	U = 116 *	Au = 197 ?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210
	O = 16	S = 32	Se = 79.4	Te = 128 ?	
	F = 19	Cl = 35.5	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85.4	Cs = 133	Tl = 204
		Ca = 40	Sr = 87.6	Ba = 137	Pb = 207
		? = 45	Ce = 92		
		? Er = 56	La = 94		
		?Yt = 60	Di = 95		
		? In = 75.6	Th = 118?		

* The symbol for element U is Ur in the original table.

Source: (for tables 2 and 3) *Interdisciplinary Science Review*, Vol. 12 (1987), pp. 23–31.

Table 3: Periodic Table of Mendeleev (1871)

Group I R_2O –	Group II RO –	Group III R_2O_3 –	Group IV RO_2 RH_4	Group V R_2O_5 RH_3	Group VI RO_3 RH_2	Group VII R_2O_7 RH	Group IV RO_4 –
H=1							
Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
K=39	Ca=40	?=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56 Co=59 Ni=59 Cu=63
(Cu=63)	Zn=65	?=68	?=72	As=75	Se=78	Br=80	
Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	?=100	Ru=104 Rh=104 Pd=106 Ag=108
(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	I=127 *	
Cs=133	Ba=137	?Di=138	?Ce=140	–	–	–	-- --
(–)	–	–	–	–	–	–	
–	–	?Er=178	?La=180	Ta=182	W=184	–	Os=195 Ir=197 Pt=198 Au=199
(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	–	–	
–	–	–	Th=231	–	U=240	–	-- --

* The symol for element I is J in the original table. Also, valency is represented by superscripts in the column headings of the original table, i.e. R^2O instead of R_2O.

Table 4: Comparison between predicted and observed properties (for eka-aluminium)

Property	Eka-aluminium	Gallium (Boisbaudran)
Atomic weight	68	69.9
Specific gravity	5.9	5.94
Melting point	Low	303.15°K
Formula of oxide	Ea_2O_3	Ga_2O_3
Solubility in acid and alkali	Dissolves slowly in both acid and alkali	Dissolves slowly in both

Table 5: Comparison between predicted and observed properties (for eka-boron)

Property	Eka-boron	Scandium (Nilson)
Atomic weight	44	43.79
Oxide	Eb_2O_3	Sc_2O_3
Specific gravity	3.5	3.864
Sulphate	$Eb_2(SO_4)_3$	$Sc_2(SO_4)_3$

Table 6: Comparison between predicted and observed properties (for eka-silicon)

Property	Eka-silicon	Germanium (Winkler)
Atomic weight	72	72.32
Specific gravity	5.5	5.47
Melting point	High	958°C
Valence	4	4
Reaction with acid and alkali	Slightly attacked by acid, resists attack by alkali	Dissolved neither by HCl nor NaOH

Table 7: Meyer's 1864 System (Part I)

Valence*	4	3	2	1	1	2
	–	–	–	–	Li = 7.03	(Be = 9.3?)
Diff. =	–	–	–	–	16.02	(14.7)
	C = 12.0	N = 14.04	O = 16.00	F = 19.00*	Na = 23.05	Mg = 24.0
Diff. =	16.5	16.96	16.07	16.46	16.08	16.0
	Si = 28.5	P = 31.0	S = 32.07	Cl = 35.46	K = 39.13	Ca = 40.0
Diff. =	$\frac{89.1}{2}$ = 44.55	44.0	46.7	44.51	46.3	47.6
	–	As = 75.0	Se = 78.8	Br = 79.97	Rb = 85.4	Sr = 87.6
Diff. =	$\frac{89.1}{2}$ = 44.55	45.6	49.5	46.8	47.6	49.5
	Sn = 117.6	Sb = 120.6	Te = 128.3	I = 126.8*	Cs = 133.0	Ba = 137.1
Diff. =	89.4 = 2×44.7	87.4 = 2×43.7	–	–	(71 = 2×35.5)	–
	Pb = 207.0	Bi = 208.0	–	–	Tl = (204?)	–

* The symbols for elements F and I are Fl and J in the orignal table.

Table 8: Meyer's 1864 System (Part II)

Valence*	4	6	4	4	4	2	
			Mn = 55.1				
	Ti = 48	Mo = 92		Ni = 58.7	Co = 58.7	Zn = 65	Cu = 63.5
			Fe = 56				
			49.2				
Diff. =	42	45		45.6	47.3	46.9	44.4
			48.3				
	Zr = 90	Vd = 137	Ru = 104.3	Rh = 104.3	Pd = 106	Cd = 111.9	Ag= 107.94
Diff. =	47.6	47	92.8=2×46.8	92.8=2×46.4	93=2×46.5	88.3=2×44.2	88.8=2×44.4
	Ta = 137.6	W = 184	Pt = 197.1	Ir = 197.1	Os = 199	Hg = 200.2	Au = 196.7

* In the original table the word werthig is used for valence.

Source: (For tables 7-10) *Journal of Chemical Education*, Vol. 46 (1969), pp. 136–39.)

Table 9: System of Meyer (1868) published after his death

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
												Li = 7.03	Be = 9.3		
Diff. =												16.02	14.7		
Diff. =			Al = 27.3	Al = 27.3				C = 12.0	N = 14.04	O = 16.00	F = 19.00*	Na = 23.05	Mg = 24.0		
			$\frac{28.7}{2}$=14.3					16.5	16.96	16.07	16.46	16.08	16.0		
								Si = 28.5	P = 31.0	S = 32.07	Cl = 35.46	K = 39.13	Ca = 40.0	Ti = 48	Mo = 92
Diff. =								$\frac{89.1}{2}$ =44.55	44.0	46.7	44.51	46.3	47.6	42	45
	Cr = 52.6	Mn = 55.1	Fe = 56.0	Co = 58.7	Ni = 58.7	Cu = 63.5	Zn = 65.0	–	As = 75.0	Se = 78.8	Br = 79.97	Rb = 85.4	Sr = 87.6	Zr = 90	Vd = 137
Diff. =	.	49.2	48.3	47.3		44.4	46.9	$\frac{89.1}{2}$ =44.55	45.6	49.5	46.8	47.6	49.5	47.6	47
		Ru = 104.3	Rh = 104.3	Pd = 106.0		Ag = 107.94	Cd = 111.9	Sn = 117.6	Sb = 120.6	Te = 128.3	I = 126.8*	Cs = 133.0	Ba = 137.1	Ta = 137.6	W = 184
Diff. =		928=2×46.4	92.8=2×46.4	93=2×46.5		88.8=2×44.4	88.3=2×44.1	89.4=2×44.7	87.4=2×43.7			71=2×35.5			
		Pt = 197.1	Ir = 197.1	Os=199.0		Au=196.7	Hg=200.2	Pb = 207.0	Bi = 208.0			?Tl = 204?			

Note for Tables 7, 8, 9: This is the difference between the atomic weights of two successive elements in the column. If the successive element is missing, then the next element in the same column is considered and the difference is then divided by two

e.g. Si = 28.5
C = 12.0
∴ Diff. = 16.5

Note the element after Si is missing and the next element is Sn = 117.6
Difference in atomic weights of Sn and Si = 89.1

∴ Diff. $= \frac{89.1}{2} = 44.55.$

* See footnote to table 7.

Table 10: System of Meyer (1870)

I	II	III	IV	V	VI	VII	VIII	IX
	B = 11.0	Al = 27.3	–	–	–	?In = 113.4	–	Tl = 202.7
	C = 11.97	Si = 28		–		Sn = 117.8	–	Pb = 206.4
			Ti = 48		Zr = 89.7			
	N = 14.01	P = 30.9		As = 74.9		Sb = 112.1		Bi = 207.5
			V = 51.2		Nb = 93.7		Ta = 182.2	
	O = 15.96	S = 31.98		Se = 78		Te = 128?		–
			Cr = 52.4		Mo = 95.6		W = 183.5	
	F = 19.1	Cl = 35.38		Br = 79.75		I = 126.5 *		–
			Mn = 54.8		Ru = 103.5		Os = 198.6?	
			Fe = 55.9		Rh = 104.1		Ir = 196.7	
			Co=Ni=58.6		Pd = 106.2		Pt = 196.7	
Li = 7.01	Na = 22.99	K = 39.04		Rb = 85.2		Cs = 132.7		–
			Cu = 63.3		Ag =107.66		Au = 196.2	
?Be = 9.3	Mg = 23.9	Ca = 39.9		Sr = 87.0		Ba = 136.8		–
			Zn = 64.9		Cd = 111.6		Hg = 199.8	

* See footnote to table 7.

Table 11: Werner's Periodic Table (1905) showing the rare earths

H 1.008																																He 4
Li 7.03																										Be 9.1	B 11	C 12	N 14.04	O 16.00	F* 19	Ne 20
Na 23.05																										Mg 24.36	Al 27.1	Si 28.4	P 31.0	S 32.06	Cl 35.4	A 39.9
K 39.15	Ca 40.1																Sc 44.1	Ti 48.1	V 51.2	Cr 52.1	Mn 55.0	Fe 55.9	Co 59.0	Ni 58.7	Cu 63.6	Zn 65.4	Ga 70	Ge 72	As 75.0	Se 79.1	Br 79.96	Kr 81.12
Rb 85.4	Sr 87.6																Y 89.0	Zr 90.7	Nb 94	Mo 96.0		Ru 101.7	Rh 103.0	Pd 106	Ag 107.9	Cd 112.4	Jn 114	Sn 118.5	Sb 120	Te 127.6	I* 126.9	Xe* 128
Cs 133	Ba 137.4	La 138	Ce 140	Nd 143.6	Pr 140.5			Sa 150.3	Eu 151.8	Gd 156	Tb 160	Ho 162	Er 166		Tu 171	Yb 173			Ta 183	W 184.0		Os 191	Ir 193.0	Pt 194.8	Au 197.2	Hg 200.3	Tl 204.1	Pb 206.9	Bi 208.5			
	Ra 225	La α ?	Th 232.5						U 239.5						Ac ?													Pb α ?	Bi α ?	Te α ?		

Source: Van Spronsen, J. W., *The Periodic System of the Chemical Elements: A History of the First Hundred Years*, Elseivier, Amsterdam, (1969).

* In the original table, the symbols for F, I, and Xe are Fl, J and X.

6. PROBLEMS POSED BY DISCOVERIES OF NEW ELEMENTS

The turn of the century witnessed revolutionary changes in human understanding of nature. With the mechanics formulated by Sir Isaac Newton, the laws of electromagnetism and thermodynamics enunciated by James Clerk Maxwell and other physicists, and the entire body of chemical reactions and properties of elements and compounds culminating in the elegant 'Periodic Table', it was possible to suggest that the framework of science was complete, and what remained to be done was just filling in the gaps. However, in the span of just ten years from 1895 to 1905, this confidence received several rude shocks. Around 1895–97 the German physicist Roentgen discovered x-rays—rays far more powerful than visible light, which could penetrate matter, and in England Sir J. J. Thomson discovered the electron, the first subatomic particle. It was also discovered around this time that atoms of some elements could be recorded on a photographic plate—the phenomenon of radioactivity. These 'rays' were found to be made up of electrically charged particles—alpha particles (positively charged) and beta particles (negatively charged). Thus, it was becoming evident that Dalton's atoms were not innocent billiard balls; that they had structure and some of them were unstable. In the light of these revolutionary ideas, the entire stock of scientific knowledge on the nature of matter had to be reconsidered. How did the periodic table withstand this revolution?

The development of the periodic table and the periodic law has been discussed in detail in previous chapters. The discovery of gallium, scandium and germanium, and the excellent agreement between the physical and chemical properties, predicted and observed, firmly established the periodic table of chemical elements. The periodic table, a little over 26 years old, had stood the test of time. Besides, chemists now knew what kind of new elements to look for, since the gaps in the periodic table carried an approximate description of the chemical and physical properties of the absent elements. It was an era of hope, confidence and excitement.

With the revolutionary scientific discoveries at the end of the nineteenth century came the discovery of new elements. The three major discoveries

Robert Bunsen (1811–1899)

You must have often used a bunsen burner in your laboratory. This burner is named after the renowned German chemist, Robert Wilhelm Bunsen, who invented it in 1855. As a chemist, he studied the burning gases and noticed that a mixture of air and a combustible gas usually burned to give a non-sooty blue flame and also produced higher temperatures. You must have noticed that the Bunsen burner in the laboratory uses some gas and also has a hole at the bottom to admit air. A band around the hole can be turned to cover the hole partly or fully to control the flow of air. The idea of burning a gas mixed with air has turned out to be important and useful. The liquid petroleum gas burner you use at home for cooking also works on the same principle.

Bunsen did substantial work in the field of chemistry. He had investigated gases produced in blast furnaces and suggested methods for minimizing heat loss. In the course of this work, he invented new methods of gas analyses and different calorimeters for heat measurement.

Bunsen produced magnesium in large quantities and showed that it could be burnt to obtain extremely bright light. This discovery proved to be of great importance in the field of photography. (Magnesium was used to produce brilliant flashes.) In his career as a chemist, he was bold and determined enough to conduct some hazardous experiments with organic compounds containing poisonous aresenic. While working with these compounds, he lost one eye in an explosion and twice nearly died of arsenic poisoning. In spite of these accidents he continued his work in the field of chemistry.

Bunsen's most important contribution to the advancement of science was the spectroscope. In 1859, Bunsen and Kirchoff (a well known physicist), working together, invented the spectroscope which played an important role in discovering new chemical elements. In fact, Bunsen and Kirchoff themselves discovered cesium and rubidium using the spectroscope.

that challenged the validity of the periodic law were the discoveries of the rare earths, the rare gases, and radioactive elements. The main difficulty lay in finding proper places for these new arrivals.

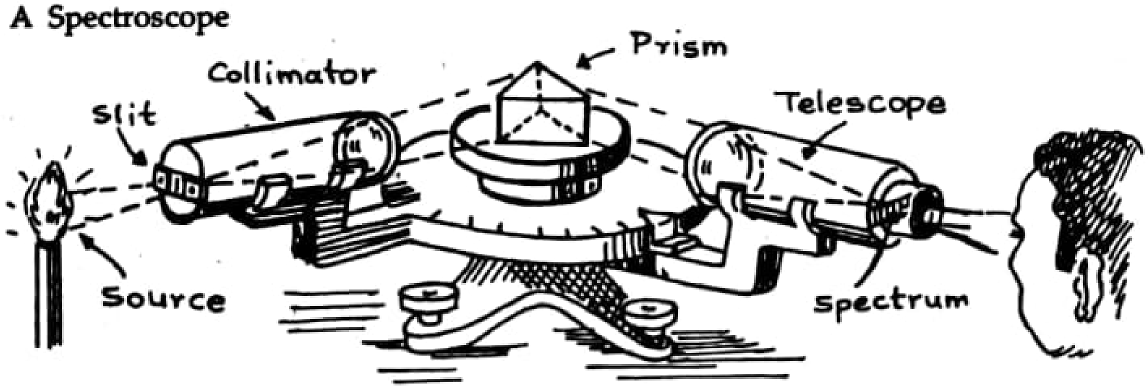
Surprisingly, the periodic table was able to accommodate all these 'problem' elements and emerged even sounder than before. It is interesting to study these crises in some detail, but let us first learn about an important scientific invention which greatly influenced the discovery of the rare gases and rare earths.

The Spectroscope

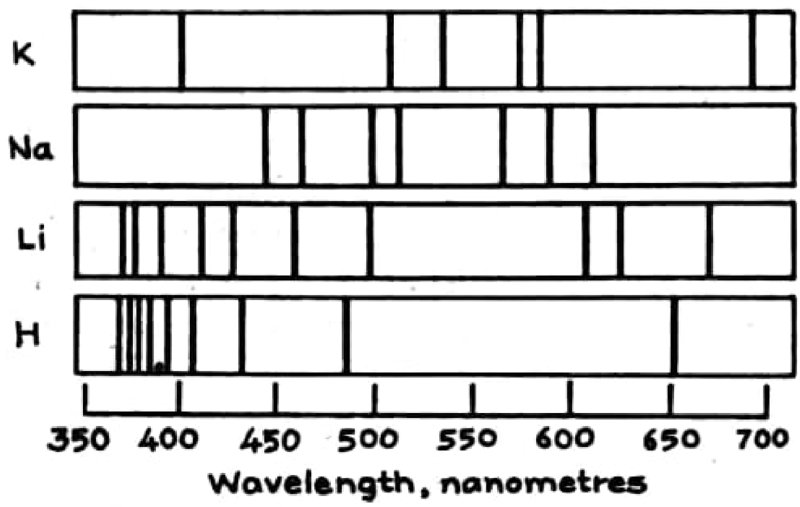
Since the sixteenth century it was known that certain substances produced characteristic glows when introduced into a flame. To distinguish between similarly coloured flames a method of looking through coloured glass was usually used. In the seventeenth century, Newton observed sunlight through a prism, which split the light into seven different colours. The prism could thus be used to analyse light. Using these two ideas, Robert Bunsen (1811–1899) and Gustav Kirchoff (1824–1887) invented the spectroscope in 1859. This instrument proved to be of great importance in the discovery of new elements.

This is how spectroscope works: A compound (solid or its solution) is introduced into a bunsen flame. As a result, the flame gives out coloured light which is characteristic of the elements present in the compound. This light passes through a narrow slit and then through a prism (set for an angle of minimum deviation), which splits the light further into different colours according to their wavelengths. When viewed through a telescope, a set of bright lines is observed. Chemists in the nineteenth century soon

A Spectroscope



Line spectra of some elements



noticed that no two elements exhibited the same pattern of spectral lines. Even more importantly, it was seen that the spectral lines due to one element were not affected by the presence of other elements. With the spectroscopic technique, it thus became possible to detect a completely new element in a sample. There was no need to go through complicated methods for separation. The spectroscope, in fact, provided a novel method which did not require knowledge of the chemical properties of an element. It was also a powerful method capable of detecting an element, since the intensities of spectral lines obtained were very bright even though the element was present in minute quantities.

The spectroscope, thus, proved to be far more effective and sensitive than the chemical methods then in use, and it was extensively used by scientists in the nineteenth century as an invaluable tool for the identification of chemical elements. Shortly after the discovery of the spectroscope, Bunsen and Kirchoff announced the discovery of two new elements—cesium (1860) and rubidium (1861), named for their sky-blue and ruby-red flame colours.

Lord Rayleigh (1842–1919)

John William Rayleigh, an English physicist, discovered the first inert gas 'argon'. This discovery astonished the scientific community, as argon was the first chemical element that did not exhibit any chemical behaviour! Moreover, in the absence of chemical properties argon could not be given a proper place in the periodic table. It is only after other inert gases were discovered that a separate group was created for these elements.

In 1904, Lord Rayleigh won the Nobel Prize for the discovery of argon. He also contributed substantially to physics and studied several types of wave motions such as light (electromagnetic) waves, sound waves, water waves, and earthquake waves. Lord Rayleigh is best known for his theory of the scattering of light by molecules and small particles. He set up mathematical equations to describe the scattering of light by gas molecules in air (now known as Rayleigh scattering) and was able to show that the blue colour of the sky is due to the fact that blue light is scattered most efficiently by the gas molecules.

Using the spectroscopic technique, Crookes discovered the element thallium in 1861 and Reich discovered the element indium in 1863.

The spectroscope played an especially vital role in the discovery of rare earths and rare gases for the study of which the conventional chemical methods then available were not useful, for reasons explained in the subsequent sections.

INERT GASES

By the end of the 19th century, five different inert gases had been discovered and the spectroscopic technique conclusively established their elemental nature. They were named inert gases (or rare gases or noble gases) as all of them were found to be chemically inactive, that is, they reacted neither with any other metallic or non-metallic elements to form compounds, nor with each other. The lack of any chemical activity made it very difficult to determine their atomic weights by the usual chemical means.

In 1894, the first element of this series was discovered (once again) simultaneously by two British scientists, John Rayleigh (1842–1919) and William Ramsay (1852–1916). When the British Association met at Oxford in August 1894, Rayleigh and Ramsay astonished the members by announcing

William Ramsay (1852–1916)

William Ramsay, a British chemist, is famous for his discovery of all the inert gases. He was an organic chemist, studying mainly the alkaloids and pyridine, the phenomenon of water loss in salts, and solubility of gases in solids.

Ramsay came across an article published in Nature *by Rayleigh describing the difference in the densities of nitrogen obtained from the atmosphere and from compounds of nitrogen. This problem fascinated Ramsay who took up a detailed investigation of gases. He discovered argon simultaneously and independently of Rayleigh, and later discovered other inert gases like helium, neon, xenon and krypton within the span of four years. The last member of this series, radon, which is radioactive, was also identified from a sample prepared by Ramsay.*

the discovery of the first inert gas, which, at the suggestion of Mr G. H. Madan, the Chairman, they proposed to call Argon, 'the lazy one'.

The existence of argon was, in general, not immediately accepted by the scientific community, first because it had not been predicted by the periodic table, and second because it did not exhibit any chemical behaviour. No one had ever come across a chemical reaction involving such an element. More importantly, even if the existence of argon was accepted, there was no place for it in the periodic table which by now was not just established but held sacred! Contemporary thinking just could not accept the existence of an element that had no use or purpose or place!

Since argon was chemically inert, and it was not possible to determine its atomic weight by the conventional methods, Rayleigh and Ramsay determined its atomic weight by the specific heat ratio and vapour density methods.

The specific heat of a substance is defined as the amount of heat required to raise the temperature of 1 gram of a substance through 1°C. It is measured at constant pressure (denoted as C_p) and at constant volume (denoted as C_v). The ratio of these specific heats, that is, C_p/C_v is a constant and depends on the atomicity of the given gas. For example, for a monoatomic gas the ratio is 1.6666.

The following table gives values for certain gases.

Gas	*Specific heat (kJ/kg - K)*		$K = (C_p/C_v)$
	C_p	C_v	
Oxygen (O_2)	0.9198	0.6595	1.395
Nitrogen (N_2)	1.0414	0.7442	1.399
Hydrogen (H_2)	14.3338	10.2043	1.400
Ozone (O_3)	0.8192	0.6456	1.269
Sulphur dioxide (SO_2)	0.6234	0.4934	1.263
Argon (Ar)	0.5215	0.3132	1.666
Helium (He)	5.2028	3.1233	1.666
Neon (Ne)	0.1039	0.0624	1.666

Note: The units of C_p and C_v are SI units, that is, kilo-joules per kilogram-degree Kelvin.

The specific heat ratios can, thus, be used to determine the atomicity of a given gas. Using the specific heat ratio, Rayleigh and Ramsay found that argon was a monoatomic gas. The atomic weight was then determined using Cannizzaro's method (that is, the density method). They concluded that the atomic weight of argon was 39.9.

With this atomic weight, argon would fall between the elements potassium and calcium; but there being no place between these two elements, the placement of argon created insurmountable problems for the periodic table. As a result of this problem, chemists looked upon argon as an 'intruder'. Several scientists made various suggestions to overcome this chemical 'monster'. Some suggested that argon be considered as a mixture of two elements. But data such as the precise melting point and precise boiling point of argon showed that argon was a pure substance. Others suggested that the atomic weight of argon was 20 instead of 39.9. With this atomic weight, it was possible to accommodate argon between the elements fluorine and sodium. In this context, the attitude of Mendeleev is of special interest. He was not happy with this new 'intruder', as it could neither be included in the periodic table, nor be ignored in the face of so much evidence. To overcome this problem, Mendeleev provided an ingenious solution. He suggested that the new 'monster' was allotrope of the element nitrogen, that is N_3, like ozone, O_3, which is an allotrope of oxygen.

The problem became even more critical with the discovery of the second inert gas, helium, which was discovered by Ramsay in 1895. The atomic weight of helium determined by the same methods as used for argon, was found to be 4. Now it became necessary to find places for *two* newly discovered inert gases. Actually, helium was first discovered in the spectrum of the sun by Janissen and Lockyer in 1868. The name helium comes from the Greek word 'helios' which means sun. Ramsay discovered this element in the atmosphere on earth, and was able to establish that it was an inert gas.

Even though argon (39.9) was marginally heavier than potassium (39), both Rayleigh and Ramsay placed argon before potassium without changing the atomic weight of argon. With this placement, a new pair of elements, namely, argon-potassium, was introduced in the periodic table, in which the atomic weight sequence was reversed.

The plot began to thicken fast. By 1898 Ramsay and Travers had discovered three more intruders. These were 'neon' (from the Greek word neos—new), 'krypton' (from the Greek word kryptos—hidden) and 'xenon' (from the Greek word xenos—stranger). Now it was necessary to find appropriate places, not for one or two strangers, but for five.

The discovery of Argon

The discovery of argon clearly illustrates the importance of not ignoring minor discrepancies in the results of scientific analysis. It also demonstrates the importance of historical perspective.

In the late 1880s and early 1890s Lord Rayleigh, a physicist, was studying the densities of various gases like oxygen, nitrogen, hydrogen, etc. In these experiments, Lord Rayleigh found that the nitrogen prepared by removing all the other known components from air, was always denser than the nitrogen prepared from chemical compounds. The puzzle was, 'Why should atmospheric nitrogen be heavier than chemical nitrogen?'

Rayleigh's results are shown in the following table:

Atmospheric N_2	Density	Chemical N_2	Density
By hot copper	2.3103	From nitrous oxide	2.29901
By hot iron	2.3100	From nitric oxide	2.3001
By ferrous hydrate	2.3102	From urea	2.2985
Average	2.3102	Average	2.2992

When Rayleigh published his results, another scientist William Ramsay, a chemist, got interested in the problem and adopted it for further study.

Both Rayleigh and Ramsay suspected the presence of some heavier unknown gas in the atmospheric nitrogen. In order to detect the presence of unknown gases, it was essential to remove the nitrogen from air along with other components, namely oxygen, carbon dioxide and water vapour.

The work of Henry Cavendish in 1785, about 100 years earlier, was brought to the notice of Rayleigh (probably by Ramsay or Dewar). Henry Cavendish had studied the composition of air. He had found that all the atmospheric nitrogen could not be converted to nitrous acid by sparking the air over caustic soda. Cavendish had concluded that '. . . If there is any part of phlogisticated air of our atomosphere which differs from the rest, . . . we might safely conclude that it is not more than 1/128th part of the whole. . .'(12)

In 1894, repeating the experiment of Cavendish, Rayleigh found that 'atmospheric nitrogen' was mixture of nitrogen and another heavier gas, which was found to be a new element. Subsequently, this new element was named argon. Ramsay also discovered argon almost at the same time by passing atmospheric nitrogen over hot magnesium. In this process, the nitrogen reacted with magnesium forming magnesium nitride, leaving behind the new element.

In 1904, Ramsay and Rayleigh were both awarded the Nobel Prize for the discovery of argon. This was for the first time that two Nobel Prizes were awarded for the same discovery in the same year to two different scientists—a chemist (Ramsay) and a physicist (Rayleigh).

The specific heat ratios of these elements showed that they were monoatomic. Using the density method, Ramsay and Travers concluded that the atomic weights of neon, krypton and xenon were 20, 82, and 128, respectively. However, not being sure about these values, they could not assign definite places for these elements in the periodic table. If these values were correct the inert gases would appear between the alkali metals and halogens. The discovery of neon with atomic weight 20, made it clear that the atomic weight of argon could not be 20. It also ruled out the possibility suggested by Mendeleev of argon being an allotrope of nitrogen.

The discovery of the first inert gas had posed an insurmountable problem. But the discovery of more inert gases, in fact, led to the final solution. As long as chemists had to deal with only one intruder, that is, argon, they tried all kinds of adjustments in the periodic table. The arrival of many more strangers at first complicated their task, but later it prompted them to think of a whole new column for these elements. The 'intruders' had, thus, legitimately arrived. Ultimately in 1900, Ramsay and Travers placed all these elements in between the alkali metals and the halogens, forming a new group, the 'Zero' group, in this order:

He (4), Ne (20), Ar (39.9), Kr (82), Xe (128).

With this arrangement, the reversal of the atomic weight sequence in the case of argon and potassium became more acceptable.

The best indication of the final acceptance of the inert gases as a new group in the periodic table, which also noted the appearance of the term 'Group 0,' was the third edition of Mendeleev's *Principles of Chemistry* in which he withdrew his opinion that argon was triatomic nitrogen. However, Mendeleev was not happy with the reversal of atomic sequence and so he assigned the atomic weight 38 to argon, instead of 40.

Thus, a totally new group was added to Mendeleev's periodic table, with an additional pair, Ar-K, in the reverse order of their atomic weights. William Ramsay would have been happy to read the following line which appears in a modern textbook of chemistry:

'. . . the inert gases have provided the key to the whole problem of valency and the interpretation of the periodic classification'. (13).

RARE EARTHS

The spectroscopic technique made it possible to detect an element present even in a complex sample, a mixture of many difficult compounds, and so spectroscopy played an important role in the discovery of the rare earths.

Rare Earths

You are familiar with elements like carbon, hydrogen, iron, copper and calcium. The periodic table of elements lists elements like praseodynium, samarium, gadolinium, promethium, etc. These names are strange and one does not come across them in daily life. The term 'rare earths' given to such elements thus seems quite appropriate.

However, it is interesting to know that the term 'rare earths' has only historical significance. They are not all that 'rare' and are not all necessarily associated with earth! It so happens that the first few rare earths were found in rather rare minerals. Hence the name.

The rare earths (now we can use the name) are extremely useful in the laboratory and in several industrial processes. Cerium oxide is used for polishing lenses, mirrors and television picture tubes. Rare earths are used as catalysts in the petroleum industry. They have an affinity for non-metals like carbon or sulphur. This property comes in handy for removing these unwanted non-metals in the processing of steel. Rare earths are also used as phosphors in colour television screens and for production of high quality magnets (especially samarium). You may have read that yttrium/ytterbium was used for making a high temperature superconductor.

Along with rare gases, the rare earths also posed serious problems regarding their placement in the periodic table. One of the basic criteria for the arrangement of chemical elements in the periodic table was the systematic and progressive change in the chemical properties of elements. Rare earths had nearly identical chemical properties, which meant that they could not be arranged in a row. At the same time, their atomic weights were such that they could not be fitted into a column, either. It was difficult, therefore, to place them in the periodic table. Because of their chemical similarities, their mutual separation was also not acceptable.

When Mendeleev formulated the periodic table in 1869, only five rare earths were known. Even with these few rare earths, Mendeleev faced considerable problems in their placement. In the table published in 1869 and 1871 Mendeleev changed the atomic weights of all the rare earths. In the second table (1871), he placed only the element cerium correctly by assigning it the correct atomic weight (140). In fact, Mendeleev and his contemporaries did not succeed in the proper placement of rare earths, mainly because they all tried to place these elements as homologues of other elements. It will not be wrong to say that if all the rare earths had been discovered at the time, Mendeleev would not have been able to set up his first periodic table so soon after the Karlsruhe Congress.

Bayley, whose periodic table appeared in 1882, was the first person who realized that the rare earths must be placed as a separate group. Doing this, Bayley presented a new version of the periodic table. Bassatte, Thompson and Werner are the other main contributors whose valuable work ultimately solved the crisis of accommodating the rare earth elements. Of these, Werner's periodic table is of greatest importance as it accommodated all the then known rare earths in their proper sequence.

Werner's periodic table which appeared in 1905 is given in Table 11 on page 66. The table shows clearly that Werner placed the rare earths as a special group between the alkaline earth metals and the transition elements. Because of this, his table represents the longest form of the periodic table (containing 33 columns). As Werner started the series of rare earths with the element lanthanum, there were 15 places available for the rare earth elements. (Modern scientists do not include lanthanum, and start with cerium, making the number of rare earths 14.) Werner also introduced the new pair, neodymium and praseodymium, in the reverse order of atomic weight sequence.

It is really remarkable that Werner successfully arranged the rare earths in the periodic table without knowing anything about electronic configuration, which eventually became the basis of the periodic table (and which also revealed that there could be only 14 rare earths).

RADIOACTIVE ELEMENTS

Even after solving the problems of placement of rare gases and rare earths, the periodic table could not be finalized. It had to face a new challenge at the beginning of the twentieth century. With the discovery of new radioactive elements, the periodic table once again faced a collapse, especially in the region of high atomic weights.

In March 1896, that is just about two months after the discovery of X-rays in Germany by Wilhelm Conrad Roentgen, the French physicist Antoine Henri Becquerel (1852–1908), observed that the salts of uranium emit certain rays, which like X-rays penetrate various substances and darken photographic plates. After Becquerel published his observations, two scientists from Paris, Marie Curie (1867–1934) and her husband Pierre Curie (1859–1906) became interested in this subject and decided to undertake further studies in it. In their work, the Curies studied different substances to find out whether they emit rays similar to those emitted by uranium salts. They found that another element, thorium, also emits similar rays. They named this phenomenon of spontaneous emission of rays radioactivity (which means ray emitting), and described substances exhibiting this property as

Two ways of getting information

How does one learn about far away lands, foreign cultures or other unknown things? There are two ways. One can get information from messengers or travellers coming from these far-off lands or one can send one's own messengers to these places. Travellers like Hiuen Tsang and Megasthenes visited India and brought knowledge of their countries to us. They also wrote accounts of their travels for the benefit of the rest of the world.

These processes occur in science also. Analysis of lava and other materials thrown out during a volcanic eruption enables geologists to guess about the earth's interior. Similarly, alpha and beta particles and gamma rays ejected by atoms in radioactive decay carry their own story. Of course, one needs to know some physics to understand these messages.

Physicists have also tried to probe the interior of the atom to get information. Lord Rutherford bombarded atoms with alpha particles and made the very significant discovery that all the positive charge and almost all the mass of the atom was concentrated at a tiny active centre called the nucleus. This discovery was an important milestone in the history of science.

Such experiments are conducted in many branches of science. Scientists use accelerators to shoot high energy particles into atomic nuclei. X-rays are used for studying crystal structure. Radioactive trace elements are used to get information about processes and affected parts in animals and humans. Space probes are sent to get information about planets. You can add many more examples to this list.

radioactive. It should be remembered that, at this stage, scientists worked with substances emitting these strange rays and not with pure elements. They were like the early metallurgists working with ores instead of with pure metals.

Initial observations led the Curies to conclude that the amount of radioactivity was proportional to the uranium content of the substances under investigation. However, they soon found that radioactivity in an ore of uranium called pitchblende was several times more than that expected from its uranium content. The Curies, therefore, suspected the presence of a new radioactive element in pitchblende. By investigating the ore further, the Curies discovered two new radioactive elements and called them polonium (in honour of Madam Curie's native country, Poland) and radium (as it was intensely radioactive). In 1899, the French scientist A. Debierne succeeded in isolating yet another radioactive element, actinium, once again from the same ore.

Thus, by 1900, five radioactive elements, namely uranium, thorium, polonium, radium, and actinium were identified. Further work in this field led to the discovery of several new radioactive elements. By 1911, the number of such radioactive elements had reached nearly thirty.

Study of the chemical properties of all these elements indicated that they had to be accommodated in the nine spaces provided by Mendeleev between the elements lead and uranium. The challenge the radioactive elements presented to the periodic table was not their curious behaviour (this was a challenge to the physicists), but the difficulty in housing these thirty elements in nine available slots. If several elements were pushed into one vacant space, the problem could be solved in an *ad hoc* fashion (*ad hoc* means only for that single purpose). Obviously, an *ad hoc* solution would be a blemish on the otherwise smoothly generalized periodic table.

A detailed study of the chemical properties of these elements had also led to an interesting observation. It was found that, in spite of differences in the atomic weights and differences in the radioactive properties, some of these elements were chemically indistinguishable, that is, they had precisely the same chemical properties. It was not possible to separate these elements using chemical methods. For example, radium B, actinium B and thorium B; or thorium A, actinium A and radium C could not be chemically separated. (It was proved later, that the first three elements were isotopes of lead and the next three were isotopes of polonium.)

In 1913, two scientists, Frederick Soddy and K. Fajans, suggested that the chemically inseparable elements, that is, elements with 'identical' chemical properties must be included in a single space, in spite of the differences in their atomic weights. Soddy called such elements isotopic elements. (*Iso* means same and *topos* means place.) This solved the puzzle. It provided some logical basis for accommodating several candidates in one space. The most crucial problem was thus successfully resolved.

We thus come to the end of our story, the story of man's attempt to classify the known chemical elements and to arrange them in a manner that revealed a deeper understanding of their properties. In the preceding pages, we have traced the early history of such attempts, culminating in the success of Dmitri Mendeleev.

In the light of modern knowledge, the periodic table acquires a meaning deeper than ever before. The work done in the last decade of the 19th century and the first four decades of the 20th century completely changed the picture of the Daltonian atom. It revealed that Dalton's atom is made of positively charged protons, negatively charged electrons and neutral particles called neutrons. Both protons and neutrons form the atomic nucleus and the

Marie Curie (1867–1934) and Pierre Curie (1859–1906)

Marie Curie, a Polish-French chemist, is the only person to win two Nobel prizes in two different disciplines of science. In 1903, she shared the Nobel prize for physics with her husband Pierre Curie and Henri Becquerel. It was awarded for work done in the field of radioactivity. In 1911, she was awarded her second Nobel prize, this time in chemistry, for the discovery of radium. The Curies separated this element (and also the element polonium) from an uranium ore called pitchblende.

After the discovery of radium, the Curies decided to produce radium in visible and weighable quantities. For this purpose, they required several tons of pitchblende which they acquired from the world's first uranium mine at Jochimstahl in Bohemia.

After four years of hard work in an old wooden shed with leaking roof and unpaved floor, and facing several other difficulties, the Curies ultimately succeeded in separating a tenth of a gram of radium from tons of pitchblende. This accomplishment represents the culmination of a supreme effort of scientific faith and perseverance. Despite their moderate income, the Curies refused to patent the process of radium production.

Madame Curie's fame did not free her from other obligations. During World War I she interrupted her work to drive an ambulance on the battlefields of France. After the war, she spent her years supervising the Paris Institute of Radium which was founded by her. The unit of radioactive decay is named after the Curies; 10^{10} *disintegrations per second is 1 Curie.*

Pierre Curie was a distinguished physicist in his own right. Besides his work in the field of radioactivity, Pierre Curie studied the magnetic properties of metals and found that, above a certain temperature, the magnetic properties either disappear or are substantially reduced. This temperature is now referred to as the Curie temperature.

He also studied the electrical properties of crystals subjected to pressure, and discovered an interesting phenomenon. It was found that certain crystals

→

subjected to pressure produced an electrical potential. He named the phenomena piezoelectricity. Piezo-electric crystals form an essential component of electronic devices such as microphones and record players.

Unfortunately, Pierre Curie was killed in a road accident in 1906, and could not share in the satisfaction of Marie Curie's second Nobel prize. In 1934, Marie Curie succumbed to cancer which had been caused by her exposure to radioactivity in the course of her dedicated work.

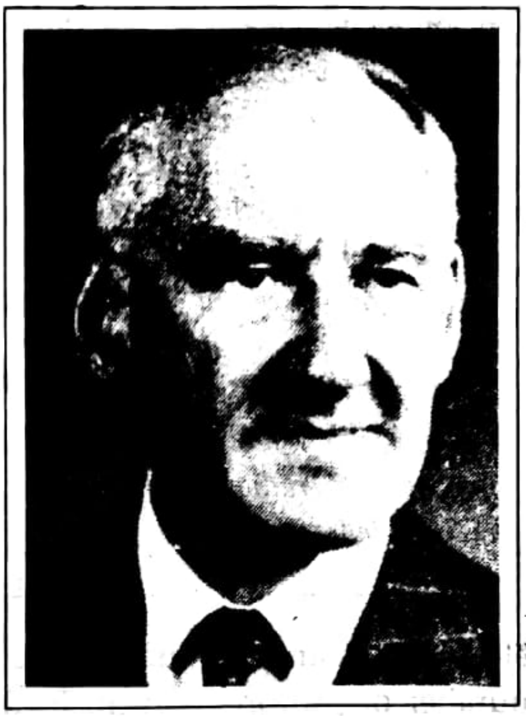
electrons distribute themselves around the nucleus in different shells. The number of protons present in the nucleus is equal to the number of electrons and is called the 'atomic number' of an element. It was further observed that the chemical properties of an element depend entirely on the number of protons present in its nucleus. Scientists learned that once the number of protons was fixed, the arrangement of electrons was also fixed. In fact, you now know that the alkali metals which have similar chemical properties have a single electron in their outermost shell. All these discoveries ultimately revealed the mystery of periodic variations in the physical and chemical properties of the chemical elements. It was also observed that an isotope was an atom of the same element with the same number of protons but a different number of neutrons. As the number of protons in the isotopes of an element is the same, their chemical properties also remain the same. All the isotopes of an element, therefore, belong to a single space in the periodic table.

Today, you know that almost all the elements in the periodic table, with few exceptions, have isotopes. The concept of isotopes helped in understanding the fractional atomic weights of certain elements. A brief discussion of the modern periodic table is given in Appendix A.

Chemistry is an interesting science. Regardless of how much we know of the subject, it keeps presenting a seemingly inexhaustible supply of unknowns. That is why even today it is considered a growing science. From this host of topics available to us, why did we single out the periodic

Frederick Soddy (1877–1956) and Kasimir Fajans (1887–1975)

Frederick Soddy



Kasimir Fajans

The work done in the beginning of the 20th century led to the discovery of several new elements. All these elements were radioactive, that is, they spontaneously emitted certain rays. The main problem for chemists was to accomodate almost 30 such radioactive elements in less than 10 spaces available in Mendeleev's periodic table.

The problem was solved simultaneously and independently by two chemists; the British chemist Soddy and the Polish chemist Fajans. Both these chemists suggested that the 'elements' with different atomic weights, but possessing identical chemical properties were merely different forms of the same element. Soddy called the different forms of the same element isotopes.

The concept of isotopes revealed for the first time that the atomic weight was not the signature of a chemical element. For example, C^{14} *and* N^{14} *have the same atomic weight but are two different elements!*

table for such a detailed description? We chose the periodic table because it illustrates how science progresses.

Also, the story of the periodic table is a tribute to the great minds who saw so much even when so little was known. One wonders at the fact that knowledge of just Dalton's very simplistic concept of the atom, the concept of atomic weights, and the properties of the 63 then known chemical elements were enough for them to formulate a structure, a model that has been able to survive a century in which science has developed at a faster rate than ever before. New knowledge has led to substantial refinement of the model, but has not yet led to its abandonment.

This story of the periodic table, therefore, highlights capabilities of human ingenuity and is ideally suited to illustrate the merits of a good theory. Maybe it will also tempt you to study various other aspects of the fascinating science of chemistry in greater detail.

APPENDIXES

APPENDIX A

The Modern Periodic Table

We now know that an atom consists of an atomic nucleus surrounded by electrons in various shells. The nucleus is made of positively charged protons and neutral particles called neutrons. The atom as a whole is electrically neutral because the number of electrons in its shells equals the number of protons in its nucleus. It is this number which identifies the atom of an element and is called the atomic number.

Why is this atomic number so important? We now know that the chemical properties of an element depend upon how the electrons are distributed in various shells. It is also important to remember that the electrons cannot distribute themselves as they please. There are strict laws, discovered by Wolfgang Pauli (1900–1958), which govern the distribution of electrons in various shells. For example, the first shell can hold a maximum of 2 electrons, the second shell can take 8 electrons, whereas the third shell can accommodate a maximum of 18 electrons, and so on. In fact, if you want to calculate the number of electrons in any given shell, use the formula '$2n^2$', where n represents the shell number, that is, 1, 2, 3, etc.

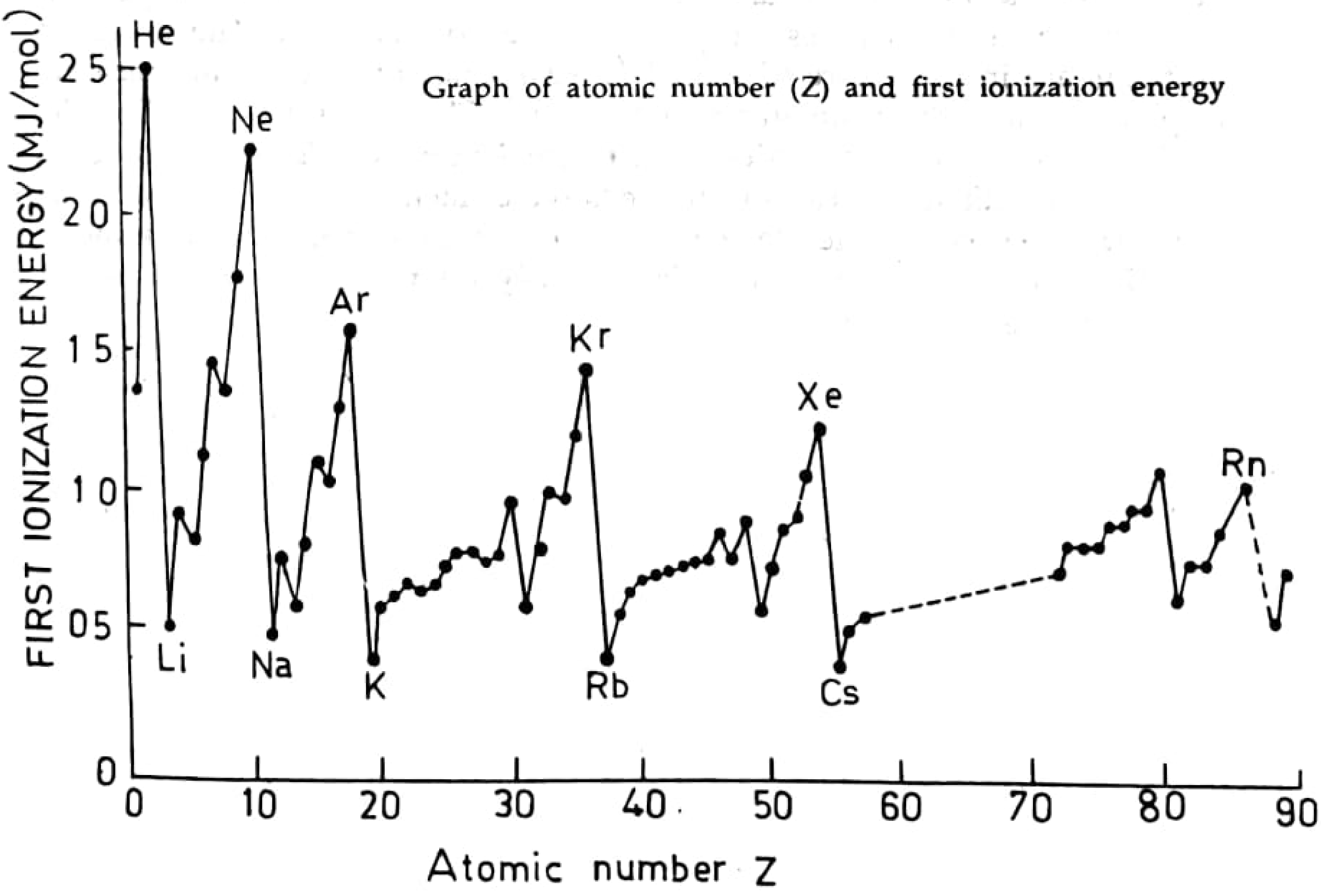
We now know that the periodicity of chemical properties arises out of the periodicity in the filling of shells. For example, consider the alkali metals. Every one of these has an inner shell completely filled with just one electron in the outermost shell, as shown below:

Li 2, 1
Na 2, 8, 1
K 2, 8, 8, 1
Rb 2, 8, 18, 8, 1
Cs 2, 8, 18, 8, 1

(Please note that this is a simplified picture. As you go to heavier atoms, the shells lose some of their distinct separate existence. There is some mixing. However, we will not go into such details here.)

What happens when more electrons are added to the same outermost shell? We move horizontally along the period. For example,

Na – 2, 8, 1
Mg – 2, 8, 2
Al – 2, 8, 3
Si – 2, 8, 4
P – 2, 8, 5
S – 2, 8, 6
Cl – 2, 8, 7
Ar – 2, 8, 8



Chemical reactions between elements involve the electrons in the outermost shells. An element with a completely filled outer shell would therefore be most stable. Do you now understand why argon is inert in nature? Consider the elements sodium and chlorine. With a transfer of one electron from sodium to chlorine, both of them acquire a stable octet configuration. You will now understand why alkali metals and halogens are extremely active and react with each other to give halides. What will happen if you go to the elements magnesium and sulphur?

This periodicity is not restricted only to chemical activity. You have already seen the periodic variations in atomic volumes. Here are some other examples. You are aware of the fact that it requires some energy to knock out an electron from an atom to convert it into an ion. This is called the ionization potential of the element. The graph on the previous page shows how ionization potential varies with atomic number. Note that the inert gases have the highest ionization potentials. You can study other properties such as melting point, boiling point, density, etc. Such a study will give you deeper insight into the periodic table.

The modern periodic table is mainly based on atomic numbers rather than atomic weights. It consists of eighteen columns and seven rows. The alkalis and alkaline earth metals are placed at the extreme left of the periodic table, while the inert gases are placed at the extreme right. The transition elements are in the centre of the table. Two series of 14 elements each are displayed below the main frame of the table. The first series is called the lanthanide series as it precedes the element lanthanum. The second series is called the actinide series as it preceeds the element actinium. The actinide series includes man-made elements (that is, elements after atomic number 92). This form of the periodic table is widely known as the long form of the periodic table and is shown opposite.

Periodic Table of Elements

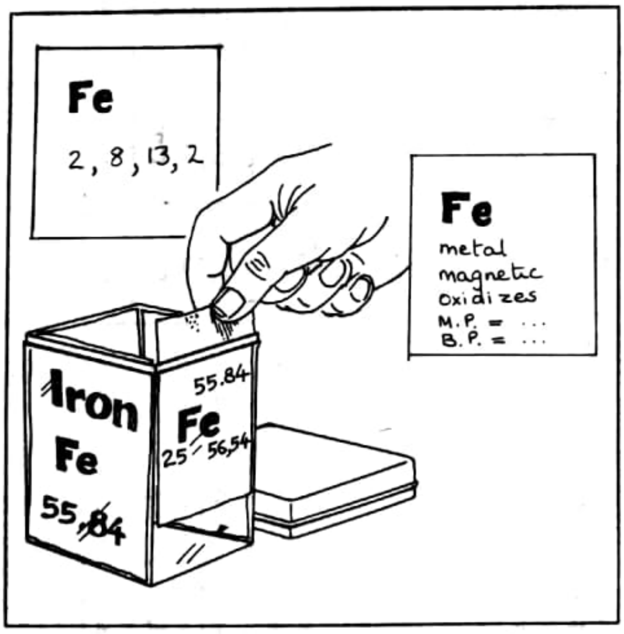
IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H Hydrogen 1.0079																	2 He Helium 4.00260
3 Li Lithium 6.941	4 Be Beryllium 9.01218											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.998403	10 Ne Neon 20.179
11 Na Sodium 22.98977	12 Mg Magnesium 24.305											13 Al Aluminium 26.98154	14 Si Silicon 28.0855	15 P Phosphorus 30.97376	16 S Sulfur 32.06	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.08	21 Sc Scandium 44.9559	22 Ti Titanium 47.90	23 V Vanadium 50.9415	24 Cr Chromium 51.996	25 Mn Manganese 54.9380	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.70	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 75.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9059	40 Zr Zirconium 91.22	41 Nb Niobium 92.9064	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.4	47 Ag Silver 107.868	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.69	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 I Iodine 126.9045	54 Xe Xenon 131.30
55 Cs Cesium 132.9054	56 Ba Barium 137.33	57* La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.2	77 Ir Iridium 192.22	78 Pt Platinum 195.09	79 Au Gold 196.9665	80 Hg Mercury 200.59	81 Tl Thallium 204.37	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium 6.941	89** Ac Actinium 227.0278	104 Unq Unnilquadium (261)	105 Unp Unnilpentium (262)	106 Unh Unnilhexium (263)												

Lanthanide Series*	58 Ce Cerium 140.12	59 Pr Praseodymium 140.9077	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9254	66 Dy Dysprosium 162.50	67 Ho Holmium 164.9304	68 Er Erbium 167.26	69 Tm Thulium 168.9342	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide Series**	90 Th Thorium 232.0381	91 Pa Protactinium 231.0359	92 U Uranium 238.029	93 Np Neptunium 237.0482	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)

A Three-dimensional Model of the Periodic Table

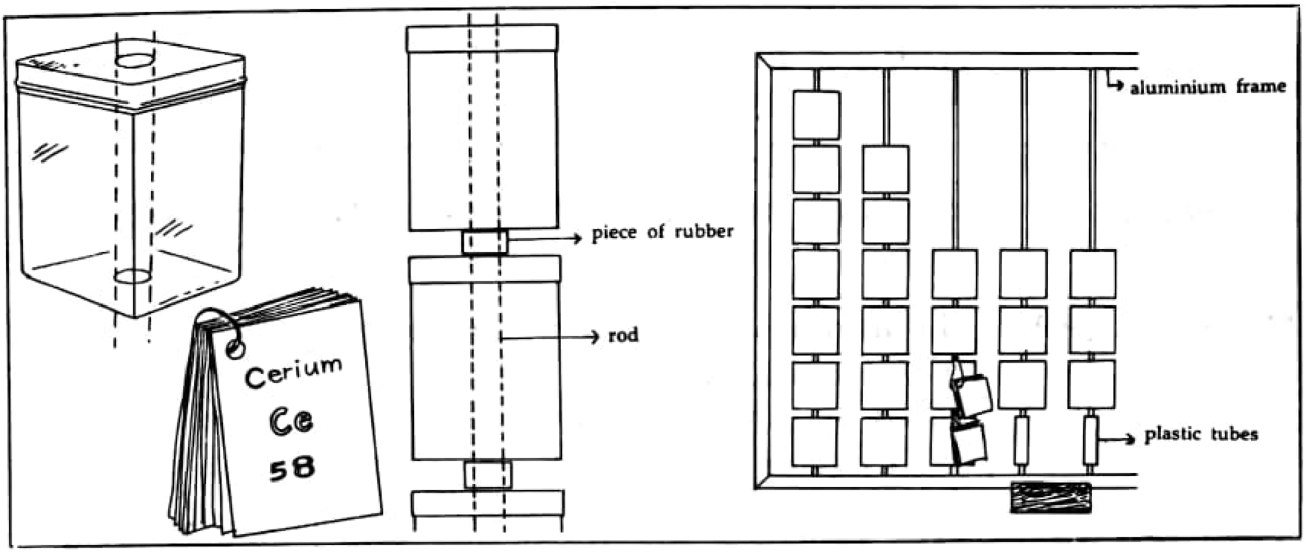
Textbooks of chemistry give charts of the periodic table. These charts do not contain all the information required for the study of elements. Apart from these charts, you may have come across a huge periodic table chart in your laboratory which gives you more information. But it is difficult to handle this chart. Moreover, you cannot take it home.

If you feel like it, you can construct your own periodic table. You will need around 85 cubic transparent plastic boxes. Ignoring the tops and bottoms, a cubic plastic box has four transparent sides. Let us take an element like iron. Using four differently coloured strips of paper cut to the size of the sides of the box, we can represent information about iron on these four sides. Face 1 would show the name, symbol and the atomic weight of the element. The second face would show its symbol along with the atomic number and mass numbers of major isotopes. The third face would show the electronic configuration, whereas the fourth face would show the properties of the element. The illustration shown here will tell you how to prepare a box for any given element. All the required information about the elements is available in standard books on chemistry.



Prepare such a box for every element. In case of elements not known to Mendeleev, you can leave one surface, preferably the one showing electronic configuration, blank. (If you find it difficult to get transparent plastic boxes, use cardboard ones and paste the information on the sides.)

Now how will you assemble this periodic table? Drill a hole through the centre of the lid and the bottom of each box. Now you can pass a rod or wire through the box. Arrange the boxes in the columns to prepare the groups as shown in your periodic table charts. A simple aluminium or wooden frame can be used to support columns of boxes. Please remember that you are using cubic boxes. They need some space to rotate about the wire. If you pack your columns too close, you will not be able to rotate the boxes. (Photographs of such a model are given on the inner cover pages of this book.)



What is the use of such a periodic table? First, you can play with it! In any given column, you can rotate the boxes to show the same colour. For example, if you bring the surface showing properties in front, you can see the variations in different properties along the rows and columns. You will also notice that these variations are quite regular at both ends of the periodic table, but are rather fuzzy in the middle. If you choose to arrange the boxes to show the electronic configuration surface, you will be able to see a pattern in how the shells are filled. You will also see (most of) the gaps that Mendeleev left. It is worthwhile spending a vacation in making such a model. It would be very rewarding investment, and students who use this model will easily become familiar with the intricacies of the periodic table. You will enjoy constructing this model, especially if you make it with a group of friends.

One last suggestion. For the lanthanides and actinides you can prepare two bunches, each of 14 cards. Each card should include the name, the symbol and the atomic number of the corresponding element. You can tie these bunches as shown in the figure above. Remember, we have only suggested to you what can be shown on the four faces of the boxes. You may like to try other ways of choosing your information and displaying it.

APPENDIX C

Table of Elements (14)

Element	*Origin of the name*	*Discoverer, year of discovery and comments*
Actinium (Ac)	Gr. *aktis, aktinos,* beam or ray	Andre Debierne, 1899 and F. Giesel, 1902
Aluminium (Al)	L. *alumen, alum.* Ancient Greeks and Romans used alum in medicine and dyeing	Wohler, 1827
Americium (Am)	The Americas	Seaborg, James, Morgan, and Ghiorso, 1944
Antimony (Sb)	Gr. *anti* + *monosia,* metal not found alone. It is found in over 100 mineral species. Sb is derived from Gr. *Stibium*	Earlier than the 17th century
Argon (Ar)	Gr. *argos,* inactive	Lord Rayleigh and Sir William Ramsay, 1894
Arsenic (As)	L. *arsenicum,* Gr. *arsenikon,* yellow orpiment, identified with *arsenikos,* male, from the belief that metals were of different sexes	Albertus Magnus, AD 1250; Schroeder, 1649
Astatine (At)	Gr. *astatos,* unstable. Longest lived isotope ^{211}At ($t_{1/2}$ = 8.3 h)	D. R. Corson, K. R. Mackensie, and E. Serge, 1940
Barium (Ba)	Gr. *barys,* heavy	Sir Humphrey Davy, 1808

Berkelium (Bk)	Berkeley, home of University of California	Thompson, Ghiorso, and Seaborg, December 1949
Beryllium (Be)	Gr. *beryllos*, beryl, a mineral	Vauquelin, 1798
Bismuth (Bi)	Ger. *weisse masse*, white mass, later Wismuth and Bisemutum	Claude Goeffroy the younger, 1753
Boron (B)	Ar. *buraq*, Pers. *burah*	Sir Humphrey Davy, and Gay-Lussac and Thenard, 1808
Bromine (Br)	Gr. *bromos*, stench	Baland, 1826
Cadmium (Ca)	L. *cadmia*, Gr. *kadmeia*—ancient name for calamine, zinc carbonate, discovered from an impurity in zinc carbonate	Stromeyer, 1817
Calcium (Ca)	L. *calx*, lime	Berzelius, Pontin and Davy, 1809
Californium (Cf)	State and University of California	Thompson, Street, Ghiorso, and Seaborg, 1950
Carbon (C)	L. *carbo*, charcoal	Prehistoric discovery
Cerium (Ce)	Named for the asteroid *Ceres* which was discovered in 1801	Klaproth, Berzelius and Hisinger, 1803.
Cesium (Cs)	L. *caesius*, sky blue	Bunsen and Kirchoff, 1860. After the removal of alkaline earths from Durkheim mineral waters, the residue was examined spectroscopically and two new blue lines were discovered

Chlorine (Cl)	Gr. *chloros*, greenish-yellow	Scheele, 1774
Chromium (Cr)	Gr. *chroma*, colour. It formed coloured compounds	Vauquelin, 1797
Cobalt (Co)	*Kobald*, from the German, goblin or evil spirit; *cobalos*, Greek, mine	Brandt, 1735
Copper (Cu)	L. *cuprum*, from the island of Cyprus	Known since prehistoric times
Curium (Cm)	Pierre and Marie Curie	Seaborg, James, and Ghiorso, 1944
Dysprosium (Dy)	Gr. *dysprositos*, hard to get at	Lecoq de Boisbaudran, 1886
Einsteinium (Es)	Albert Einstein	Ghiorso, December 1952
Element 104	Nuclear Research Institute at Dubna (USSR) named it Kurchatovium (Ku) in honour of Igor Vasilerich Kurchatov. Ghiorso and the Berkeley group proposed the name of Rutherfordium (Rf). IUPAC solved the dispute and the name Unnilquadium (Unq) was given in 1964.	
Element 105	Both the Soviet group at Dubna and the Berkeley group detected the element. The latter gave it the name Hahnium (Ha) after the late German scientist Otto Hahn. IUPAC renamed it Unnilpentium (Unp) (June 1967).	
Element 106	Both Dubna and Berkeley-Livermore group have worked on this. IUPAC named it Unnilhexium (Unh) (June 1974).	
Element 107	1976, Soviet scientists at Dubna announced the discovery. But it has not yet been confirmed.	
Erbium (Er)	Ytterby, a town in Sweden	Urbain and James isolated it independently, 1905

Europium (Eu)	Europe	Boisbaudran, 1890. Demarcay isolated this earth in pure form, 1901
Fermium (Fm)	Enrico Fermi	Ghiorso, 1952
Flourine (F)	L. and F. *fluere*, flow, or flux	Isolated by Moissan in 1886. In 1529, Georgius Agricola described the use of flourspar as a flux
Francium (Fr)	France	Mlle. Marguerite Perey, 1939
Gadolinium (Gd)	gadolinite, a mineral named after Gadolin, a Finnish chemist	
Gallium (Ga)	L. *Gallia*, France; also from L. *gallus*, a translation of Lecoq, a cock	Lecoq de Boisbaudran, 1875
Gold (Au)	Sanskrit *jual*; Anglo-Saxon *gold*, Au (L. *aurum*, shining dawn)	Known and highly valued from the earliest times
Hafnium (Hf)	*Hafnia*, Latin name for Copenhagen	D. Coster and G. von Hevesey, 1923
Helium (He)	Gr. *helios*, the sun	In 1868, Janissen detected a new line in the solar spectrum during the solar eclipse. He believed it to exist only in the sun. Crookes found the same line during the spectroscopic examination of the residual gas from Hildebrand's experiment
Holmium (Ho)	L. *Holmia*, for Stockholm, Cleve's native city	Cleve

Hyrodgen (H)	Fr. *hydro*, water, and *genes*, forming	Cavendish, 1766
Indium (In)	Brilliant indigo line in its spectrum	Reich and Richter
Iodine (I)	Gr. *iodes*, violet coloured	Courtois, 1811
Iridium (Ir)	L. *iris*, rainbow; its salts are highly coloured	Tennant, 1803
Iron (Fe)	Anglo-Saxon *iron*, Fe (L. *ferrum)*	Known since prehistoric times. (Iron pillar dating about AD 400 stands in Delhi)
Krypton (Kr)	Gr. *kryptos*, hidden	Ramsay and Travers, 1898
Lanthanum (La)	Gr. *lanthanein*, to lie hidden	Mosander, 1839
Lawrencium (Lr)	Ernest O. Lawrence, inventor of the cyclotron	A. Ghiorso, T. Sikkeland A. E. Larsh, and R. M. Latimer, March 1961
Lead (Pb)	Anglo-Saxon *lead*, Pb (L. *plumbum)*	Known since prehistoric times
Lithium (Li)	Gr. *lithos*, stone found in igneous rocks	Arfvedson, 1817
Lutetium (Lu)	Lutetia, ancient name for Paris	Urbain, 1907
Magnesium (Mg)	Magnesia, district in Thessaly	Isolated by Davy, 1808
Manganese (Mn)	L. *magnes*, magnet, from magnetic properties of pyrolusite; It. *manganese*, corrupt form of magnesia. Both names are derived from Magnesia, an ancient city in Asia Minor	Scheele, Bergman, and Gahn, 1774

Mendelevium (Md)	Dmitri Mendeleev	Ghiorso, Harvey, Choppin, Thompson, and Seaborg, early 1955
Mercury (Hg)	Planet Mercury; Hg (hydragyrum, liquid silver)	Known since prehistoric times
Molybdenum (Mo)	Gr. *molybdos*, lead. The mineral molybdenite was thought to be the ore of lead	Scheele, 1778
Neodymium (Nd)	Gr. *neos*, new; *didymos*, twin—an inseparable twin brother of lanthanum	von Welshack, 1885
Neon (Ne)	Gr. *neos*, new	Ramsay and Travers, 1898
Neptunium (Np)	Planet Neptune	McMillan and Abelson, 1940
Nickel (Ni)	Ger. *Nickel*, Satan or 'Old Nick's' and from *Kupfernickel* meaning false copper	Cronstedt, 1751
Niobium (Nb)	Niobe, daughter of Tantalus	Hatchett, 1801
Nitrogen (N)	L. *nitrium*; Gr. *nitron*, native soda; *genes*, forming	Daniel Rutherford, 1772
Nobelium (No)	Alfred Nobel, inventor of dynamite	A. Ghiorso, T. Sikkeland, J.R. Walton, and G.T. Seaborg, April 1958
Osmium (Os)	Gr. *osme*, a smell	Tennant, 1803
Oxygen (O)	Gr. *Oxys*, sharp, acid, and *genes*, forming, acid former	Priestley

Palladium (Pd)	Asteroid Pallas; Gr. *Pallas*, goddess of wisdom	Wollaston, 1803
Phosphorus (P)	Gr. *phosphorus*, light bearing; ancient name of the planet Venus when appearing before sunrise	Brand, 1669
Platinum (Pt)	Sp. *platina*, silver	Ulloa, 1735 and Wood, 1741
Plutonium (Pu)	Planet Pluto	
Polonium (Po)	Poland, native country of Marie Curie	Marie Curie, 1898
Potassium (K)	English *potash*, pot ashes L. *kalium*; Ar. *Qali*, alkali	Davy, 1807
Praseodymium (Pr)	Gr. *prasios*, green; *didymos*, twin	von Welsbach, 1885
Promethium (Pm)	Prometheus, who according to mythology, stole fire from heaven	Wu, Segre and Bethe, 1942
Protactinium (Pa)	Gr. *protos*, first. Protoactinium was shortened to Protactinium	K. Fajans and O.H. Gohring in 1913
Radium (Ra)	L. *radius*, ray	Pierre and Marie Curie, 1898
Radon (Rn)	From radium; called niton at first, L. *nitens*, shining	Dorn, 1900
Rhenium (Re)	L. *Rhenus*, Rhine	Noddack, Tacke and Berg, 1925
Rhodium (Rh)	Gr. *Rhodon*, rose	Wollaston, 1803

Rubidium (Rb)	L.*rubidius*, means deepest red	Bunsen and Kirchoff, 1861. They examined the line spectra of the residue from lepidolite after the removal of other alkali salts and discovered two dark red lines (at the red end of the spectrum)
Ruthenium (Ru)	L. *Ruthenia*, Russia	Klaus, 1844
Samarium (Sm)	Samarskite, a mineral	Lecoq de Boisbaudran, 1879
Scandium (Sc)	L. *Scandia*, Scandinavia	Nilson, 1876
Selenium (Se)	Gr. *selene*, moon	Berzelius 1871. He found it associated with Tellurium, named after the earth
Silicon (Si)	L. *silex*, silicis, flint	Berzelius, 1824; crystalline silicon discovered by Deville, 1854
Silver (Ag)	Anglo-Saxon *seolfur*, *siolfur*, Ag. (L. argentum)	Known since ancient times
Sodium (Na)	English *soda*; medieval Latin *sodanum*, headache remedy; Na (L. *Natrium*)	Davy, 1807
Strontium (Sr)	Strontian, town in Scotland	Davy, 1808. Adair Crawford, 1790
Sulphur (S)	Sanskrit, *sulvere*; L. *sulphurium*	Ancient times
Tantalum (Ta)	Tantalus, Greek mythological character, father of Niobe	Ekeberg, 1802
Technetium (Tc)	Gr. *technetos*, artificial, first element to be produced artificially	Perrier and Segre, 1937

Tellurium (Tl)	L. *tellus*, earth	Muller von Reienstein, 1782
Terbium (Tb)	Ytterby, village in Sweden	Mosander, 1843
Thallium (Tl)	Gr. *thallos*, a green shoot or twig; (due to beautiful green spectral line, which identified the element)	Crookes, 1861
Thorium (Th)	Thor, Scandinavian god of war	Berzelius, 1828
Thulium (Tm)	Thule, the earliest name of Scandinavia	Cleve, 1879
Tin (Sn)	Anglo-Saxon *tin*, Sn (L. *stannum)*	Ancient times
Titanium (Ti)	L. *Titans*, the first sons of the Earth, mythology	Gregor, 1791
Tungsten (W)	Swedish *tungsten*, heavy stone	Peter Woulfe, 1779 (mineral-wolframite) and Scheele, 1781 (Scheelite)
Uranium (U)	Planet Uranus	Klaproth, 1789
Vanadium (V)	Scandinavian goddess, Vanadis, because of its beautiful multicoloured compounds	del Rio, 1801
Xenon (Xe)	Gr. *xenos*, stranger	Ramsay and Travers, 1898
Ytterbium (Y)	Ytterby, village in Sweden near Vauxholm	Gadolin, 1794
Zinc (Zn)	Ger. *zink*, of obscure origin	Known since ancient times; zinc was used in the 13th century AD in India

Zirconium (Zr)	Ar. *zargun*, gold colour	Klaproth, 1789

Gr : Greek L : Latin Sp : Spanish Ger : German
Ar : Arabic F : French It : Italian

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You may like to go through the following books:

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India is rich in mineral resources

Note: This is a sketch map. Lakshadweep and Andaman and Nicobar Islands are not shown in the map. The boundary and coastline of India shown in this sketch are neither authentic nor correct.