Section 5: MULTI-ELECTRON ATOMS

In this section, we describe the atomic structure and general properties of elements that form the Periodic Table of Elements.

Multi-electron Atoms

PAULI EXCLUSION PRINCIPLE AND ELECTRON SHELLS

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 (orbits) 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.

However, also note that electrons obey the **Pauli Exclusion Principle** which states that:

No two electrons can occupy precisely the same state.

- Electrons with spin ½ have 2 possible orientations – up and down. Therefore, the maximum number of electrons in any shell = $2n^2$.
- 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.

n	Shell	Maximum number of electrons $2n^2$
1	K	2
2	L	8
3	M	18
4	N	32
--	--	--

- Atoms with filled shells are known to be very stable and are chemically inert. They form the **inert** or **noble gases**: For example,
  - Helium (Z = 2) has a full K-shell (2 electrons).
  - Neon (Z = 10) has a full K-shell (2 electrons) and a full L-shell (8 electrons).

When a shell is full the next electron must occupy a higher state.

- E.g. lithium (Z = 3) has a full K-shell plus one electron in its less tightly-bound L-shell.
- Lithium, therefore, is chemically active as it can readily lose its outermost electron to form a Li^+ ion, which has just two electrons filling its K-shell.
- Similarly, sodium (Z = 11) has full K- and L-shells plus one extra electron in its M-shell.
- It has similar properties to lithium and both of are known as **alkaline metals**.

SUB SHELLS

The outer atomic shells consist of a number of separate groups of states called **sub-shells.**

- All states in a sub-shell have the same orbital angular momentum L
- They are identified by a second integer quantum number ℓ.
- ℓ denotes the number of discrete units of $\hbar = h/2\pi$ [see section 3], which make up the angular momentum, i.e.

$$L = \ell\hbar \tag{4.1}$$

where $\ell = 0, 1, 2, 3, \cdots < n$.

A letter is commonly used to specify the angular momentum quantum number.

- Specifically, S, P, D, F, G, etc. correspond to ℓ = 0, 1, 2, 3, 4, etc.

Different sub-shells have different energies, which is why a shell is divided into sub-shells of states.

However, states in a given sub-shell do not necessarily have different energies. They correspond to different orientations of L in space and in the absence of any external electric or magnetic field, the states of a given sub-shell will all have the **same** energy

Different sub-shells can contain different numbers of electrons.

- The M-shell (n = 3) is made up of 3 sub-shells (ℓ = 0, 1 and 2).

- They are labelled ^{3}S, ^{3}P, ^{3}D, which can contain up to 2, 6, and 10 electrons, respectively.
- The superscript denotes the *n* quantum number.
- The capacities of these three sub-shells sum to a total of 18 electrons for the shell.

The next inert gas, after neon, is argon ($Z = 18$).

- It has full K- and L-shells but only eight electrons in its M-shell corresponding to filled ^{3}S and ^{3}P sub-shells.
- The energy of the N-shell ($n = 4$) is close to the M-shell.
- The lowest energy (^{4}S) sub-shell of the N-shell lies **below** the highest-energy (^{3}D) sub-shell of the M-shell.

The next element after argon is potassium ($Z = 19$).

- It has eight electrons in its M-shell (filled ^{3}S and ^{3}P sub-shells) and one electron in its N-shell, in addition to filled K- and L-shells.
- The one electron in the N-shell is relatively weakly bound, which is why potassium is also an alkali metal with similar properties to lithium and sodium.

Arranging the elements in order of increasing Z - it is found that the chemical properties of the inert gases, the alkali metals, etc. recur in a periodic manner.

- This arrangement is called the **Periodic Table.**
- The reason for the periodic properties is that all elements with similar electron configurations in the outer shells have similar chemical properties.

PERIODIC TABLE of ELEMENTS

Period	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB		VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	Noble gases
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.179
3	11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.064	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.098	20 **Ca** 40.08	21 **Sc** 44.956	22 **Ti** 47.90	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.847	27 **Co** 58.933	28 **Ni** 58.70	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.22	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** (99)	44 **Ru** 101.07	45 **Rh** 102.905	46 **Pd** 106.4	47 **Ag** 107.868	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.905	54 **Xe** 131.30
6	55 **Cs** 132.905	56 **Ba** 137.33	57 **La** 138.905	72 **Hf** 178.49	73 **Ta** 180.948	74 **W** 183.85	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.09	79 **Au** 196.966	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.2	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf(?)** (261)	105 **Ha(?)** (262)	106 (257)	107 (260)											

58 **Ce** 140.12	59 **Pr** 140.907	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.35	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.26	69 **Tm** 168.934	70 **Yb** 173.04	71 **Lu** 174.96
90 **Th** (232)	91 **Pa** (231)	92 **U** (238)	93 **Np** (239)	94 **Pu** (239)	95 **Am** (240)	96 **Cm** (242)	97 **Bk** (245)	98 **Cf** (246)	99 **Es** (247)	100 **Fm** (249)	101 **Md** (256)	102 **No** (254)	103 **Lr** (257)

For each element the average atomic mass of the mixture of isotopes occurring in nature is shown. For elements having no stable isotope, the approximate atomic mass of the most common isotope is shown in parentheses.