3 STRUCTURE OF ATOM AND PERIODIC TABLE

WHAT WE HAVE LEARNT

- **In an atom , electrons revolve in different shells around the positively charged nucleus.**
- **The maximum number of electrons that each shell can accommodate is $2n^2$.**
- **The physical and chemical properties of elements depend on their atomic number.**
- **Periodicity is found in atomic size, electronegativity, electropositive nature and valency of elements.**
- **The ability to enter into chemical reactions is different for each atom.**

STRUCTURE OF ATOM AND PERIODIC TABLE

More than a hundred and ten elements are known to us. Their physical and chemical properties have also been defined. The elements are arranged in the periodic table in such a way that their chemical and physical properties can be predicted. We can find out the properties of an element if its position in the periodic table is known and we can also know the position in the periodic table, if its properties are known. The basis for the arrangement of the various elements in the periodic table is the similarities and differences in their atomic structure.

Atoms are minute particles. If ten lakhs of atoms are arranged one after the other, it would come to a length of one millimeter only. How can we study the structure of such small particles? Through experiments, scientists have developed certain ideas about the internal structure of the atom which is not visible even through the most powerful microscope. It is possible to explain the properties of atoms and elements on this basis of these ideas.

You have learnt that the electrons of an atom are arranged in different shells around a nucleus. The basis of this arrangement is the energy level of the electrons. The attraction of the nucleus on the electrons decreases as the distance from the nucleus increases. Therefore, the energy of the electrons decrease as their distance from the nucleus increases. That is, the electrons in the first shell K will have the least energy. Likewise, the energy of electrons progressively increases from L to M and to N. Hence, each shell can be considered as an energy level. You have learnt to calculate the maximum number of electrons that each shell can accommodate using the formula $2n^2$. Calculate the maximum number of electrons in the shells K,L,M and N and record it in your science diary.

Elements from hydrogen which has only one electron to darmstadtium (Ds) that has 110 electrons are familiar to us. These electrons are randomly distributed around the nucleus. They are arranged in the atom in accordance with certain general laws.

Electron configuration in shell and subshell

Examine the Bohr models of potassium, calcium and scandium given below and complete the table.

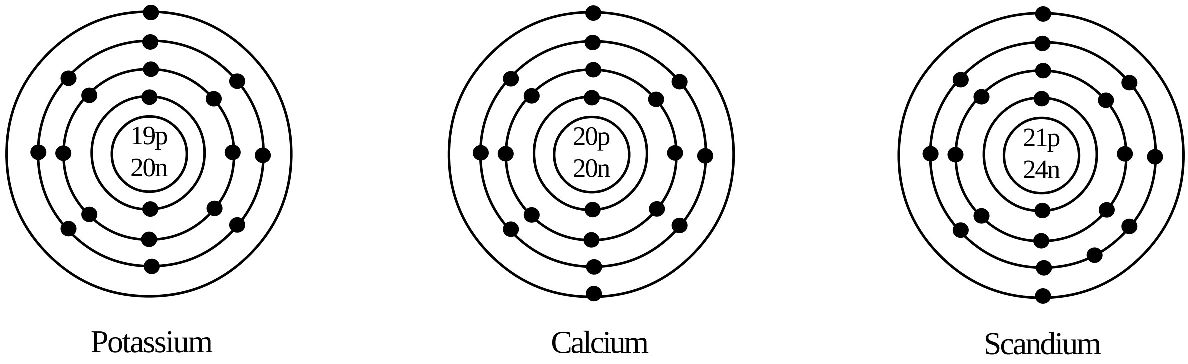

Figure 3.1

Element	Shells			
	K	L	M	N
$_{19}K$				
$_{20}Ca$				
$_{21}Sc$				

Table 3.1

- **To which shell does the last electron enter in potassium and calcium atoms? Why? Now examine the case of scandium.**
- **Electrons are not distributed randomly within the atom. They are most likely to be seen in certain areas of the atom. The potential energy of the electrons decides where electrons can be seen in an atom.**

Higher the potential energy of an electron, greater will be its distance from the nucleus. There are some areas where the possibility of finding an electron is greatest. These areas are found around the nucleus, one around the other.

Imagine a glass marble placed within a ball. This ball is placed within another ball which is in turn contained within a bigger ball. Each ball is then equivalent to an area where electron can be found. These can be called as shells. It is important to realise that shells are not physical entities. They are merely the shape of areas where the probability of finding electrons is the highest. The electron with the lowest potential energy will be found in the shell closest to the nucleus. As potential energy increases, electrons will be distributed in shells further away from the nucleus.

When there are more than one electron in a shell, they are arranged according to their potential energy. Electron with the least potential energy will be placed at the lowest level in the shell (ie., nearest to the nucleus). Electrons with higher potential energy will go to higher levels.

In other words, it is similar to the arrangement of electrons around the nucleus. Electrons are found in areas arranged one around the other, energy levels within the shells also follow the same arrangement.

These energy levels within a shell can be called subshells. They are named as s, p, d, f.

Like shells, subshells can accommodate only a limited number of electrons. The maximum number of electrons that can be accommodated in 's' subshell is 2. Shells and subshells in each shell are given in Table 3.1 below. Find out the number of electrons in subshells and fill in the table.

Subshells in the same shell differ in their energy. For example, subshells in the fourth shell can be shown as below in the order of increasing energy.

4s < 4p < 4d < 4f

Shell number	1	2		3			4			
Name of the shell	K	L		M			N			
Maximum number of electrons	2	8		18			32			
Sub shell	s	s	p	s	p	d	s	p	d	f
Number of electrons in sub shell	2	2	—	—	—	—	—	—	—	—

Table 3.2

- Which subshell is common to all shells?
- Which are the subshells in the second shell?
- Is there a relation between shell number and number of subshells?
- Out of 8 electrons in L shells, if two electrons are in the 's' subshell, how many electrons will there be in p-subshell?
- Which shell does not have a 'p' subshell?
- How many electrons can d and f subshells accommodate?

You have seen from the table 3.2 that there are subshells of the same name in different shells. The subshells are written prefixing the shell number of the shell to which it belongs so as to identify the sub shells. The 's' subshells in different shells are written in their order of increasing energy, as under.

1s < 2s < 3s < 4s

Which subshells are seen in the 5th shell? Write them in their order of increasing energy.

5s < ....

The first letters of the words 'sharp, principal, diffuse and fundamental' are used to name the subshells as s, p, d and f respectively. These words are associated with atomic structure. Among the elements discovered so far, 118th element has the highest atomic number. s,p,d,f subshells are sufficient to write the electron configurations upto the 118th element. If in future a new element will have a fifth sub shell, it will be called as 'g - subshell'.

Subshell electron configuration

When more electrons come to a particular shell in an atom, they are arranged in different sub energy levels. That is, electron filling takes place in subshells. Let us see how this electron filling takes place in subshells.

Take the case of hydrogen atom. There is only one electron. It goes to the 's' subshell in the first shell. The subshell electron configuration of hydrogen atom can be illustrated as under.

Main energy level — $1S^1$ — Number of electron

Sub shell

(You may read this as "one ess one")

Now, see the electron configuration of helium. $1s^2$

Some of the subsequent elements are given in table 3.3 below. Fill up suitably.

Examine the sub shell electron configuration of potassium.

$1s^2\ 2s^2 2p^6\ 3s^2 3p^6\ 4s^1$

Besides the s, p subshells in the third energy level (M shell), there is the 'd' subshell too in it. Instead of entering into the 3d subshell, why do electrons go to the next subshell (4s)? Analyse figure 3.2 showing the energy of subshells.

- Between 3d and 4s subshells, which has less energy?
- In potassium, to which subshell is the last electron added to?

Electron filling takes place in the ascending order of the energy of subshells. This is known as aufbau principle.

Why the 19 th electron of potassium enters into the 4s subshell must now be clear to you.

When the 4s subshell is filled, which subshell does the next electron enter?

Element	Electron configuration in shell	Electron configuration in sub shell
$_3Li$	2, 1	$1s^2, 2s^1$
$_6C$	2, 4	$1s^2, 2s^2, 2p^2$
$_{10}Ne$		
$_{11}Na$		
$_{13}Al$	2, 8, 3	$1s^2, 2s^2, 2p^6, 3s^2, 3p^1$
$_{17}Cl$		
$_{18}Ar$		
$_{19}K$	2, 8, 8, 1	
$_{20}Ca$		

Table 3.3

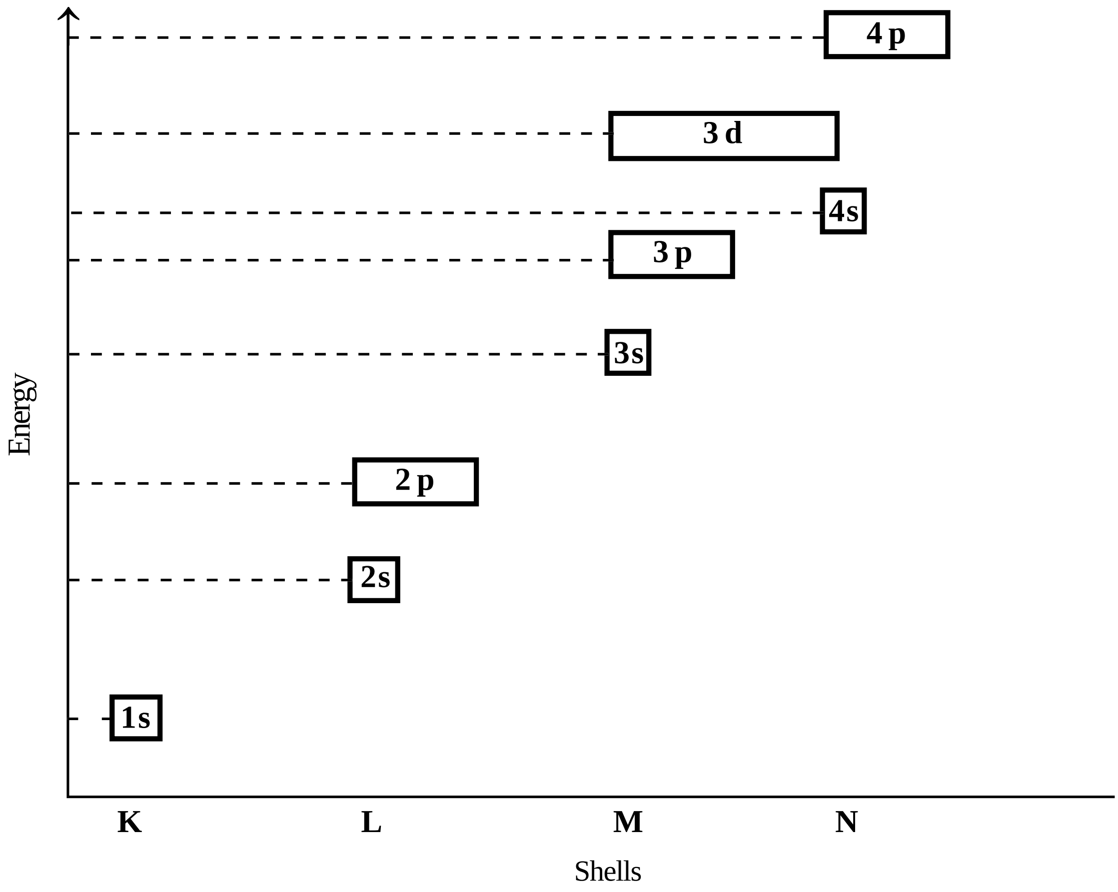

Figure 3.2

Let us write the electron configuration of scandium.

$1s^2$ $2s^22p^6$ $3s^23p^6$ $4s^23d^1$

Figure 3.3 will help you find the increasing order of energy of different subshells. In each column, subshells that have an increase in energy from top to bottom are shown.

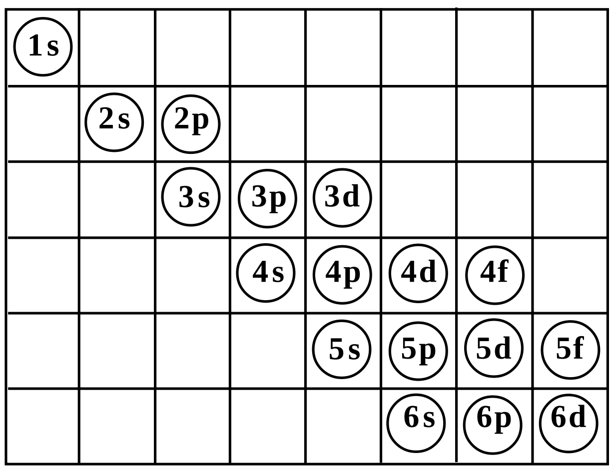

Figure 3.3

When we write the subshell electron configuration of an atom, it is enough that we put the symbol of the preceding noble gas in bracket first and then write the subshell configuration of the remaining electrons.

Chromium and Copper

Examine the subshell electron configuration of $_{24}Cr$, and $_{29}Cu$

Cr - [Ar] $3d^5$ $4s^1$

Cu - [Ar] $3d^{10}$ $4s^1$

In their 3d subshell they have 5 and 10 electrons respectively. This should have been **[Ar] $3d^4 4s^2$** and **[Ar]$3d^9 4s^2$**, as per principle. But, d^5 is "half filled" and d^{10} is "completely filled". Half filled and completely filled subshell electron configurations are more stable than partially filled configurations. In chromium and copper, instead of filling the 4s subshell with 2 electrons, one electron goes to the 3d subshell in order to attain the 'more stable' electron configuration.

For example, electron configuration of calcium is **$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $4s^2$.** You can represent this as **[Ar] $4s^2$**. Like this, try writing the subshell electron configuration of elements given.

Element	Electron configuration in subshell
$_{22}Ti$	[Ar] $3d^2$ $4s^2$
$_{25}Mn$	
$_{27}Co$	
$_{30}Zn$	
$_{31}Ga$	

Table 3.4

Blocks in Periodic Table

In the modern periodic table elements are classified into 18 groups based on electron configuration. These electrons are seen in different subshells.

s, p block elements

Write the subshell electron configuration of elements of the first and second group.

Group - 1	Group - 2
Li – [He] $2s^1$	Be - [He]$2s^2$
Na – [Ne] $3s^1$	Mg - [Ne] $3s^2$
K - [Ar] $4s^1$	Ca - [Ar] $4s^2$
Rb................	Sr................
Cs................	Ba................
Fr................	Ra................

Table 3.5

To which subshell does the last electron enter? The reason for calling these elements as 's' block elements is clear now. Write the electron configuration of elements of group 13-18 . Find why they are called 'p' block elements and record it in your 'science diary'.

Write the electron configuration of elements in table 3.6 and find

- the relationship between the number of principal shells and the period number.
- the relationship between the number of outer most shell and the period number.
- the relationship between the total number of electrons in the outermost shell and group number.

s - block | d - block | p - block | f - block

1.0 H hydrogen 1																	4.0 He helium 2
7.0 Li lithium 3	9.0 Be beryllium 4											10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12											27.0 Al aluminium 13	28.0 Si silicon 14	31.0 P phosphorus 15	32.0 S sulphur 16	35.5 Cl chlorine 17	40.0 Ar argon 18
39.0 K potassium 19	40.0 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	51.0 V vanadium 23	52.0 Cr chromium 24	55.0 Mn manganese 25	55.8 Fe iron 26	59.0 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	75.0 As arsenic 33	79.0 Se selenium 34	80.0 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	93.0 Nb niobium 41	96.0 Mo molybdenum 42	Tc technetium 43	101.7 Ru ruthenium 44	103.0 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	127.0 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56		178.5 Hf hafnium 72	181.0 Ta tantalum 73	183.9 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.0 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	Bi bismuth 83	Po polonium 84	At astatine 85	Rn radon 86
Fr francium 87	226.0 Ra radium 88		Rf rutherfordium 104	Db dubnium 105	Sg seaborgium 106	Bh bohrium 107	Hs hassium 108	Mt meitnerium 109	Ds Darmstadtium 110	Uuu unununium 111	Uub ununbium 112						

Lanthanides	138.9 La lanthanum 57	140.1 Ce cerium 58	140.9 Pr praseodymium 59	144.2 Nd neodymium 60	Pm promethium 61	150.4 Sm samarium 62	152.0 Eu europium 63	157.3 Gd gadolinium 64	158.9 Tb terbium 65	162.5 Dy dysprosium 66	164.9 Ho holmium 67	167.3 Er erbium 68	168.9 Tm thulium 69	173.0 Yb ytterbium 70	175.0 Lu lutetium 71
Actinides	227.0 Ac actinium 89	232.0 Th thorium 90	231.0 Pa protactinium 91	238.0 U uranium 92	237 Np neptunium 93	Pu plutonium 94	Am americium 95	Cm curium 96	Bk berkelium 97	Cf californium 98	Es einsteinium 99	Fm fermium 100	Md mendelevium 101	No nobelium 102	Lr lawrencium 103

Element	K	L		M			N			
	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f
$_{11}Na$										
$_{12}Mg$										
$_{13}Al$										
$_{14}Si$										
$_{15}P$										
$_{16}S$										
$_{17}Cl$										
$_{18}Ar$										

Table 3.6

- the metallic and non-metallic properties of s, p block elements.

Find whether the tendencies are like this in the case of other elements in s, p blocks.

On the basis of the following points, discuss why s, p block elements are called representative elements.

- tendency for periodicity
- metals, non metals, metalloids, solids, liquids and gases

Record your inferences in the science diary.

d block elements

Find from the periodic table which are the groups of elements that come between s-block and p-block. The electron configuration of certain elements in the fourth period is given below.

Sc	21	[Ar] $3d^1$ $4s^2$
Ti	22	[Ar] $3d^2$ $4s^2$
V	23	[Ar] $3d^3$ $4s^2$
Mn	25	[Ar] $3d^5$ $4s^2$
Co	27	[Ar] $3d^7$ $4s^2$
Ni	28	[Ar] $3d^8$ $4s^2$
Zn	30	[Ar] $3d^{10}$ $4s^2$

- Which is the outermost shell in these?
- In which shell and subshell does the electron filling take place?
- How many electrons are there in the outermost shell?
- What is special about the number of electrons in the outermost shell?

The electron in the outermost shell decides the chemical properties of elements. Has it become clear why the 'd' block elements show horizontal similarities in their properties? The 'd' block elements are called 'transition elements".

One of the well known transition element is iron. Write its electron configuration.

Write the oxidation states of iron in **$FeCl_2$ and $FeCl_3$**.

In the compound **$FeCl_2$**, electron from which subshell does iron lose?

When the compound **$FeCl_3$** is formed, one of the electrons in 3d subshell is also lost along with the two electrons in the 4s subshell. Thus, iron loses three electrons. This happens so because the energy difference between 4s and 3d subshells is very little. So, iron exhibits two oxidation states. All transitional elements, except Zn, show different oxidation states.

For example, the chemical formulae of some manganese compounds are given. Calculate the oxidation state of manganese in each.

$MnCl_2$, MnO_2, Mn_2O_4, Mn_2O_7

The atomic number of manganese is 25. Write the electron configuration. Can you tell the reason for the different oxidation states of manganese?

Analyse the table given below:

Compound	Colour
Copper sulphate	Blue
Sodium chloride	Colourless
Potassium dichromate	Orange
Potassium nitrate	Colourless
Potassium permanganate	violet
Calcium chloride	Colourless
Cobalt chloride	Blue
Copper chloride	Green
Ferrous sulphate	Green
Calcium hydroxide	Colourless
Thorium oxide	Colourless
Cerium sulphate	Colourless

Table 3.7

Which metals form coloured compounds? To which block do they belong?

List the salient features of d-block elements.

Prepare and present a short writeup explaining how the 'd' block elements differ from 's' and 'p' block elements.

f- block elements

You already know about lanthanones and actinones in the periodic table. Which are the elements having atomic number 61 and 94? Write their electron configuration. In them, the last electron goes to the f-subshell of the ante penultimate shell. Now you know for sure which are the 'f' block elements.

With the help of modern periodic table, find the following and record it in your Science diary.

- Number of groups
- Number of periods
- Number of elements in each of s, p, d and f - blocks.
- If the electron configuration of an element is **[Rn] $7s^2$ $5f^5$,** to which block does it belong? What is the group number and period number of this element?

Ionisation energy

You have learnt about the change that happens to the size of an atom along the periods and groups in the periodic table. As the size of the atom increases, the distance from the nucleus to the outermost shell also increases. The positively charged nucleus of the atom attracts the electrons. So, if electrons are to be removed from the outermost shell of an atom, they are to be brought out of the field of attraction of the nucleus. For this, certain amount of energy is to be provided. This is called the ionisation energy.

Analyse the graph given below and find out how ionisation energy and size of atom are related to one another.

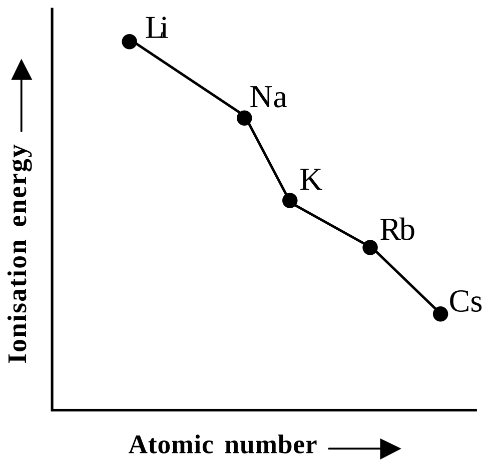

Figure 3.4

- **Down the group, does the ionisation energy increase or decrease?**
- **Which element has the highest ionisation energy? Which period does it come in?**
- **Which is the element having the least ionisation energy? Which period?**
- **How is ionisation energy associated with metallic character?**

Consider the following facts and discuss the reason for the decrease in ionisation energy down the group.

- **number of shells**
- **size of atom**
- **the force of attraction that the nucleus has on the electrons in the outermost shell.**

Now let us see how the ionisation energy varies along a period. The ionisation energies of elements of the 3rd period are given in the table.

Element	Ionisation energy kJ/mol
$_{11}Na$	502
$_{12}Mg$	744
$_{13}Al$	584
$_{14}Si$	792
$_{15}P$	1020
$_{16}S$	1010
$_{17}Cl$	1260
$_{18}Ar$	1530

Draw a graph of the above and find the following:

- **What will be the order of change in ionisation energy? As the atomic number increases, will the ionisation energy increase or decrease?**
- **Which element has the highest ionisation energy? In which group does it come? Is it a metal or non metal?**
- **Which element has the least ionisation energy? What is its group? Is it a metal or a non-metal?**

On the basis of the following, analyse the reason for the increase in ionisation energy of elements as the atomic number increases along a period.

- **change in the nuclear charge.**
- **electron filling takes place in the same shell.**
- **change in the size of the atom.**
- **the force of attraction that the nucleus has on the valence electrons.**

Structure of atom and chemical properties

It is now clear to you that the basis for the arrangement of elements in the periodic table is the relationship between the atomic structure and chemical properties of elements. It is on the basis of atomic structure that the elements have been divided into groups.

Explain the link between the electron configuration in the outer shell and the difference in chemical properties of elements of groups **1, 2, 13, 14, 15, 16, 17 and 18**.

e.g., Group 1 - Alkali metals

Li $1s^2\ 2s^1$

Na $1s^2\ 2s^2\ 2p^6\ 3s^1$

K $1s^2\ 2s^2\ 2p^6\ 3s^3\ 3p^6\ 4s^1$

- **Due to the low ionisation energy of these elements, the electron in the outermost shell can be removed easily.**

On the basis of the electron configuration of alkali metals, explain the following properties.

- **form ions with 1+ charge**
- **form ionic compounds.**
- **display high reactivity**
- **metallic property is very high**

Prepare a note for your science diary on the characteristics of other groups, relating them to their position in the periodic table and electron configuration.

SUMMARY

- 'Subshells' are the sub-energy levels in a principal energy level. They are named s, p, d and f
- Number of electrons that can be accommodated in each sub shell is s-2, p-6, d-10, f-14
- Electron filling takes place in the order of increasing energy of sub-shells
- Elements are grouped into s, p, d and f blocks based on which subshell the last electron in one atom goes to.
- The s, p block elements which obey the periodicity completely, represent all the elements in the periodic table. They are hence called representative elements.
- The energy required to remove the electron in the outermost shell of an atom is its ionisation energy.
- Ionisation energy decreases down the group. Along the period it increases from left to right.

MORE ACTIVITIES FOR YOU

1. A section of the periodic table is given below.

B	C	N	O	F	Ne
Al	Si	P	S	Cl	Ar

   a. Which element has the lowest ionisation energy?

   b. Which element has the highest ionisation energy?

2. Examine the periodic table. Find the elements with highest ionisation energy, element with the lowest ionisation energy and their positions. Explain your findings.

3. Draw a model of the periodic table, colour the different blocks and paste it in your Science diary.

4. **$[Ne]3s^1$ $[Ne]3s^2\ 3p^4$ $[Ar]4s^2\ 3d^1$**

with respect to the above elements, find the following:

- **name of element**
- **atomic number**
- **subshellwise electron configuration in full form**
- **period**
- **group**
- **block**
- **metal or non-metal**

5. Find the incorrect arrangement.

   $3s^1$, $2d^5$, $3p^6$, $3f^5$, $2p^7$, $3d^{10}$, $4s^3$

6. An atom has 24 electron. Find

   - **atomic number**
   - **name of element**
   - **number of subshells**
   - **number of 's' electrons**
   - **period, group and block**

7. The atomic number of nickel and copper is 28 and 29 respectively. Write the subshell electron configuration of the following:

   1. Cu^{2+} -

   2. Cu^{+} -

   3. Ni^{2+} -

8. Find the incorrect electron arrangement

   $1s^2\ 2s^2\ 3s^1$

   $1s^2\ 2s^2\ 2p^2$

   $1s^2\ 2s^2\ 2p^4\ 3s^2$

   $1s^2\ 2s^2$

9. Which among the following are the elements in period with highest ionisation energy?

   1. halogens

   2. noble elements

   3. alkali metals

   4. transitional elements

10. The common outershell electron configuraion of some family of elements are given under. Find the family

    1. $ns^2\ np^3$

    2. ns^1

    3. $ns^2\ np^5$

    4. $ns^2\ np^1$

11. The outershell electron arrangement of some elements are given.

    $ns^2\ np^1$

    ns^2np^4

    ns^2np^5

    Select the arrangement related with the following:

    - **element with highest electro negativity**
    - **element with lowest ionisation energy**
    - **element of oxygen family**

12. The atomic numbers of elements A, B and C are Z-1, Z and Z+1 respectively. B is an inert gas (not helium). Answer the following:

    - **Predict the group of A and C**
    - **Which element has highest ionisation energy? Why?**
    - **Which element has lowest ionisation energy? Why?**

12. The ionisation energy of certain elements are given below. One of them is that of an inert gas. Roman letters indicate the elements.

    I - 2372 kJ/mole

    II - 520 kJ/mole

    III - 900 kJ/mole

    IV - 1680 kJ/mole

a. Which is the most reactive metal?

b. Which is the most reactive non-metal?

c. Which is the inert gas?

d. Which metal forms the compound AX_2 (X is a halogen)

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