

# CHEMISTRY



## Periodic Table of Elements

|               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |    |    |    |    |    |    |    |    |
|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|----|----|----|----|----|----|----|----|
| 1             |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               | 18            |    |    |    |    |    |    |    |    |
| H<br>1.008    |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               | Ar<br>39.948  |    |    |    |    |    |    |    |    |
| 2             |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               | 36            |    |    |    |    |    |    |    |    |
| He<br>4.0026  |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               | Kr<br>83.80   |    |    |    |    |    |    |    |    |
| 3             | 4             |               |               |               |               |               |               |               |               |               |               |               |               |               |               | 54            | 86            |    |    |    |    |    |    |    |    |
| Li<br>6.941   | Be<br>9.0122  |               |               |               |               |               |               |               |               |               |               |               |               |               |               | Xe<br>131.29  | Rn<br>222     |    |    |    |    |    |    |    |    |
| 5             | 6             |               |               |               |               |               |               |               |               |               |               |               |               |               |               | 72            | 84            |    |    |    |    |    |    |    |    |
| Na<br>22.990  | Mg<br>24.305  |               |               |               |               |               |               |               |               |               |               |               |               |               |               | Hf<br>178.49  | Po<br>209     |    |    |    |    |    |    |    |    |
| 9             | 10            |               |               |               |               |               |               |               |               |               |               |               |               |               |               | 80            | 118           |    |    |    |    |    |    |    |    |
| F<br>18.998   | Ne<br>20.180  |               |               |               |               |               |               |               |               |               |               |               |               |               |               | Hg<br>200.59  | Og<br>284     |    |    |    |    |    |    |    |    |
| 11            | 12            | 13            | 14            | 15            | 16            | 17            | 18            | 19            | 20            | 21            | 22            | 23            | 24            | 25            | 26            | 27            | 28            | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| K<br>39.098   | Ca<br>40.078  | Sc<br>44.956  | Ti<br>47.88   | V<br>50.942   | Cr<br>52.004  | Mn<br>54.938  | Fe<br>55.845  | Co<br>58.933  | Ni<br>58.693  | Cu<br>63.546  | Zn<br>65.38   | Ga<br>69.723  | Ge<br>72.630  | As<br>74.922  | Se<br>78.96   | Br<br>79.904  | Kr<br>83.80   |    |    |    |    |    |    |    |    |
| 37            | 38            | 39            | 40            | 41            | 42            | 43            | 44            | 45            | 46            | 47            | 48            | 49            | 50            | 51            | 52            | 53            | 54            |    |    |    |    |    |    |    |    |
| Rb<br>85.468  | Sr<br>87.62   | Y<br>88.906   | Zr<br>91.224  | Nb<br>92.906  | Mo<br>95.94   | Tc<br>98      | Ru<br>101.07  | Rh<br>101.07  | Pd<br>106.36  | Ag<br>107.868 | Cd<br>112.411 | In<br>114.818 | Sn<br>118.710 | Sb<br>121.757 | Te<br>127.6   | I<br>126.905  | Xe<br>131.29  |    |    |    |    |    |    |    |    |
| 55            | 56            | 57            | 58            | 59            | 60            | 61            | 62            | 63            | 64            | 65            | 66            | 67            | 68            | 69            | 70            | 71            | 72            |    |    |    |    |    |    |    |    |
| Cs<br>132.905 | Ba<br>137.327 | La<br>138.905 | Ce<br>140.12  | Pr<br>140.908 | Nd<br>144.24  | Pm<br>145     | Sm<br>150.36  | Eu<br>151.964 | Gd<br>157.25  | Tb<br>158.925 | Dy<br>162.50  | Ho<br>164.930 | Er<br>167.259 | Tm<br>168.930 | Yb<br>173.054 | Lu<br>174.967 |               |    |    |    |    |    |    |    |    |
| 73            | 74            | 75            | 76            | 77            | 78            | 79            | 80            | 81            | 82            | 83            | 84            | 85            | 86            | 87            | 88            | 89            | 90            |    |    |    |    |    |    |    |    |
| Ta<br>180.948 | W<br>183.84   | Re<br>186.207 | Os<br>190.23  | Ir<br>192.222 | Pt<br>195.084 | Au<br>196.967 | Hg<br>200.59  | Tl<br>204.383 | Pb<br>207.2   | Bi<br>208.980 | Po<br>209     | At<br>210     | Rn<br>222     | Fr<br>223     | Ra<br>226     | Ac<br>227     | Th<br>232.038 |    |    |    |    |    |    |    |    |
| 91            | 92            | 93            | 94            | 95            | 96            | 97            | 98            | 99            | 100           | 101           | 102           | 103           | 104           | 105           | 106           | 107           | 108           |    |    |    |    |    |    |    |    |
| Pa<br>231.036 | U<br>238.029  | Np<br>237.048 | Pu<br>244.064 | Am<br>243.061 | Cm<br>247.07  | Bk<br>247.07  | Cf<br>251.08  | Es<br>252.083 | Fm<br>257.10  | Md<br>258.10  | No<br>259.10  | Lr<br>262.10  | Rf<br>261.10  | Db<br>262.10  | Sg<br>266.10  | Bh<br>264.10  | Hs<br>277.10  |    |    |    |    |    |    |    |    |
| 109           | 110           | 111           | 112           | 113           | 114           | 115           | 116           | 117           | 118           | 119           | 120           | 121           | 122           | 123           | 124           | 125           | 126           |    |    |    |    |    |    |    |    |
| Mc<br>288.10  | Nh<br>289.10  | Ds<br>291.10  | Rg<br>292.10  | Cn<br>295.10  | Nh<br>296.10  | Fl<br>299.10  | Mc<br>300.10  | Lv<br>303.10  | Ts<br>304.10  | Og<br>304.10  | 119           | 120           | 121           | 122           | 123           | 124           |               |    |    |    |    |    |    |    |    |
| 127           | 128           | 129           | 130           | 131           | 132           | 133           | 134           | 135           | 136           | 137           | 138           | 139           | 140           | 141           | 142           | 143           | 144           |    |    |    |    |    |    |    |    |
| Uut<br>288.10 | Uuq<br>290.10 | Uub<br>292.10 | Uut<br>293.10 | Uuq<br>295.10 | Uub<br>296.10 | Uut<br>299.10 | Uuq<br>300.10 | Uub<br>303.10 | Uut<br>304.10 | Uuq<br>307.10 | Uub<br>308.10 | Uut<br>311.10 | Uuq<br>312.10 | Uub<br>315.10 | Uut<br>316.10 | Uuq<br>319.10 | Uub<br>320.10 |    |    |    |    |    |    |    |    |

|       |               |
|-------|---------------|
| 1     | ATOMIC NUMBER |
| H     | SYMBOL        |
| 1.008 | ATOMIC WEIGHT |

### Elemental forms:

- **Monatomic:** Noble gases: helium, neon, argon, krypton, xenon, and radon; nonreactive
- **Diatomic:** Gases: fluorine, chlorine, hydrogen, oxygen, and nitrogen; Liquid: bromine; Solid: iodine
- **Molecular solids:** Sulfur
- **Covalent solids:** Carbon (diamond, graphite)
- **Metals:** Most common type of element; high coordination numbers; very dense

### Types of compounds: Large variety due to ionic, covalent, and metallic bonding options

- **Ionic:** Electron exchange
- **Covalent:** Shared electrons
  - Polar covalent: Unequal sharing
- **Ion complex:** Central ion + Solvent
- **Transition metal compounds:**
  - Coordination compounds: Non-bonding ligands
  - Organometallics: Metal-C bond
- **Complex, minerals:** Metal oxides and silicates

### Periodicity: The chemical properties of an element depend on valence electrons

- **Family of elements:** Column in periodic table
- The addition of d-orbitals produces an expanded octet

### Periodic Trends

- Chemistry determined by the behavior of valence electrons
- Atoms or ions get larger as you go down the column; electron shells are added
- Cation and anions (same charge) decrease in size as the atomic number ( $Z$ ) increases

• **Ionization energies:** Noble gases are the most stable; alkali metals are the easiest to ionize; electron screening lessens  $Z$ -effect on orbital energy

• **Atomic and ionic radii:** Not real properties; derive from structural data; divide bond into radii using a consistent scheme

- **Ionic radius:** Depends on charge, counter ion, and coordination (crystal type)
- **Atomic radius:** Based on diatomic gas data or metallic solid structural data

### Development of the Periodic Table

- Missing elements were predicted using periodicity
- **Columns 1:** Alkali metals
- **Columns 2:** Alkaline earth metals
- **First transition series:** Titanium-Copper
- **Column 17:** Halogens: fluorine, chlorine, bromine, iodine, and astatine
- **Column 18:** Rare gases: helium, neon, argon, krypton, xenon, and radon
- **Actinides:**  $Z = 90$  or above; radioactive
- **Lanthanides:** f-subshell elements; starts with  $Z = 58$



### Practical Application

- The colors of fireworks depend on the elements in the explosive

d-subshell  
5 orbitals

Orbitals

Orbitals

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## Atomic Structure

- **Atomic number ( $Z$ ):** The number of protons in the nucleus; for a neutral atom,  $Z$  = number of electrons; for an anion of charge  $-q$ ,  $Z = q$  electrons; for a cation of charge  $+q$ ,  $Z = q$  electrons
- **Mass number ( $A$ ):**  $A = Z + N$ , where  $N$  = the number of neutrons in the nucleus
- **Isotopes:** Atoms with the same  $Z$ , different  $A$ ; an element can have one or more isotopes; any sample contains a number of isotopes; in practical work, use the average mass number or atomic weight (weighted average of natural isotopes for a given element)

First Ionization Potential vs.  $Z$



Atomic Radius vs.  $Z$



## Atomic Quantum Numbers & Orbitals

- **$n$ : principle**
  - $n$ : magnetic (orbital direction)
  - $n$ : electron spin
- For each  $n$ , the possible  $l$  values are  $0, 1, \dots, n-1$
- For each  $l$ , the possible  $m_l$  values are  $-l, \dots, 0, \dots, +l$
- $m_s$  has two possible values:  $+\frac{1}{2}$  and  $-\frac{1}{2}$  (spin up, spin down)
- Each value of  $n$  denotes a "shell" in the atomic structure; each  $l$  denotes a subshell
- s-orbital:  $l = 0$ , 1 type
- d-orbital:  $l = 2$ , 5 types
- p-orbital:  $l = 1$ , 3 types
- f-orbital:  $l = 3$ , 7 types

### Many-Electron Atoms

Orbitals and quantum numbers derived for the hydrogen atom are used to describe all many-electron atoms and ions; a more rigorous treatment determines exact energy levels and orbital properties; the main result is that subshells have different energies; the filling of levels is guided by the Aufbau principle:

Aufbau Order for Filling Subshells



| $n$ | $l$ | $m_l$ | $m_s$          | element |
|-----|-----|-------|----------------|---------|
| 1   | 0   | 0     | $+\frac{1}{2}$ | H       |
| 1   | 0   | 0     | $-\frac{1}{2}$ | He      |
| 2   | 0   | 0     | $+\frac{1}{2}$ | Li      |
| 2   | 0   | 0     | $-\frac{1}{2}$ | Be      |
| 2   | 1   | -1    | $+\frac{1}{2}$ | B       |
| 2   | 1   | 0     | $+\frac{1}{2}$ | C       |
| 2   | 1   | 1     | $+\frac{1}{2}$ | N       |
| 2   | 1   | -1    | $-\frac{1}{2}$ | O       |
| 2   | 1   | 0     | $-\frac{1}{2}$ | F       |
| 2   | 1   | 1     | $-\frac{1}{2}$ | Ne      |

- **Electron configuration:** Atomic orbital occupancy for an atom
- **Pauli exclusion principle:** Each electron has a unique set of quantum numbers; an orbital may hold up to two electrons: one with spin up,  $m_s = +\frac{1}{2}$ , and one with spin down,  $m_s = -\frac{1}{2}$
- **Hund's rule:** Electrons fill p, d, and f subshells in a manner to maximize the number of unpaired electrons (half-filled orbitals); spin is maximized
- **Ionization potential (IP):** Energy required to remove electron from an atom or ion
  - **First IP:** Removal of first valence electron
- **Electronegativity:** Tendency of an atom to attract electrons in a chemical bond; 0-4 scale, 0 for rare gas

# Lavc Chemistry Study Guide

**F Rizvi**



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