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Are History Aspects Related to the Periodic Table Considered in Ethiopian Secondary School Chemistry Textbooks?

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Abstract. The aim of this study was to evaluate Ethiopian secondary school chemistry textbooks with respect to presentation of history and philosophy of science (HPS) related aspects of the periodic table. We focused on how the textbooks approached the periodic table as a conceptual tool for organizing the chemical elements, and understanding their properties. For this purpose, three grade 9 chemistry textbooks (introduced in the last two decades by the Ministry of Education of Ethiopia) were selected. We conducted the evaluation qualitatively using an adopted version of a four-point criterion developed based on HPS framework. Our evaluation revealed that that only one of the three textbooks addressed just only one of the four HPS aspects of the periodic table satisfactorily, while in the other two textbooks all of the four aspects are generally ignored. It is concluded that most HPS related aspects of the periodic table are missed from Ethiopian secondary school chemistry textbooks, and the few aspects which are addressed are not properly presented. We believe that this could have negative consequences on the students' attitude and interest towards science as well as on their understanding of science concepts and performance in the subject.

Keywords. History and philosophy of science (HPS), chemistry textbooks, Ethiopian secondary school, periodic table, evaluation.

1. INTRODUCTION

The current structure of the Ethiopian education system can be described as 8-2-2-3+ i.e. eight years primary (grade 1–8; age 7–14), two years secondary first cycle (grade 9–10), two years secondary second cycle (grade 11–12), and 3 to 6 years university education. In Ethiopia, formal teaching and learning of science begins at the primary level; and chemistry, biology and physics begin to be taught as separate subjects, compulsory for all students, at grade 7. This continues up to grade 10. Starting from grade 11, as a preparation for higher education, students have to choose between two options: *natural science* and *social studies*. Students majoring in science study chemistry, biology, and physics as principal subjects. Each subject has its own syllabus, teacher's guide and textbook (prepared by the Ministry of Education) which is uniformly used across the country. Despite the policy recommendations for a concise and student-centered curricula (where a variety of teaching methods shall be used)[1], studies have indicated that the Ethiopian science curricula were too theoretical and overloaded; and the method of teaching used by teachers as teacher-centered (commonly called "chalk and talk") emphasizing recall of large amounts of factual information to pass examinations.[2,3,4,5]

Textbooks are usually considered to be the primary reference materials to carry out classroom instruction in many countries. This is particularly true in schools of developing countries where both teachers and students heavily rely on textbooks for their lessons. For instance, according to Yager, nearly 100% of Nigerian science teachers rely on textbooks to select appropriate content to teach their students.[6] In our experience as science educators and researchers in the country, due to various reasons, Ethiopian science/chemistry teachers too rely solely on textbooks. However, these textbooks have not yet reached the standards of developed communities as they are prepared by individuals (usually school teachers or university lecturers) who have little/no experience in textbook preparation, or even worst by foreign (commonly Indian) writers who are unacquainted with the Ethiopian classroom context. As such, these textbooks can be a source of students' learning and teachers' teaching difficulties. This is in agreement with the findings of other international studies which reported that textbook presentation of science content are often incompatible with the suggestions of science education research, and may entail problems if used uncritically.[7,8] In addition, in the Ethiopian context, studies revealed that school chemistry teachers have a variety of misconceptions about various chemical concepts.[9,10,11] As indicated in the country's national learning assessment report and in a survey study conducted by USAID/IQPEP Ethiopia, the presence of such compounded problems might be among the possible causes of the alarmingly declining students' science performance in regional and national examinations.[12]

As a remedy to the above mentioned problems as well as other teaching-learning deficiencies, many researchers and teachers have suggested the inclusion of history and philosophy of science (HPS) in the science curriculum, textbooks, and classroom.[13,14,15] Teaching and learning of science using HPS approach has been reported to have several merits: e.g. for teaching and learning about science as a process, for promoting conceptual change and a deeper understanding of scientific ideas, for fostering public understanding of science, and for positively impacting students' attitudes and interests toward science.[14,15,16] However, it has been argued that science textbooks rarely address in a meaningful way the historical development of science and the nature of science, instead presenting science in a distorted and ahistorical way.[17,18]

In the Ethiopian context, there is no explicit standard which promotes the inclusion of the HPS approach of teaching and learning of science. In addition, despite the Policy recommendation for application of a variety of teaching approaches, the curricular materials (syllabus, student textbooks and teacher's guide) which are issued by the Ministry of Education do not allow for flexibility as teachers are expected to strictly follow these documents. This practically means that there is little/no room for teachers to flexibly implement HPS based teaching (i.e. to use historical cases) in their lessons. This is similar to what has been reported by Van Bertel et al.[19], who on the basis of content analysis of school chemistry textbooks (published in UK and Netherlands) identified school chemistry as a form of "normal science education" which is considered to be "dangerous" in that it isolates the learner from the HPS and, as such, is narrow and rigid and tends to instill a dogmatic attitude towards science.

The periodic table is considered to be an important topic of secondary school and undergraduate chemistry textbooks worldwide. It serves as a source of information for students to learn the fundamental building blocks of chemistry, the chemical elements, and the relationship between them. However, previous studies have reported problems in presenting the periodic table in the textbooks which led to difficulties in teaching and learning the concepts behind it.[20,21,22] According to Niaz and Luiggi, most students consider the periodic table to be a difficult topic.[23]

Studies on chemistry textbooks dealing with the periodic table can be found in many developed countries. This is not, however, the case in developing countries. In Ethiopia, specific well-documented studies of chemistry textbooks presentations of the periodic table are lacking. The purpose of this study was therefore to contribute to the understanding of how the periodic system is taught in Ethiopia. This way, based on textbook presentations, we will help provide perspectives from an African school practice, and by so doing, contribute to giving a fuller picture of how the periodic table is taught in schools all over the world.

2. ASPECTS OF HISTORY OF THE PERIODIC TABLE WORTHY OF CONSIDERATION IN CHEMISTRY TEXTBOOKS

The periodic table has been considered a conceptual tool because it has contributed much more than mere classification; it has predicted new elements, predicted unrecognized relationships, served as a corrective device, and fulfilled a unique role as a memory and organization device[24] which in turn has led to a better understanding of chemistry. In this section, some selected HPS related aspects of the periodic table (based on Brito et. al.[25] and Niaz and Luiggi[23]) which we believe are worthy of including in secondary school chemistry textbooks are briefly discussed.

In view of this, it should be noted that there were early ideas about atomic theory and accumulation of data with respect to the atomic weights of the elements and their properties; and that there were several attempts to classify elements between 1817 and 1860. For example, by 1829, the German chemist Johann Döbereiner (1780-1849) presented the law of triads as he noted a similarity among the physical and chemical properties of several groups of three elements and the relation of their atomic weights.[24] A major hindrance to the widespread acceptance of such classifications was that no consensus on atomic weight values existed. A significant progress was made only after the Karlsruhe conference of 1860 at which the Italian chemist Stanislao Cannizzaro (1826-1910) presented one specific system for atomic weights and wrote a pamphlet which convinced many chemists, after which the stage was set for the discovery of the periodic system. It is generally acknowledged that the periodic system was independently discovered during the 1860s by six individuals, namely: French geologist and mineralogist Alexander Beguyer De Chancourtois (1820-1886), English chemist William Odling (1829-1921), American chemist Lothar Meyer (1830-1895), English chemist John Newlands (1837-1898), German chemist Gustavus Hinrichs (1836-1923), and Russian chemist Dmitri Mendeleev (1834-1907).[28,27] By 1869, a total of 63 elements had been discovered and in the same year, Mendeleev completed his first form of the periodic system in which he arranged all of these elements based on their atomic weights.[23,28] In the 1920s, based on the work of the English physicist Henry Moseley (1887-1915) and others some years earlier,[25] the periodic table was organized according to atomic number instead of atomic weight. This, and the discoveries of the sub-atomic particles, in turn helped chemists to have a deeper understanding of the organization of the periodic table and the properties of the individual elements. Inclusion of the above HPS related aspects of the periodic table in textbooks may help present the development of the periodic table as a progressive, collective and at the same time sequential and simultaneous endeavor based on different contributions; and thus, it stimulates and encourages students to understand how science progresses and the tentative nature of scientific findings.

Other HPS related aspects of the periodic table that arguably deserve attention in chemistry textbooks are the importance of *accommodation* (i.e. agreement of observed properties of the elements such as atomic weight/number and other properties with the theory) and *prediction* (of new elements). The latter can be highlighted by providing as an example at least one of the three elements gallium, scandium, or germanium, and a comparison of the predicted and experimental properties without forgetting to mention that not all predictions were successful. It should also be explained to readers that there has been some controversy among historians and philosophers of science with respect to the relative importance of accommodation and prediction[25]. However, for classroom teaching, it is sufficient to explain that the success of the periodic table could be partly attributed to accommodations, predictions, or both. This might facilitate the understanding that the same experimental data can be explained by alternative interpretations.

Overall, inclusion of the HPS aspects of the periodic table in chemistry textbooks might help students understand how science evolves through the interactions of theories, experiments, and the work of actual scientists.[18]

3. RESEARCH METHOD

Overall, the study involved four stages. In the first stage, we reviewed literatures that are relevant to the historical and philosophical development of the periodic table and their educational implications. In the second stage, based on the reviewed literature, and particularly inspired by Brito et al.,[25] we designed a four point evaluation criteria for evaluating Ethiopian secondary school chemistry textbooks with respect to how they addressed the periodic table. The third stage involved selection of textbooks for the evaluation in which we selected three 9th grade chemistry textbooks (written by Sharma et al.,[29] Abera and Abusie,[30] and Mamo and Tassew[31]) that the Ministry of Education of Ethiopia has introduced in the last two decades. We selected 9th grade textbooks for the reason that in the Ethiopian secondary school chemistry curricula, the topic of periodic table is included in grades 9 and 11 only; and from our survey of these textbooks, we learned that no historical cases of the periodic table are presented in the grade 11 textbooks (as the discussion started from the topic of 'the modern periodic table'). The grade 9 chemistry textbooks, however, had addressed some of the historical aspects. The fourth stage of the study involved evaluation of the selected textbooks based on the developed criteria in which each criterion was scored qualitatively as Satisfactory (S), Mention (M), or No Mention (N). Detailed description of the evaluation criteria is given below:

Evaluation criteria

Criteria 1: Development of the periodic table as a case of progressive sequential/simultaneous discovery.

- **Satisfactory (S)**: If the textbook emphasizes the development of the periodic table as progressive, collective and at the same time sequential and simultaneous endeavor based on the following contributions: (a) early ideas about atomic theory and accumulation of data with respect to the atomic weights of the elements and their properties; (b) the first attempt to classify the elements by Döbereiner, and later by De Chancourtois, Odling, Meyer, Newlands, Hinrichs, and other attempts before Mendeleev; (c) Mendeleev's first periodic table in 1869 based on atomic weights and subsequent contributions; and (d) the contribution of Moseley (1913), and the shift from atomic weight to atomic numbers (modern periodic table).
- **Mention (M):** if the textbook mentions some of the major contributors without establishing a sequential, collective and progressive development explicitly.
- **No mention (N):** if the textbook included Mendeleev and Moseley only or if the textbook simply starts from the modern periodic table.

Criteria 2: The importance of accommodation in the development of the periodic table:

- **Satisfactory (S):** If the textbook explains and emphasizes that an important aspect of the periodic table is accommodation of the different elements with respect to atomic weight/number and other properties such as density, atomic volume, atomic/ionic radii, ionization energy, electronegativity, electron affinity, etc.
- **Mention (M):** if the textbook simply mentions that accommodation of the different elements was important.
- **No mention (N):** If the textbook did not at all mention the role played by accommodation.

Criteria 3: The importance of prediction as evidence to support the periodic law.

- **Satisfactory (S):** If the textbook emphasizes the importance of prediction in the development of the periodic table by providing as an example at least one of the three elements gallium, scandium, or germanium, and a comparison of the predicted and experimental properties; as well as reminding the reader that not all predictions were successful.
- **Mention (M):** A simple mention that Mendeleev made predictions of new elements, and provides an example (without comparing predicted and experimental properties).
- **No mention (N):** If the textbook states that Mendeleev made predictions, and does not provide an example.

Criteria 4: Relative importance of accommodation and prediction in the development of the periodic table.

- **Satisfactory (S)**: If the textbook explicitly explains the presence of debates among historians and philosophers of science with respect to the relative importance of accommodation and prediction, and presents the merits and demerits of each, and indicates to the students that the success of the periodic table could be partly attributed to accommodations, predictions, or both.
- **Mention (M)**: A simple mention and comparison of alternate ways of explaining the success of the periodic table with no mention of rivalry and controversy.
- **No Mention (N)**: If the textbook mentions the role played by accommodation and prediction with no attempt to compare the two.

4. ETHIOPIAN SECONDARY SCHOOL CHEMISTRY TEXTBOOKS ACCOUNTS: RESULTS AND DISCUSSION

As outlined above, three secondary school chemistry textbooks were analyzed to see how the textbooks presented the historical and philosophical aspects of the periodic table; and how accurate, coherent and complete these presentations are.

Criterion 1: Development of the Periodic Table as a case of progressive simultaneous/ sequential discovery

The key idea behind this criterion is to assess the chemistry textbooks to see whether or not they presented the development of the periodic table as a case of progressive and simultaneous/sequential discovery based on different contributions in such a way that it stimulates and encourages students to think that there is more to scientific progress than simple accumulation of data and linear progress through individual discoveries.[25] We found that none of the textbooks presented this aspect of the periodic table satisfactorily (S). All the three textbooks simply mentioned (M) three to four of the contributors without establishing a sequential, collective and

Table 1. Some quotations from the evaluated textbooks.

Textbook	Quote
Sharmaet al.[29]	Early attempts to classify elements were based on atomic mass [weight]. The first attempt was made in 1817 by J.Dobereiner [who presented the law of triads]. In 1864, John Newlands reported the law of octaves. In 1869 Mendeleev and Lothar Mayer independently published periodic arrangements. In 1913 Henry Mosley determined the atomic number by analyzing X-ray spectra.
Abera andAbusie[30]	The periodic table has been developed over many years. In 1817 J.W. Dobereiner observed that the atomic mass [weight] of bromine was very nearly equal to the average masses [atomic weights] of chlorine and iodine. In 1864, John Newlands reported the law of octaves. The periodic law was proposed independently by Mendeleev and Lothar Mayer. [Clemens]Winkler, in 1876 [1886], discovered germanium. Henry Moseley, between the years 1911 and 1914, discovered a new fundamental property of elements.
Mamo and Tassew[31]	In 1817 J.W. Döbereiner observed groups of three elements with similar properties. In 1864, John Newlands reported the law of octaves. The periodic law was proposed independently by Mendeleev and Lothar Mayer.

progressive development explicitly. The following quotes (see Table 1) are provided as examples:

As can be understood from the quotes, the writers of the textbooks have tried to endorse the tentative nature of scientific theories/models. However, the information presented is not articulated, it's just a string of events with no details; it confuses the teachers and the students even more, as it does not provide them with a way to relate these earlier developments to the final outcome. The scientific process looks even messier. So this is unsatisfactory and unproductive.

Criterion 2: Importance of Accommodation in Development of the Periodic Table

From the analysis, we found that there are no substantial differences in the way the three textbooks emphasized the importance of accommodation (of the different elements with respect to their physicochemical properties) in the development of the periodic table. None of the three textbooks presented a satisfactory (S) description; three of them just give a simple mention (M). For example Sharma et al.[29] mentioned the following: "Dmitri Mendeleev developed the periodic table and formulated the periodic law. Because his classification revealed recurring patterns (periods) in the elements…" (p. 39).

Criterion 3: The importance of prediction as evidence to support the periodic law

Sharma et al.[29] is the only textbook to emphasize the importance of prediction satisfactorily (S) as evidence to support the periodic law. Furthermore this textbook compared the properties of at least one of the predicted

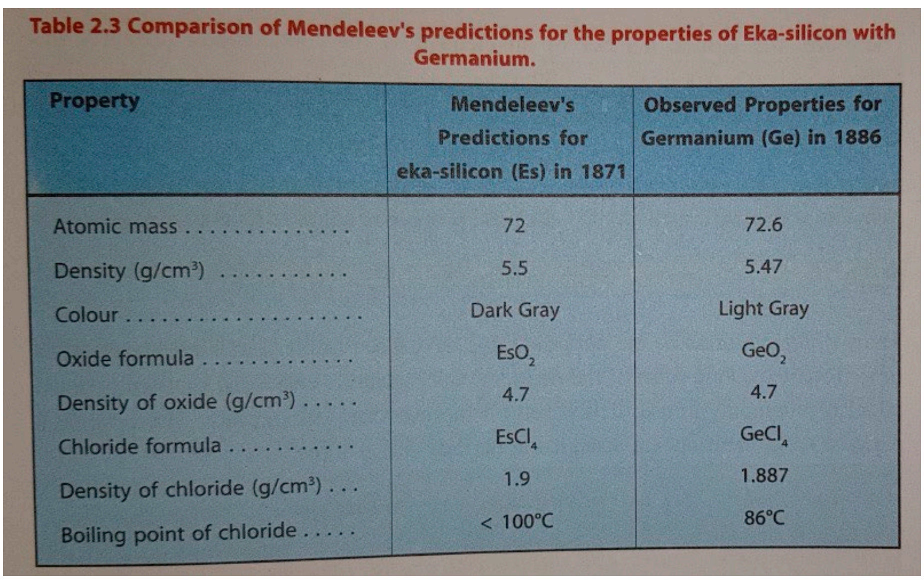

Table 2.3 Comparison of Mendeleev's predictions for the properties of Eka-silicon with Germanium.

Property	Mendeleev's Predictions for eka-silicon (Es) in 1871	Observed Properties for Germanium (Ge) in 1886
Atomic mass	72	72.6
Density (g/cm³)	5.5	5.47
Colour	Dark Gray	Light Gray
Oxide formula	EsO_2	GeO_2
Density of oxide (g/cm³)	4.7	4.7
Chloride formula	$EsCl_4$	$GeCl_4$
Density of chloride (g/cm³) . . .	1.9	1.887
Boiling point of chloride	< 100°C	86°C

Figure 1. Sharma et al.[29] textbook representation of importance of prediction as evidence to support the periodic law.

elements (Ga, Sc, and Ge) with the observed values. The following are specific examples taken from Sharma et al.[29]: "Mendeleev left blank spaces for these two elements in the table, just under aluminum and silicon. He called these unknown elements 'eka-aluminum' and 'eka-silicon'. What he meant by 'eka-aluminum' is a currently known element (gallium) following aluminum. Later on, in 1874, the element gallium (eka-aluminum' in Mendeleev's system) was discovered. The observed properties of these elements were remarkably very close to those in Mendeleev's prediction." (p. 39)

This textbook also compared the properties of at least one of the predicted elements (eka-silicon) with the observed properties of germanium. In the textbook, the comparison is clearly presented in the form of a table (see Figure 1). The other two textbooks made no mention (N) and hence ignored the issue.

In the same way, Abera andAbusie[30] stated the following: "The periodic law provided a working basis for the predication of new elements or unfamiliar elements. It also provided an important stimulus for further chemical investigations." (p. 75)

Criterion 4: Relative importance of accommodation and prediction in the development of the periodic table

None of the textbooks explained the relative importance of accommodation and prediction in the development of the periodic table satisfactorily, and only a textbook by Sharma et al.[29] made a simple mention (M) and comparison of alternate ways of explaining the success of the periodic table with no mention of rivalry and controversy as exemplified in the quote below:

Early attempts to classify elements were based merely on atomic mass [weight]... scientists begun to seek relationships between atomic mass and other properties of the elements (p. 37).
Mendeleev observed that when elements are arranged according to increasing atomic mass, the chemical and physical properties of the elements recur at regular intervals (p. 40).
Mendeleev left blank spaces for the undiscovered elements and also predicted masses [atomic weights] and other properties of these unknown elements almost correctly (p. 40).

From the above quote, one can conclude that the textbook by Sharma et al.[29] does recognize the importance of accommodations and predictions separately but not the relative importance of the two. In agreement with Brito et al[25]., we argue that textbooks should inform learners that the success of the periodic table could be attributed to accommodations, predictions, or both. This will help students to take the view that the same experimental data can be explained by alternative interpretations.

5. CONCLUSION AND IMPLICATIONS FOR CHEMISTRY EDUCATION

The purpose of this study was to evaluate Ethiopian secondary school chemistry textbooks with respect to the presentation of the historical development of the periodic table of chemical elements which is considered to be a conceptual tool[24] that helps to organize a great deal of information, leading to a better understanding of chemistry. As mentioned earlier, three grade 9 chemistry textbooks were selected for the evaluation. We conducted the analysis qualitatively by reading the relevant pages of the textbooks based on a four point evaluation criteria adopted from previous researchers[25]. As can be seen from Table 2, of the four historical aspects of the periodic table, a satisfactory description of only one of them (namely, the importance of *prediction*s as evidence to support the periodic law) is presented by one textbook (by Sharma et al.[29]) only. The same textbook has attempted to present the first aspect i.e. *the development of the periodic table as a sequence of discoveries* but not in such a way that it informs the student that such development of the periodic table went through a continual controversy in which scientists presented various tentative theoretical ideas. In addition, the information presented is not articulated; it is just a string of events with no details; it may confuse the teachers and the students even more; and as such the scientific process looks even messier. In the other two textbooks (Abera and Abusie[30]and Mamo and Tassew[31]), all the four historical aspects of the periodic table including the importance of *accommodation* in development of the periodic table, and the *relative importance of accommodation and prediction* are generally ignored (i.e. simple mention or no mention).

We may conclude that the HPS aspects of the predict table are not satisfactorily addressed in Ethiopian secondary school chemistry textbooks. That means, the textbooks' presentation of the said aspects does not

Table 2. Results of analysis of Ethiopian secondary school chemistry textbooks accounts of the periodic table based on the history and philosophy of science framework.

Textbook	Criteria				
	1	2	3	4	5
Sharma et al.[29]	M	M	S	M	N
Abera and Abusie[30]	M	M	N	N	N
Mamo and Tassew[31]	M	M	N	N	N

facilitate the students' understanding of how science evolves as well as its tentative nature which in turn may have negative implications on the students' chemistry/science interest as well as on their understanding of and performance in the subject. This is similar to what is concluded by Van Berkel, De Vos, Verdonk, Pilot[19], who based on their study identified school chemistry as a form of "normal science education" which is considered to be "dangerous" in that it isolates the learner from the HPS and, as such, is narrow and rigid and tends to instill a dogmatic attitude towards science. As the scope of the current study is limited in several ways, to get a fuller understanding of how HPS related aspects of science are taught in Ethiopian/African schools, it is recommended for more comprehensive studies to be conducted in the future.

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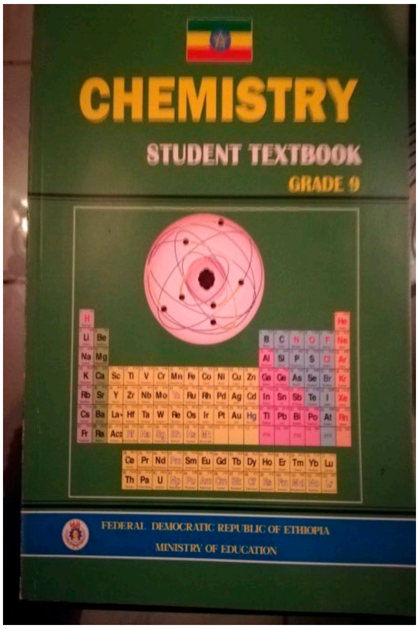
APPENDIX.
ETHIOPIAN GRADE 9 CHEMISTRY TEXTBOOKS CONSIDERED FOR THE STUDY



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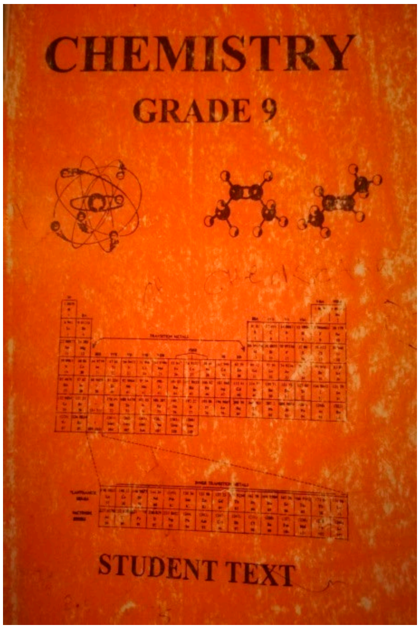

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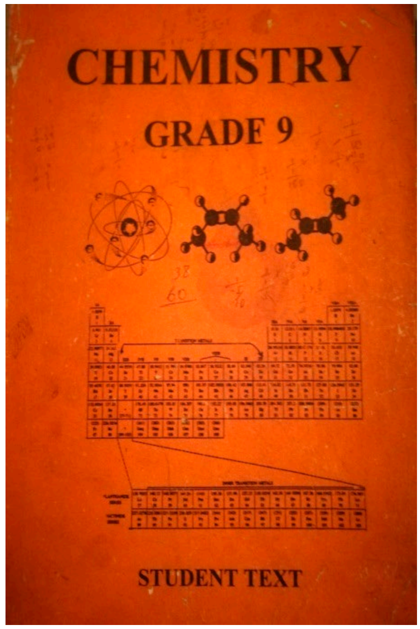

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