• Atoms with \( Z > 1 \) contain \( >1 \) electron. This changes the atomic structure considerably because in addition to the electron-nucleus interaction, there is the repulsive electron-electron interaction.

• Calculations show that allowed electron energies are no longer solely determined by the single quantum number, \( n \).

• Several distinct electron states (orbitals) exist, all with the same \( n \), forming a `shell' of states.

• In general, these states have different energies.

• The number of different orbital states in a shell of a given \( n \) is \( n^2 \).
Multi electron atoms

• The electrons interact not only with the nucleus but also among themselves. It is difficult to get the wave function.

• Electron configuration: How do the electrons fill the shells and subshells? How to get its ground state?

• In the ground states of atoms, electrons occupy the lowest energy states available consistent with the exclusion principle.
The Pauli exclusion principle states that only one electron can be in a given state, which is labeled by four quantum numbers \((n,l,m_l,m_s)\):

- \(n\), Principal quantum number, the energy level
- \(l\), Orbital quantum number, orbital angular momentum,
- \(m_l\) (Orbital) magnetic quantum number,
- \(m_s\) Spin (magnetic) quantum number,
Hund’s rule

- Greatest stability results if the atomic orbitals (AO) in a degenerate set are half-filled with electrons before any of them are filled.
Aufbau principle

- A maximum of two electrons are put into orbitals in the order of increasing orbital energy: the lowest-energy orbitals are filled before electrons are placed in higher-energy orbitals.

- Orbitals are filled in the order of increasing $n+l$;

- Where two orbitals have the same value of $n+l$, they are filled in order of increasing $n$.

- This gives the following order for filling the orbitals:
  1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, and 7p
Each shell is identified by a letter according to its n value: The innermost shell (n = 1) is called the K-shell, the next innermost shell (n = 2) is called the L-shell, etc.

- No two electrons can occupy precisely the same state.

<table>
<thead>
<tr>
<th>n</th>
<th>Shell</th>
<th>Maximum number of electrons (2n^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>K</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
<td>32</td>
</tr>
<tr>
<td>......</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The periodic table

- When the elements are listed in order of atomic number, elements with similar chemical and physical properties recur at regular interval, known as the periodical law.
- Elements with similar properties form the groups shown as vertical columns in the table.
- The horizontal rows in the table are called periods. Across each period is a more or less steady transition from an active metal through less active metals and weakly active nonmetals to highly active nonmetals and finally to an inert gas.
For **inert gases**, atoms contain only closed shells. The atoms do not easily donate electrons to or accept electrons from other elements.

s-subshell elements form the first two column (groups) with the **alkalis** \((ns^1)\) and **alkaline earths** \((ns^2)\). Alkali metals have a single \(s\) electron in its outer shell, which can be easily lost. Elements in this group often form singly positive ions.

**Transition metals** are placed in the three rows (4-6) in which the \(d\) subshell is filling.

The **lanthanide** (rare earths) series involves completing mainly the 5d and 4f subshells.
Z=10 \((1s^22s^22p^6)\), **neon**, an inert gas, shell & subshells are full. It does not readily give up or to accept an electron, generally not combining with other elements to form compounds. Its boiling point are low and ionization energy is high.

Z=9 \((1s^22s^22p^5)\), F, **fluorine**, halogens, p-subshell element \(np^5\), It is one electron **shy** of being full. It easily accepts an electron from other elements to form a compound, highly reactive. \(F^-\), **Negative** ions.

Z=11 \((1s^22s^22p^63s)\), Na, **sodium**, alkali, s-subshell element \(ns^1\), The electron can be easily detached to other elements in a chemical reaction, highly reactive. \(Na^+\), **Positive** ions.
# Periodic Table of Elements

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>H, He</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Li, Be, B, C, N, O, F, Ne</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Na, Mg, Al, Si, P, S, Cl, Ar</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, Po, At, Rn</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Actinium, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Rf, Db, Sg, Bh, Hs, Mt,Ds, Rg, Uut, Uuo, Uuh</td>
</tr>
</tbody>
</table>

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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