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Chunking Strategy as a Tool for Teaching Electron Configuration

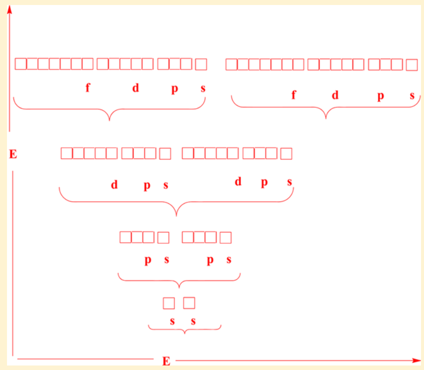
Chandan Adhikary,[†] Sibananda Sana,[‡] and K.N. Chattopadhyay*[,§]

[†]Department of Chemistry, Government College of Education, Burdwan, 713102 West Bengal, India

[‡]Department of Chemistry, Government Training College, Hooghly, 712103 West Bengal, India

[§]Department of Education, The University of Burdwan, Golapbag, Burdwan, 713104 West Bengal, India

ABSTRACT: Chunk-based strategy and mnemonics have been developed to write ground state electron configurations of elements, which is a routine exercise for the higher secondary (pre-university) level general chemistry students. To assimilate a better understanding of the nature of chemical reactions, an adequate knowledge of the periodic table of elements is mandatory. Valence shell electrons of elements participate in redox chemical reactions. Chemistry students thus must be able to write electron configurations correctly. Here we have explored a chunking tool for determining the electron configurations of elements having atomic numbers up to 120.



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Chunking, a memorizing tool, is often used for taking individual units of information and grouping them into larger units.[1] By grouping disparate individual elements into larger blocks, information becomes easier to retain, recall, and recognize. The chunking strategy minimizes cognitive overload and thereby increases the student's mental storage capacity.[2] In terms of chunking, memory has been classified into two categories, namely short-term memory (STM or working memory) with limited capacity and long-term memory (LTM) with unlimited capacity.[3] A schematic model of learning in terms of STM and LTM is shown in Figure 1.[4] The STM acts as a temporary zone for activities such as reasoning, mental mathematics, and problem solving by processing the information from the LTM.[5] In the LTM, the information is stored in connected pieces that can be retrieved by a single act of recognition. These pieces are designated as chunks. A chunk can then be defined as "a collection of elements having strong associations with one another, but weak associations with elements within other chunks".[6] Chase and Simon and later Gobet, Retschitzki, and de Voogt showed that chunking could explain several phenomena linked to expertise in chess.[7,8] Several successful computational models of learning and expertise have been developed using this idea such as EPAM (elementary perceiver and memorizer) and CHREST (chunk hierarchy and retrieval structures). Chunking has also been used with models of language acquisition and symbol sequences.[9] Application of chunking strategy has been well documented in the literature of chemistry education covering areas such as chemistry problem solving, schemes, chemical equations, etc.[9]

Electron configurations of elements and ions serve as key features to the understanding of chemical reactions. Many of the tasks that are presented to students in the area of chemical bonding rely upon the correct assignments of electron configurations to the atoms or ions in a compound.[10] Determination of electron configurations for the elements and ions is a routine exercise that few introductory, general, or inorganic chemistry students escape. In our usual classroom instruction, it is experienced that the students can easily write the correct electron configurations of elements having lower atomic numbers, but they face greater difficulties in determining electron configurations of elements of higher atomic numbers especially for transition and rare earth elements. We hope that the chunking strategy may help the students to overcome such difficulties. In this study, we have designed a chunk-based mnemonics methodology for writing electron configurations of elements accurately.

■ PREVIOUS METHODOLOGIES

A number of methods have been previously developed for determining ground state electron configurations of neutral, isolated polyelectron systems.[11−17] These methods are based upon the Aufbau principle associated with increasing order of energy of the sub levels to predict electron configurations. The most widely accepted strategies of determining electron configurations of elements are collated in Figure 2. The strategies are very similar and follow the mnemonic scheme as first proposed by Yi (Figure 2A) in which electrons are fed into the sublevel diagonally with increasing energy.[14] Later,

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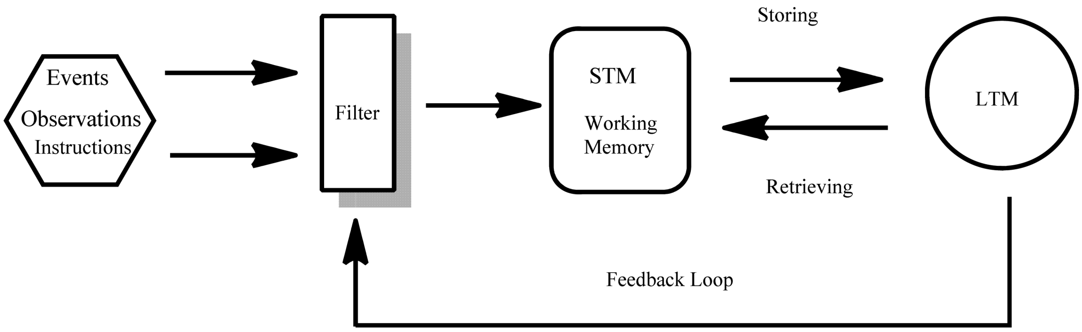

Figure 1. Block diagram of learning model (adapted from ref 4).

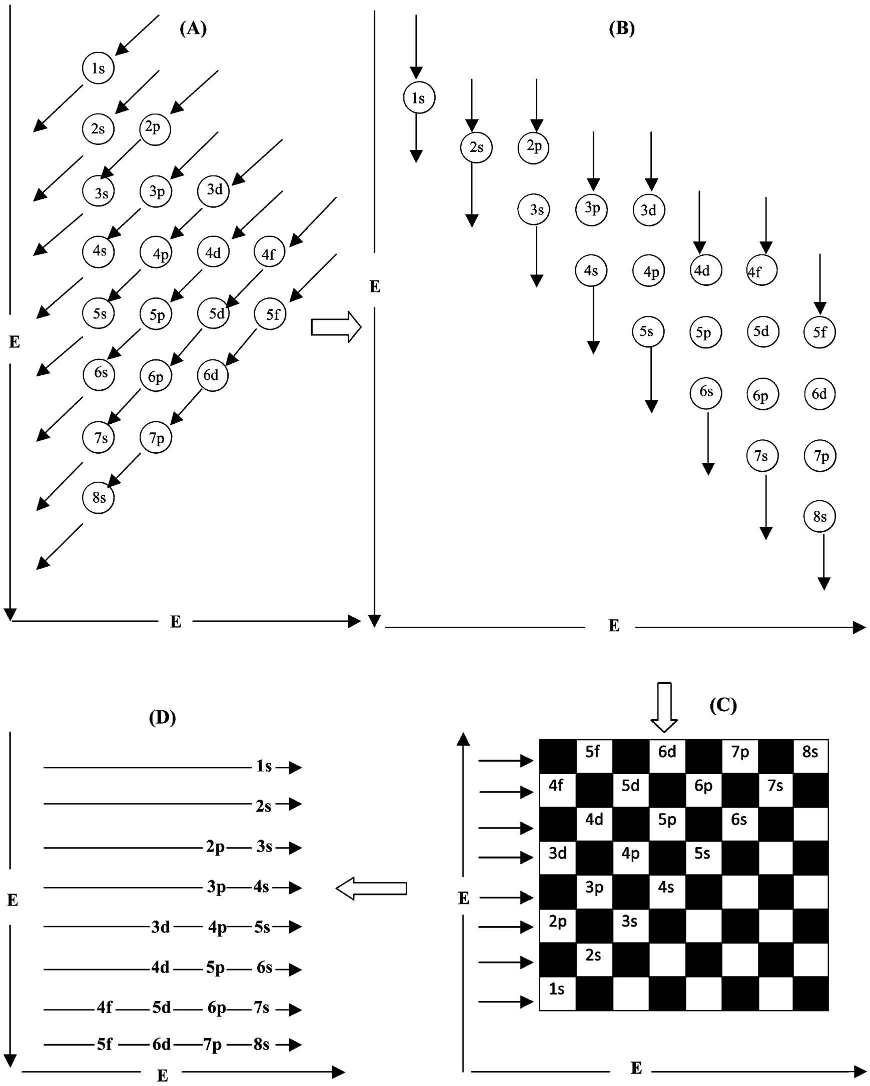

Figure 2. Different strategies for determining electron configurations of elements. (A) Yi's orbital diagram (adapted from ref 14); (B) Carpenter's model (adapted from ref 15); (C) Hovland's chessboard (adapted from ref 16); (D) Parson's scheme (adapted from ref 17).

Carpenter devised a strategy (Figure 2B) where electrons are placed into the orbitals vertically and then horizontally with increasing energy.[15] Hovland derived a scaffolding technique by using the chessboard as a frame of reference for writing electron configuration (Figure 2C) where electrons are occupied into the orbitals left to right in a checkerboard with increasing energy of sublevels.[16] Later, Parson constructed a left-to-right sequence of reading atomic orbitals (Figure 2D) for determination of electron configurations.[17] In his scheme, the n number of s orbitals has been arranged vertically in numerical sequence in a right-justified column, and in the next column immediate to the left are the $(n - 1)$ number of p orbitals again in numerical sequence and so on for $(n - 2)$ number of d and $(n - 3)$ number of f orbitals. Here, electrons are put into the atomic orbitals from left to right sequence with increased energy. Most chemistry textbooks now teach a method where students produce electron configurations of elements using the periodic table.[18] The arrangement of the periodic table provides

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J. Chem. Educ. XXXX, XXX, XXX−XXX

a method for remembering the order of orbital filling. Beginning at the top left and moving across successive rows, the order is 1*s*, 2*s*, 2*p*, 3*s*, 3*p*, 4*s*, 3*d*, 4*p*, and so on. Our proposed methodology is a further investigation in this line that will assist the students to write electron configurations of elements accurately and quickly.

■ PROPOSED METHODOLOGY

This paper proposes a new chunk-based mnemonic scheme for arriving at the electron configurations of elements.

Electron Configurations of Elements

The Aufbau building principle may be written in the following way, as a chunk-based mnemonic:

school school public school public school

dawn public school dawn public school

follow dawn public school follow dawn public school (1)

Here, the phrase "school school" represents a chunk. Similarly, the phrase "public school public school" represents another chunk, and so on. The second chunk is framed by inserting the term "public" before each word "school", and the third chunk is generated by inserting the term "dawn" before each phrase "public school". In the same manner, the fourth chunk is made by placing the term "follow" before each term "dawn public school". In each chunk, there is a repetition of same terminology. For example, in chunk one, "school" is used two times; in chunk two, "public school" is used two times; in chunk three, "dawn public school" is used two times; and, same as before, in chunk four, "follow dawn public school" is used two times.

Step-1: Consider only the first letter of each word, and the above mnemonic phrase becomes a chunk of appropriate orbital letter as follows:

$$s\ s\quad p\ s\ p\ s\quad d\ p\ s\ d\ p\ s\quad f\ d\ p\ s\ f\ d\ p\ s \tag{2}$$

Step-2: Assign the orbitals by inserting numerals in increasing order before each orbital letter. Note that there are eight *s* orbitals in eq 2, and they are assigned unique *s* orbital numbers from 1–8 (Table 1). As a result, the first chunk

Table 1. Shell Number and Assignment of Orbitals

Shell Number	Assignment of Orbitals			
1	1*s*			
2	2*s*	2*p*		
3	3*s*	3*p*	3*d*	
4	4*s*	4*p*	4*d*	4*f*
5	5*s*	5*p*	5*d*	5*f*
6	6*s*	6*p*	6*d*	
7	7*s*	7*p*		
8	8*s*			

becomes 1*s* 2*s*. Again, there are six *p* orbitals in the above equation, and each *p* orbital is assigned unique *p* orbital numbers from 2–7. Hence, the second chunk becomes 2*p* 3*s* 3*p* 4*s*. In the same manner, the *d* orbital begins with 3, and the *f* orbital begins with 4. Therefore, we can easily say that the third chunk becomes 3*d* 4*p* 5*s* 4*d* 5*p* 6*s*, and the fourth chunk becomes 4*f* 5*d* 6*p* 7*s* 5*f* 6*d* 7*p* 8*s*. As a consequence, eq 2 turns into

$$1s\ 2s\quad 2p\ 3s\ 3p\ 4s\quad 3d\ 4p\ 5s\ 4d\ 5p\ 6s\quad 4f\ 5d\ 6p\ 7s\ 5f\ 6d\ 7p\ 8s \tag{3}$$

This is actually Aufbau's building-up principle written on one line. The expression (eq 3) is the most reliable master skeleton for electron configurations of all the elements present in the periodic table.

Step-3: Now electrons are fed in each orbital by following the +4 rule (2, 2 + 4 (= 6), 2 + 4 + 4 (= 10), 2 + 4 + 4 + 4 (= 14)) for *s*, *p*, *d*, and *f* orbitals, respectively.

This means that the *s* orbital is occupied by a maximum of two electrons, the *p* orbital is occupied by a maximum of six electrons (2 + 4), the *d* orbital houses a maximum of 10 electrons (6 + 4), and the *f* orbital's maximum occupancy is 14 (10 + 4) (Table 2).

Table 2. Maximum Number of Electrons That Orbitals Can Accommodate

Orbital	*s*	*p*	*d*	*f*
Max. no. of electrons	2	6	10	14

Step-4: Rearrangement of electron configurations for systematic and sequential presentation of outermost sub shells.

The use of our proposed chunking strategy for assigning electron configurations of elements may be understood clearly from the following examples.

Example 1: Electron configuration of $_{37}$Rb (*s*-block element).

Step-1: Consider the chunking topology: $\underline{s\ s}\ \underline{p\ s\ p\ s}\ \underline{d\ p\ s\ d\ p\ s}\ \underline{f\ d\ p\ s\ f\ d\ p\ s}$.

Step-2: Assign the orbital numbers as mentioned. This results the skeleton as 1*s* 2*s* 2*p* 3*s* 3*p* 4*s* 3*d* 4*p* 5*s* 4*d* 5*p* 6*s* 4*f* 5*d* 6*p* 7*s* 5*f* 6*d* 7*p* 8*s*.

Step-3: Now electrons are fed in each orbital by following +4 rule, that is, the maximum occupancy for *s*, *p*, *d*, and *f* orbitals are 2, 6, 10, and 14 electrons, respectively. This results in the electronic configuration of $_{37}$Rb as $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^1$.

Example 2: Electron configuration of $_{51}$Sb (*p*-block element).

Step-1: $\underline{s\ s}\ \underline{p\ s\ p\ s}\ \underline{d\ p\ s\ d\ p\ s}\ \underline{f\ d\ p\ s\ f\ d\ p\ s}$.

Step-2:1*s* 2*s* 2*p* 3*s* 3*p* 4*s* 3*d* 4*p* 5*s* 4*d* 5*p* 6*s* 4*f* 5*d* 6*p* 7*s* 5*f* 6*d* 7*p* 8*s*.

Step-3: $_{51}$Sb: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^3$.

Step-4: Rearranged electron configuration of $_{51}$Sb: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 4d^{10}5s^2\ 5p^3$.

Example 3: Electron configuration of $_{25}$Mn (*d*-block element).

Step-1: $\underline{s\ s}\ \underline{p\ s\ p\ s}\ \underline{d\ p\ s\ d\ p\ s}\ \underline{f\ d\ p\ s\ f\ d\ p\ s}$.

Step-2:1*s* 2*s* 2*p* 3*s* 3*p* 4*s* 3*d* 4*p* 5*s* 4*d* 5*p* 6*s* 4*f* 5*d* 6*p* 7*s* 5*f* 6*d* 7*p* 8*s*.

Step-3: $_{25}$Mn: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^5$.

Step-4: Rearranged electron configuration of $_{25}$Mn: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^2$

Example 4: Electron configuration of $_{62}$Sm (*f*-block element).

Step-1: $\underline{s\ s}\ \underline{p\ s\ p\ s}\ \underline{d\ p\ s\ d\ p\ s}\ \underline{f\ d\ p\ s\ f\ d\ p\ s}$.

Step-2:1*s* 2*s* 2*p* 3*s* 3*p* 4*s* 3*d* 4*p* 5*s* 4*d* 5*p* 6*s* 4*f* 5*d* 6*p* 7*s* 5*f* 6*d* 7*p* 8*s*.

Step-3: $_{62}$Sm: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^2\ 4f^6$.

Step-4: Rearranged electron configuration of $_{62}$Sm: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 4f^6\ 6s^2$.

Implementation of the Proposed Method. We have administered three separate strategies for teaching electron

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J. Chem. Educ. XXXX, XXX, XXX–XXX

configurations of elements to three equivalent groups of higher secondary (class XII, pre-university) students (science group, chemistry major) of Burdwan Model School, West Bengal, India and evaluated the effectiveness of the strategies. For this purpose, we selected 30 students and categorized them into three equivalent groups comprising ten students in each group, and interventions were given for about 1 h in each case. The equivalency of the groups has been determined on the basis of students' score in chemistry in their previous annual examination (class XI). By employing a lottery, two groups were assigned to be the control groups, and the third one was assigned to the experimental group, namely, the chunk-based group. The first control group was taught by Yi's method (Figure 2A) (method 1). The second control group was taught by Parson's method (Figure 2D) (method 2). Our proposed chunk-based method [$\underline{s\ s}\ \underline{p\ s\ p\ s}\ \underline{d\ p\ s\ d\ p\ s}\ \underline{f\ d\ p\ s\ f\ d\ p\ s}$ (eq 2] (method 3) was administered to the chunk-based group. After instruction, learning outcomes have been quantified by applying an achievement test consisting of 25 problems on writing electron configurations of the elements. The students were allowed 40 min to answer the problems. The statistical results of the three groups are summarized in Table 3.

Table 3. Statistical Results of Three Groups

Group	Mean	Standard Deviation
Yi's group	13.55	5.61
Parson's group	17.4	5.07
Chunk-based group	20.1	2.51

When we compared the means of Yi's group and our chunk-based group, it was found that the t value is 3.34, which implies that there is a significant differences in mean at 0.01 level of significance. On the other hand, when we compared the performance between Parson's group with our proposed chunk-based group, it was observed that the difference between means is not statistically significant at 0.05 level.

It should be noted that our proposed methodology will not be helpful for determination of some exceptional electron configurations of some transition elements and rare earth elements. These anomalies are due to consequence of unusual stability of both half-filled and fully-filled subshells, high exchange energy, and relativistic stabilization for heavier elements.[18−20] Chromium, for example, which we would predict to have the configuration [Ar] $4s^2\ 3d^4$, actually has the configuration [Ar] $4s^1\ 3d^5$. By moving an electron from the orbital to an energetically similar orbital, chromium trades one filled subshell ($4s^2$) for two half-filled subshells ($4s^1\ 3d^5$), which thereby allows the two electrons to be farther apart. In the same way, copper, which we would predict to have the configuration [Ar] $4s^2\ 3d^9$, actually has the configuration [Ar] $4s^1\ 3d^{10}$.

■ CONCLUSIONS

An electron configuration indicates the order in which electrons are arranged around the nucleus of an atom. The position of an element in the periodic table, its chemical nature, and reactivity can be predicted from its valence shell electron configurations. From this stand-point, everybody associated with the chemical world should know the appropriate determination of electron configurations of the elements. Our proposed methodology is based on rote memorization of a mnemonic that possesses a rhythm of repetitive phrases. A student can remember such a mnemonic in a play way manner, and thus writing of electron configurations of elements will be easier. Although the method has some limitations with respect to determination of exceptional electron configurations of some elements, it may be applied for the introductory chemistry beginners. It is also our speculation that the proposed method will help the students to retain the sequence of atomic orbitals into their long-term memory for a longer time period as it is based on the chunking strategy.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: knc_bu@yahoo.co.in.

Notes

The authors declare no competing financial interest.

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