## Chapter 8 Electron Configuration and Periodicity

These Notes are to SUPPLIMENT the Text, They do NOT Replace reading the Text Material. Additional material that is in the Text will be on your tests! To get the most information, READ THE CHAPTER prior to the Lecture, bring in these lecture notes and make comments on these notes. These notes alone are NOT enough to pass any test!

The author is providing these notes as an addition to the students reading the text book and listening to the lecture. Although the author tries to keep errors to a minimum, the student is responsible for correcting any errors in these notes.
8.1 Electron Spin and Pauli Exclusion Principle: A beam of hydrogen atoms is split into 2 by a magnetic field.

Atoms are Magnetic: Stern and Gerlach observed the splitting of a beam of hydrogen atoms by a magnetic field. This shows the atoms are magnetic - the electrons of different atoms spin in opposite directions [ $\mathrm{M}=-$ $1 / 2$ and $+1 / 2$ ]


Electron Configuration of an atom is a particular distribution of electrons among available subshells
Orbital Diagrams show how the orbital's of a subshell are occupied by electrons:

$$
\begin{array}{lll}
\uparrow \downarrow & \uparrow \downarrow & \uparrow 00 \\
\mathbf{1} \mathbf{S} & \mathbf{2 S} & \mathbf{2 p}
\end{array}
$$

$$
\uparrow=m_{s}[\text { spin }]=+1 / 2 \quad \downarrow=m_{s}=-1 / 2
$$

Paui exclusion principle: no two electrons in an atom have the same 4 Quantum Numbers

| Subshell | \#Orbitals | Max \# of Electrons |
| :---: | :---: | :---: |
| $\mathrm{s}(\mathrm{l}=0)$ | 1 | 2 |
| $\mathrm{p}(\mathrm{l}=1)$ | 3 | 6 |
| $\mathrm{~d}(\mathrm{l}=2)$ | 5 | 10 |
| $\mathrm{f}(\mathrm{l}=3)$ | 7 | 14 |

Example 8.1: Which orbital diagrams are possible

| 1 s | 2 s |  | 2p |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ |  | $\uparrow$ - |  |  |  | Possible |
| $\uparrow \downarrow$ | $\uparrow \downarrow \uparrow$ |  | - - - |  |  |  | Impossible |
| $\uparrow \downarrow$ | $\uparrow$ |  | $\uparrow \uparrow-$ |  |  |  | Impossible |
| $1 \mathrm{~s}^{3}$ | $2 \mathrm{~s}{ }^{1}$ |  |  |  |  |  | Impossible |
| $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}{ }^{1}$ | $2 \mathrm{p}^{7}$ |  |  |  |  | Impossible |
| $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}{ }^{2}$ | $2 \mathrm{p}{ }^{6}$ | $3 \mathrm{~s}^{2}$ | $3 p^{6}$ | $3 \mathrm{~d}^{8}$ | $4 \mathrm{~s}^{2}$ | Possible |

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## Which orbital diagrams are possible

|  | 1 s |  | 2 s |  | 2 p |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| a, | $\uparrow$ |  | $\uparrow$ |  |  |  |
| b. | $\uparrow$ |  | $\uparrow$ |  | $\uparrow \downarrow$ | $\uparrow \downarrow$ |
| c. | $\uparrow \downarrow$ |  | $\uparrow \downarrow$ |  | $\uparrow \downarrow$ |  |
| d. | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | $2 \mathrm{p}^{4}$ |  |  | $\uparrow$ |
| e. | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{4}$ | $2 \mathrm{p}^{2}$ |  |  |  |
| e. |  |  |  |  |  |  |
| f. | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | $2 \mathrm{p}^{6}$ | $3 \mathrm{~s}^{2}$ | $3 \mathrm{p}^{10}$ | $3 \mathrm{~d}^{10}$ |

Discuss how NMR works!


NMR Spectrum of Ethanol: $\mathrm{CH}_{3}-\mathrm{CH}_{2}-\mathrm{OH}$


### 8.2 Build up Principle of the Periodic Table

Ground State: Configuration of the lowest energy level
Excited State: All other configurations
AufBau Build Up Principle: scheme used to reproduce the electron configuration of the ground state by successively filling subshells with electrons in a specific order. This order represents an increase in energy for different subshells. Different orbitals of a subshell all have the same energy [ each of the 3 basic electrons of a p subshell have the same energy ].


## NOTE CHANGE OF FILL PATTERN FROM 3p $\rightarrow 4 s$

## Filling a subshell gives a stable configuration

Table 8.2: $D o Z=1$ to 36 of $Z$ \& Configuration, fill all subshells. Note: filling a $p$ subshell is a stable configuration. Atomic Number $=\mathrm{z}=\#$ of protons $=\#$ of electrons


Orbital Energies of Scandium, $\mathrm{Z}=21$. Note order $4 \mathrm{~s}>3 \mathrm{~d}>3 \mathrm{~d}$ (??)
Using the Noble Gas Core abbreviations [ inner shell configuration is a noble gas ]

$$
\mathrm{Z}=2 \quad \mathrm{He} \quad 1 \mathrm{~s}^{2}
$$

Fill the 2s subshell

| $\mathrm{Z}=3$ | Lithium | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{1}$ |
| :--- | :--- | :--- | :--- |
| $\mathrm{Z}=4$ | Beryllium | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | | $[\mathrm{He}]$ | $2 \mathrm{~s}^{1}$ |
| :--- | :--- | :--- |
| $[\mathrm{He}]$ | $2 \mathrm{~s}^{2}$ |

Start filling the $2 p$ subshell

| $\mathrm{Z}=5$ | Boron | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | $2 \mathrm{p}^{1}$ |
| :--- | :--- | :--- | :--- | :--- |
| $\mathrm{Z}=6$ | Carbon | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | $2 \mathrm{p}^{2}$ |
| $\ldots$ |  |  |  |  |
| $\mathrm{Z}=10$ | Neon | $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | $2 \mathrm{p}^{6}$ |

$\begin{array}{lll}{[\mathrm{He}]} & 2 \mathrm{~s}^{2} & 3 \mathrm{p}^{1} \\ {[\mathrm{He}]} & 2 \mathrm{~s}^{2} & 3 \mathrm{p}^{2}\end{array}$
[ He ] $2 \mathrm{~s}^{2} \quad 3 \mathrm{p}^{6}$
Fill the 3s subshell
$\begin{array}{llllll}\mathrm{Z}=11 & \text { Sodium } & 1 \mathrm{~s}^{2} & 2 \mathrm{~s}^{2} & 2 \mathrm{p}^{6} & 3 \mathrm{~s}^{1} \\ \mathrm{Z}=12 & \text { Magnesium } & 1 \mathrm{~s}^{2} & 2 \mathrm{~s}^{2} & 2 \mathrm{p}^{6} & 3 \mathrm{~s}^{2}\end{array}$
[ Ne ] $3 \mathrm{~s}^{1}$
[ Ne ] $3 \mathrm{~s}^{2}$
Fill the 3p subshell

| $\mathrm{Z}=13$ | Aluminum | $1 \mathrm{~s}^{2}$ | $2 s^{2}$ | $2 p^{6}$ | $3 s^{2}$ | $3 p^{1}$ | $[\mathrm{Ne}] 3 s^{2}$ | $3 p^{1}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\ldots$ |  |  |  |  |  |  |  |  |
| $\mathrm{Z}=18$ | Argon | $1 s^{2}$ | $2 s^{2}$ | $2 p^{6}$ | $3 s^{2}$ | $3 p^{6}$ | $[\mathrm{Ne}] 3 s^{2}$ | $3 p^{6}$ |

Noble Gases - Very Unreactive
$\mathrm{Z}=2$
He
$1 \mathrm{~s}^{2}$

Z=10 Neon
Z=18 Argon
Z=36 Krypton
$1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2} \quad 2 \mathrm{p}^{6}$
$1 s^{2} \quad 2 s^{2} \quad 2 p^{6}$ $\begin{array}{ll}3 s^{2} & 3 p^{6} \\ 3 s^{2} & 3 p^{6}\end{array}$ $3 d^{10} \quad 4 s^{2}$ $4 p^{6}$

Group IIA, Alkaline Earth Metals - Moderately reactive, loose 2 electrons
$\mathrm{Z}=4 \quad$ Beryllium $1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2}$
$\mathrm{Z}=12$ Magnesium $1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2}$
$\mathrm{Z}=20$ Calcium $1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2}$

[ He ] $2 \mathrm{~s}^{2}$
[ Ne ] $3 \mathrm{~s}^{2}$
[ Ar ] $4 \mathrm{~s}^{2}$

Group IIIA,
$\mathrm{Z}=5$ Boron
$1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2}$
$2 \mathrm{p}^{1}$
$1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2} \quad 2 \mathrm{p}^{6}$
$3 \mathrm{~s}^{2} \quad 3 \mathrm{p}_{6}^{1}$
[ He ] $2 \mathrm{~s}^{2} \quad 3 \mathrm{p}^{1}$
$\mathrm{Z}=13$ Aluminum
$1 \mathrm{~s}^{2} \quad 2 \mathrm{~s}^{2}$
$2 \mathrm{p}^{6} \quad 3 \mathrm{~s}^{2} \quad 3 \mathrm{p}^{6}$
$3 d^{10}$
$4 s^{2}$
$4 p^{1}$ $[\mathrm{Ne}] 3 \mathrm{~s}^{2}$
$[\mathrm{Ar}] 4 \mathrm{~s}^{2}$ $3 p^{1}$
$4 p^{1}$

Boron and Aluminum have the noble gas cores plus 3 electrons
Gallium has an additional filled 3d subshell.
Pseudo-Noble-Gas core is a noble gas core with $(n-1) d^{10}$ electrons
Valence Electrons: Electrons in an atom outside the Noble-Gas or Pseudo-Noble-Gas core.


Periodic Table with valence-shell electrons. Note groups have similar electron configuration [and properties] Going Across a Period:

| $\mathbf{1 A}$ | IIA | IIIA | IVA | VA | VIA | VIIA | VIIIA |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathbf{X s}^{1}$ | Xs $^{2}$ | $\mathrm{Xs}^{2} \mathrm{p}^{1}$ | $\mathrm{Xs}^{2} \mathrm{p}^{2}$ | $\mathrm{Xs}^{2} \mathrm{p}^{3}$ | Xs $^{2} \mathrm{p}^{4}$ | Xs $^{2} \mathrm{p}^{5}$ | Xs $^{2} \mathrm{p}^{6}$ |

Transition Metals, d subshell fills

| IIIB | IVB | VB | VI | VIIB | VIIIB | VIIIB | VIIIB | IB | IIB |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Sc | Ti | Y | $\mathbf{C r}$ | Mn | Fe | Co | Ni | $\mathbf{C u}$ | Zn |
| $\mathrm{Z}=21$ | $\mathrm{Z}=22$ | $\mathrm{Z}=23$ | $\mathbf{Z}=\mathbf{2 4}^{*}$ | $\mathrm{Z}=25$ | $\mathrm{Z}=26$ | $\mathrm{Z}=27$ | $\mathrm{Z}=28$ | $\mathbf{Z}=\mathbf{2 9} \boldsymbol{*}$ | $\mathrm{Z}=230$ |
| $\mathrm{Xd}^{1} 4 \mathrm{~s}^{2}$ | $\mathrm{Xd}^{2} 4 \mathrm{~s}^{2}$ | $\mathrm{Xd}^{3} 4 \mathrm{~s}^{2}$ | $\mathbf{X d}^{\mathbf{5}} \mathbf{4 s}^{\mathbf{1}}$ | $\mathrm{Xd}^{5} 4 \mathrm{~s}^{2}$ | $\mathrm{Xd}^{6} 4 \mathrm{~s}^{2}$ | $\mathrm{Xd}^{7} 4 \mathrm{~s}^{2}$ | $\mathrm{Xd}^{8} 4 \mathrm{~s}^{2}$ | $\mathbf{X d}^{\mathbf{1 0}} \mathbf{4 s}^{\mathbf{1}}$ | $\mathrm{Xd}^{10} 4 \mathrm{~s}^{2}$ |

* One electron is promoted from the 4 s to the $4 d$ subshell for $Z=14 \& 29$

Exceptions to the Build up Principle
$\mathrm{Cr} \quad \mathrm{Z}=24$
[Ar] 3d ${ }^{4}$
$\mathrm{Cu} \quad \mathrm{Z}=29$
[Ar] $3 \mathrm{~d}^{9}$
$\begin{array}{lll}4 s^{2} & \rightarrow & 3 d^{5} \\ 4 s^{2} & \rightarrow & 3 d^{10}\end{array}$
$4 s^{1}$
$4 s^{1}$

X-Ray is generated when an electron beam that falls on a metal target.
With sufficient energy, the electron knocks an electron from an inner shell giving a metal ion with a missing inner orbital. An electron from a higher orbital drops down and an X-Ray photon is emitted.

Electron configuration from the Periodic Table: $\quad$ 1s $\quad 3 \mathrm{~d} \quad 3 \mathrm{p}$


## Note: The Principal Quantum Number of the Valence Shell Electron must equal the Period!

Example: 8.2 What is the ground state configuration for $\mathrm{Ga} \mathrm{Z}=31$

|  | 1 s | 2 s 2 p | 3 s 3 p | 4 s | 3 d | 4 p |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  |  |  | $4 \mathrm{~s}^{2}$ | $3 \mathrm{~d}^{10}$ | $4 \mathrm{p}^{1}$ |  |
| Then fill |  |  | From the AufBau Build Up Principle |  |  |  |
| Valence Shell is |  |  | $4 \mathrm{~s}^{2}$ |  | $4 \mathrm{p}^{1}$ |  |

$\mathbf{n s}^{\mathbf{a}} \quad \mathbf{n p}{ }^{\mathbf{b}} \quad \mathrm{n}$ is the Principle Quantum Number
\# of Valence Shell Electrons $=\mathrm{a}+\mathrm{b}=3$. So the Group Number $=3$
Example: 8.3 What are the outer shell configuration of $\mathrm{Te}, \mathrm{Z}=52$
From the Periodic Table, Te is in Period 5, Group VIA: $n=5$, \# electrons $=6$

$$
5 s^{2} \quad 5 p^{4}
$$

Exercise 8.3 What is the valence shell configuration of arsenic (As, $\mathrm{Z}=33$ )?
Arsenic is a main group element in Period 4, Group VA, of the periodic table.
The five outer electrons should occupy the $4 s$ and $4 p$ subshells $4 s^{2} 4 p^{3}$.
Concept Check 8.2 Two adjacent elements in Period 3. One has only s electrons in it's valence shell, the other has only 1 p electron. $\quad \mathrm{Mg} \& \mathrm{Al}$
8.4 Hunds Rule: The lowest energy arrangements of electrons in a subshell is putting the electrons into separate orbital's of the subshell with the same spin before paring them.

| $\mathbf{1 s}$ | $\mathbf{1 p}$ | $\mathbf{2 p}$ |
| :--- | :--- | :--- |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ |  |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow$ |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \uparrow$ |



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Table 8.2 Orbital Buildup Diagram

| Atom | Z | Configuration | 1s | $2 s$ | $2 p$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Hydrogen | 1 | $1 s^{1}$ | (1) |  |  |
| Helium | 2 | $1 s^{2}$ | (11) | $\bigcirc$ |  |
| Lithium | 3 | $1 s^{2} 2 s^{1}$ | (11) | (1) |  |
| Beryllium | 4 | $1 s^{2} 2 s^{2}$ | (11) | (11) |  |
| Boron | 5 | $1 s^{2} 2 s^{2} 2 p^{1}$ | (11) | (11) |  |
| Carbon | 6 | $1 s^{2} 2 s^{2} 2 p^{2}$ | (11) | (11) |  |
| Nitrogen | 7 | $1 s^{2} 2 s^{2} 2 p^{3}$ | (11) | (11) |  |
| Oxygen | 8 | $1 s^{2} 2 s^{2} 2 p^{4}$ | (11) | (11) | D 1 |
| Fluorine | 9 | $1 s^{2} 2 s^{2} 2 p^{5}$ | (11) | (11) |  |
| Neon | 10 | $1 s^{2} 2 s^{2} 2 p^{6}$ | (11) | (11) |  |

Example 8.4 Iron is $1 s^{2} 2 s^{2} 2 p^{6} 3 s^{2} 3 p^{6} 3 d^{6} 4 s^{2}$. Draw the orbitals

| $1 \mathrm{~s}^{2}$ | $2 \mathrm{~s}^{2}$ | $2 \mathrm{p}^{6}$ | $3 \mathrm{~s}^{2}$ | $3 \mathrm{p}^{6}$ | $3 \mathrm{~d}^{6}$ | $4 \mathrm{~s}^{2}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow \downarrow \downarrow \uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow \uparrow \downarrow \uparrow \downarrow$ | $\uparrow \downarrow \uparrow \uparrow \uparrow \uparrow \uparrow$ | $\uparrow \downarrow$ |

Build up for Sodium, atomic number 11:

| 1 s | 2 s |  | 2 p |  | 3 s |
| :--- | :--- | :--- | :---: | :---: | :---: |
|  |  | -1 | 0 | +1 |  |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow$ |

Build up for Chlorine, atomic number 17:

| 1 s | 2 s |  | 2 p |  | 3 s | 3 p |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :---: |
|  |  | -1 | 0 | +1 |  | -1 | 0 |  |
| +1 |  |  |  |  |  |  |  |  |
| $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ | $\uparrow \downarrow$ |  |
|  |  | $\uparrow$ |  |  |  |  |  |  |

Paramagnetic Substance: a substance that is weakly attracted by a magnetic field and this attraction is generally the result of unpaired electrons.

Diamagnetic Substance: a substance that is not attracted by a magnetic field or is very slightly repelled by such a field. The substance has only paired electrons.

### 8.5 Mendellev's Predictions

This section is not normally covered during lectures.

### 8.6 Some Periodic Properties

The Periodic Law states the when the elements are arranged by atomic number, their physical and chemical properties vary periodically.
Atomic Radius
1
2

Effective Nuclear Charge

## Ionization Energy

First Ionization Potential:
Second Ionization Potential:

## Electron Affinity

Electron affiniy is the energy change for the process of adding an electron to a neutral atom in the gaseous state to form a negative ion.

### 8.7 Periodicity in the Main Group Elements

## Practice Questions:

Review Questions: All Example Problems in the chapter
Concept Questions: 7.19, 7.23, 7.27
Practice Problems: $\quad 7.33,7.35,7.41$
$7.43,7.45,7.51$
7.57, 7.59, 7.61, 7.63


