There is Much More to Mendeleev's Periodic Table Than Meets the Eye

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Recognition of periodic trends in the properties of elements is important for understanding and predicting the role of trace metals in biology.

Introduction

The great Russian chemist Mendeleev believed that there should be a perfect order in the occurrence and properties of the elements in nature. At his time only 63 elements were known. Among them were gases, liquids and solids. He arranged the elements according to the increasing order of their atomic weights. His aim in arranging those elements was essentially to group them according to their similarities, so that their study could be simplified. He found that the properties of elements showed definite periodicity. In 1869, he enunciated the periodic law – *the physical and chemical properties of elements are periodic functions of their atomic weights.*

The periodical occurrence of the properties was so systematic that Mendeleev predicted the occurrence of two then unknown elements and named them eka-aluminium and eka-silicon, and predicted their properties which were later found to be correct. The importance of this work was recognized when these two elements gallium and germanium were discovered.

In 1912, the young English physicist Moseley (1887–1915) studied X-ray spectra of more than fifty elements and derived a better basis for the classification of elements. As a result, Mendeleev's periodic law was modified and termed the modern periodic law which states – *the physical and chemical properties of elements are periodic functions of their atomic numbers.*

With the advent of the modern periodic law, the dependence of the properties of elements on their electronic configuration was

Box 1

The elements in the same column of the periodic table belong to a group. In the modern format, there are 18 groups. The valence electronic configuration is the same for all elements in a given group. For example, all the elements in group 1 have the s^1 configuration. Chemical properties of elements in a group are similar. The rows in the periodic table are called periods. There are 7 periods. Properties vary along a period in a systematic manner.

realized. This knowledge has been incorporated into the long form of the periodic table and the elements are classified into *s*, *p*, *d* and *f* blocks according to their electronic configuration. This arrangement lends itself very well to study, understand and predict the behaviour of a particular element (see *Box 1*).

Chemists have long recognized many systematic patterns from the periodic table. But the significance and the utility of these have not been generally noted by biologists, environmentalists, biochemists or medical scientists. In this article, we view the periodic properties of elements from the perspective of biology.

Trace Elements of Biological Importance

The essentiality of certain metal ions (e.g. Ca^{2+}, Fe^{2+}, Fe^{3+}, Mg^{2+}) in living organisms, be it a plant or animal, has long been recognised. The need for certain metal ions in trace quantities (e.g. Cu^{2+}, Zn^{2+}) is also well known. The accumulation, depletion and deficiency of certain metals in the human body cause definite diseases. For example accumulation of Al^{3+} in the brain has been suspected to be partly responsible for the onset of Alzheimer's disease (AD); that of copper causes Wilson's disease; and that of lead results in plumbism. The deficiency of iron causes anemia and that of iodine leads to iodine deficiency diseases (IDD) and hypothyroid disorders. The depletion of calcium causes osteoporosis. As industrialization progresses many more non-essential metal ions are bound to be ingested and accumulated or depleted both in plants and animals, with possible deleterious biological consequences.

At the same time, beneficial aspects of certain metals in the treatment of diseases are also well known: for example, lithium in the treatment of mental depression, cobalt in pernicious anemia, zinc in Wilson's disease and potassium in thallium poisoning.

A better understanding of the gradation of properties among elements in the columns (groups) and rows (periods) of the long form of the periodic table would help in understanding, explaining and predicting the behaviour of metal ions in biology.

Properties of Elements in a Group

All the elements belonging to a group show similarities and **gradation** in their physical and chemical properties which are due to (a) similar outer electronic configuration, (b) increasing size of the atom and (c) the increasing electropositive nature (i.e, metallic nature) down the group.

The significance of these periodic trends in the biological role of certain elements is summarised in *Table 1*.

The Inter Pair Effect

The resistance to lose *s*-electron in the valence shell (among 13, 14 and 15 group elements) is termed as the **inert pair effect,** due to which the lower oxidation state of an element becomes more and more stable down the vertical column. For example, the last element thallium (in 13) with $6s^2 6p^1$ outer electronic configuration forms more stable thallous ion (Tl^+) than the tripositive thallic ion, lead ($6s^2 6p^2$) forms stable dipositive ion and bismuth ($6s^2$ $6p^3$) forms the tripositive ion. The stable ions have properties similar to those of cations of other groups. This interesting variation also has implications for the biological role of these elements (*Table 2*).

Diagonal Relationship

The size of an atom of an element increases down a group and decreases across the period. As a result, if one considers two elements placed diagonal to each other, such as Li and Mg, the properties, related to size seem to be the mean of the two opposing effects and therefore close to each other. Such diagonally placed elements often show similar physical and chemical properties. These also seem to have **antagonistic effects** on **biological systems** (see *Table 3*).

Amphoteric Elements

There are a few amphoteric elements, among which Zn and Al

Table 1. Significance of periodic trends within groups in biology.

Group	Element	Known mode of action in biological systems.	The known/plausible therapeutic uses
1	Li Na K Rb Cs Fr	Li^+ acts antagonistic to Na^+ in a nerve cell Li_2CO_3 is used to treat manic depression.	If the unipositive Li^+ can be antagonistic to Na^+, the antagonistic ability of the other unipositive ions may be in the order $H^+ > Li^+$. In other words a mere pH change may activate a depressed nerve cell.
2	Be Mg Ca Sr Ba Ra	Ions of group 2 elements are bone seekers. Between a pair of these ions, the lighter is preferentially absorbed, excreting the heavier. For example, excessive intake of Mg^{2+} results in the excretion of Ca^{2+} and so on.	Mg^{2+} has a protective effect towards heart muscles. It is harmful to remove Mg^{2+} from common salt NaCl samples to make them dry and free flowing. On the contrary, magnesium enriched common salt may be a preventive measure against ischaemic heart diseases.
13	B Al Ga In Tl	Boron (as boric acid) seems to reverse the pathology caused by Al^{3+} in protein molecules.	Boron is a potential antidote to Al-toxicity. because it is in the same group as Al and has diagonal relation to silicon.
11	Cu Ag Au	The ions of group 11 elements exhibit 'oligo-dynamic' (anti-microbial) property.	Will silver be a better material for injection needles and surgical instruments, to avoid microbial contamination?
		Copper-T (Intra-uterine contraceptive device) is known to deplete calcium and therefore may be the cause for excessive bleeding.	Will silver-T or gold-T be a better IUD ?
12	Zn Cd Hg		Zn^{2+} is a constituent of a number of ointments used in healing wounds and against burns. The compounds of Cd^{2+} and mercury are used as insecticides as well as fungicides.

Table 2. Significance of the inert pair effect in biology.

Group	Element	Known mode of action in biological systems	The known/plausible therapeutic uses
13	B Al Ga In Tl	Thallous ion (Tl^{+}) resembles potassium ion in its electropositive nature.	K^{+} (as KCl solution) is administered intravenously to treat thallium poisoning.
14	C Si Ge Sn Pb	Pb^{2+} is also a bone seeker like alkaline earth metals. The fall of the Roman Civilization has been attributed to lead poisoning. The analysis of their bone samples reveals evidence to this effect.	Ca^{2+} is used in the treatment of lead poisoning (plumbism).
15	N P As Sb Bi	The precipitated hydroxide of bismuth, in gastric acid, coats the ulcer crater with an antacid glycoprotein complex. The latter is slowly permeable to the H^{+} ion and acts as a diffusion barrier to gastric acid.	Salts of Bi^{3+} (e.g. pepto Bismol) are used in the treatment of gastric ulcers.

show greater similarities. For example, their hydroxides can neutralize acids and they dissolve in strong bases forming zincates and aluminates and their phosphates are insoluble in water.

$Al(OH)_3$ is widely used as an antacid. It is also used to treat dialysis patients, as it facilitates the excretion of phosphate as solid waste. However, deleterious effects of Al^{3+} on the nervous system are an established fact. Since Al^{3+} has no known role in biological systems it is high time that a better substitute is sought. $Zn(OH)_2$ may prove to be a suitable substitute as Zn^{2+} is known to have beneficial effects in biological systems (see *Table 4*).

A Specific Application

Aluminium toxicity is reduced by silicic acid. Since the elements

Table 3. Importance of diagonal relationship among elements in biology

Diagonal pairs		Known mode of action in biological systems	The known/plausible therapeutic uses.
1 Li	2 Mg	Li^+ activates depressed cells, whereas Mg^{2+} depresses central nervous system (CNS).	Mg^{2+} possesses local anesthetic activity.
2 Be	13 Al		Will beryllium and aluminium act as antagonists? If so will Be reverse the pathology caused by Al in Alzheimer's disease?
13 B	14 Si	Al-toxicity is reduced by silicic acid (antagonistic effect).	If silicic acid can reduce Al-toxicity, boric acid should have a similar effect (due to their diagonal positions).
2 Ca Sr	12 Cd Hg	Ca^{2+} is an antidote to cadmium toxicity (antagonistic effect).	If that is so, can Sr^{2+} be useful in treating mercury poisoning?
16 Se	17 I	Iodine and selenium are essential trace elements. Some of their metabolic roles may be inter-related. Selenium has a role in thyroid hormone metabolism.	In the treatment of iodine deficiency diseases (IDD), selenium may be playing a vital role which is to be investigated.

boron and silicon are diagonally positioned, they exhibit similar physical and chemical properties. Therefore, boric acid is also expected to reduce Al-toxicity.

Though boron and silicon are similar in their action in counteracting the effect of aluminium on brain proteins, it must be remembered that boron is a nutrient while silicon is not. In this respect they are dissimilar if not antagonistic to each other. This is in conformity with other diagonally placed elements which are chemically similar, but play dissimilar/antagonistic

Table 4. Uses of aluminium and its compounds.

Uses	Alternatives
Al $(OH)_3$ is widely used as an antacid. Large doses of Al $(OH)_3$ are administered to dialysis patients. As a result, these patients suffer from progressive dementia.	Zn has several important biological roles. Can $Zn(OH)_2$ be a better antacid? (See *Table 1*, group 12 elements.)
Al is a highly reactive metal. It reacts even with cold water. While cooking in Al-utensils, the metal dissolves. Al is believed to accumulate in brain cells.	Use of clay or glass is the best option for cooking purposes as metal toxicity is avoided.
Potash alum $K_2SO_4\ Al_2\ (SO_4)_3,\ 24H_2O$ is used in water treatment to facilitate the coagulation of suspended particles.	Fe $(OH)_3$ is a good substitute. It coagulates the suspended particles thus rendering water clear during treatment.

roles in biological systems (see *Table 3*).

Conclusion

Certain actions of different elements in biological systems apparently are determined by their positions in the periodic table. Gradation in some form, i.e. vertical or diagonal seems to be significant and calls for a wider study so as to include other elements about which very little or nothing is known. Even the small number of examples discussed in this article seems to justify such studies which may lead to a better under-standing of the plausible role of different elements in biological systems with eventual therapeutic applications. Will the interdisciplinary groups of chemists, biologists and medical researchers revisit the periodic table?

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