

# CHEMISTRY



## Periodic Table of Elements

1																	18																										
H 1.008																	Ar 39.948																										
2																	36																										
He 4.0026																	Kr 83.80																										
3	4															54	86																										
Li 6.941	Be 9.0122															Xe 131.29	Rn 222																										
5	6															72	84																										
Na 22.990	Mg 24.305															Hf 178.49	Po 209																										
9	10															80	118																										
F 18.998	Ne 20.180															Hg 200.59	Og 294																										
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 39.098	Ca 40.078	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe								
17	18	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72								
Cl 35.453	Ar 39.948	K 39.098	Ca 40.078	Sc 44.956	Ti 47.88	V 50.942	Cr 52.004	Mn 54.938	Fe 55.845	Co 58.933	Ni 58.693	Cu 63.546	Zn 65.38	Ga 69.723	Ge 72.630	As 74.922	Se 78.96	Br 79.904	Kr 83.80	Rb 85.468	Sr 87.62	Y 88.906	Zr 91.224	Nb 92.906	Mo 95.94	Tc 98	Ru 101.07	Rh 101.07	Pd 106.32	Ag 107.868	Cd 112.411	In 114.818	Sn 118.710	Sb 121.757	Te 127.6	I 126.905	Xe 131.29						
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72								
Rb 85.468	Sr 87.62	Y 88.906	Zr 91.224	Nb 92.906	Mo 95.94	Tc 98	Ru 101.07	Rh 101.07	Pd 106.32	Ag 107.868	Cd 112.411	In 114.818	Sn 118.710	Sb 121.757	Te 127.6	I 126.905	Xe 131.29	Cs 132.905	Ba 137.327	La 138.905	Ce 140.12	Pr 140.908	Nd 144.24	Pm 145	Sm 150.36	Eu 151.964	Gd 157.25	Tb 158.925	Dy 162.50	Ho 164.930	Er 167.259	Tm 168.930	Yb 173.054	Lu 174.967									
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91									
La 138.905	Ce 140.12	Pr 140.908	Nd 144.24	Pm 145	Sm 150.36	Eu 151.964	Gd 157.25	Tb 158.925	Dy 162.50	Ho 164.930	Er 167.259	Tm 168.930	Yb 173.054	Lu 174.967					Fr 223	Ra 226	Ac 227	Th 232.038	Pa 231.036	U 238.029	Np 237.048	Pu 244.064	Am 243.061	Cm 247.070	Bk 247.070	Cf 251.083	Es 252.083	Fm 257.103	Md 258.103	No 259.108	Lr 262.105								
73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108								
Hf 178.49	Ta 180.948	W 183.84	Re 186.207	Os 190.23	Ir 192.222	Pt 195.084	Au 196.967	Hg 200.59	Tl 204.383	Pb 207.2	Bi 208.980	Po 209	At 210	Fr 223	Ra 226	Ac 227	Th 232.038	Pa 231.036	U 238.029	Np 237.048	Pu 244.064	Am 243.061	Cm 247.070	Bk 247.070	Cf 251.083	Es 252.083	Fm 257.103	Md 258.103	No 259.108	Lr 262.105	Rf 261.102	Db 262.102	Sg 266.107	Bh 264.104	Hs 277.103	Mt 268.103	Ds 271.103	Rg 272.103	Cn 285.103				
109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150		
Cs 132.905	Ba 137.327	La 138.905	Ce 140.12	Pr 140.908	Nd 144.24	Pm 145	Sm 150.36	Eu 151.964	Gd 157.25	Tb 158.925	Dy 162.50	Ho 164.930	Er 167.259	Tm 168.930	Yb 173.054	Lu 174.967	Fr 223	Ra 226	Ac 227	Th 232.038	Pa 231.036	U 238.029	Np 237.048	Pu 244.064	Am 243.061	Cm 247.070	Bk 247.070	Cf 251.083	Es 252.083	Fm 257.103	Md 258.103	No 259.108	Lr 262.105	Rf 261.102	Db 262.102	Sg 266.107	Bh 264.104	Hs 277.103	Mt 268.103	Ds 271.103	Rg 272.103	Cn 285.103	
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Cs 132.905	Ba 137.327	La 138.905	Ce 140.12	Pr 140.908	Nd 144.24	Pm 145	Sm 150.36	Eu 151.964	Gd 157.25	Tb 158.925	Dy 162.50	Ho 164.930	Er 167.259	Tm 168.930	Yb 173.054	Lu 174.967	Fr 223	Ra 226	Ac 227	Th 232.038	Pa 231.036	U 238.029	Np 237.048	Pu 244.064	Am 243.061	Cm 247.070	Bk 247.070	Cf 251.083	Es 252.083	Fm 257.103	Md 258.103	No 259.108	Lr 262.105	Rf 261.102	Db 262.102	Sg 266.107	Bh 264.104	Hs 277.103	Mt 268.103	Ds 271.103	Rg 272.103	Cn 285.103	
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257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
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407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
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457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
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1	ATOMIC NUMBER
H	SYMBOL
1.008	ATOMIC WEIGHT

- Elemental forms:**
  - Monoatomic:** 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

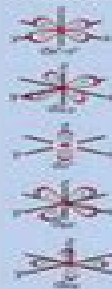
- Missing elements were predicted using periodicity
- Columns 1: Alkali metals
- Columns 2: Alkaline earth metals
- First transition series: Titanium-Copper
- Column 17: Halogens: fluorine, chlorine, bromine, iodine, and astatine
- Column 18: Rare gases: helium, neon, argon, krypton, xenon, and radon
- 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



p-subshell 3 orbitals



s-subshell 1 orbital



## 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)



## Atomic Quantum Numbers & Orbitals

- $n$ : principle**
  - $n$ : magnetic (orbital direction);  $n, l$  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	0	$-\frac{1}{2}$	N
2	1	+1	$+\frac{1}{2}$	O
2	1	+1	$-\frac{1}{2}$	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

# College Chemistry Study Guide

**Wolfgang Guggemos**



## **College Chemistry Study Guide:**

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