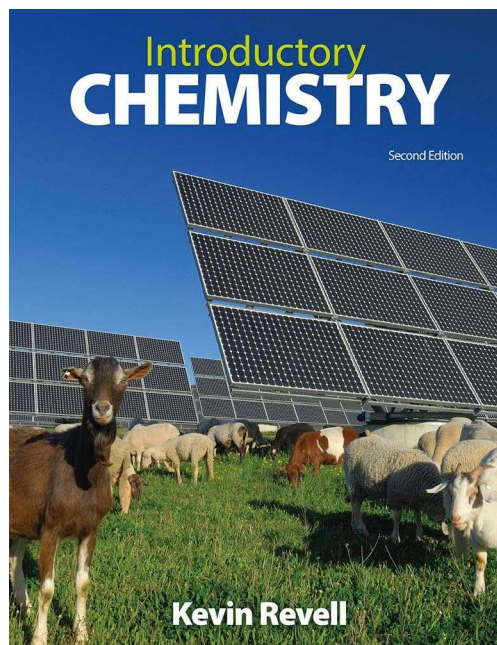


Introductory Chemistry  
Chem 103

# Chapter 4 – Light and Electronic Structure

Lecture Slides



## The Electromagnetic Spectrum

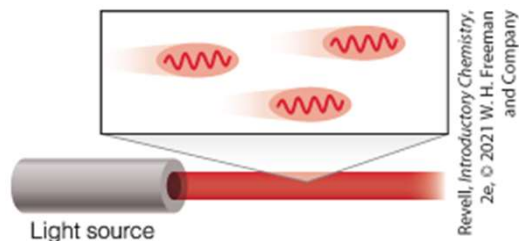


Photo credits clockwise from top left: Anna\_Om/Deposit Photos; Gerald D. Tang / TangaPhoto Stock; Kevin Revell

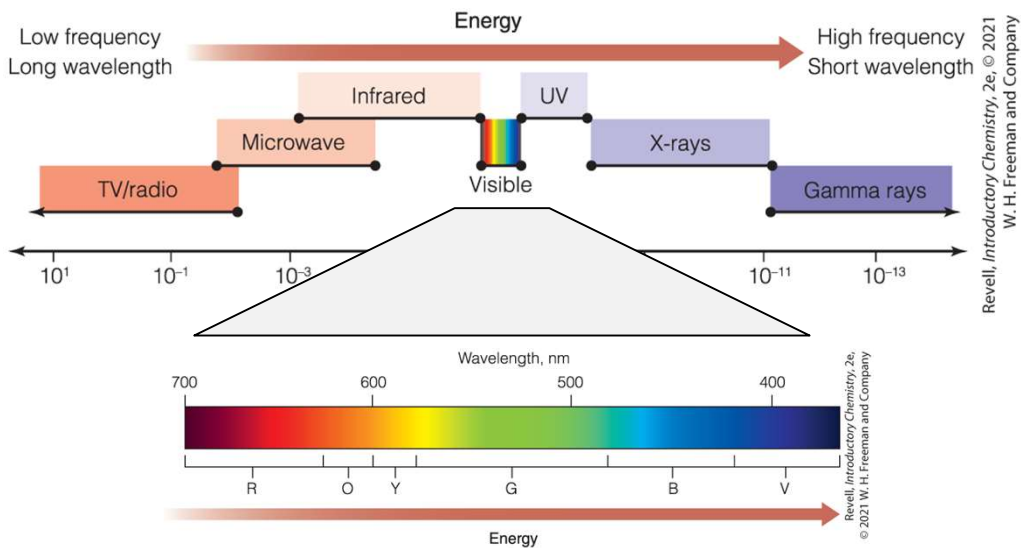
# What is Light?

## electromagnetic radiation

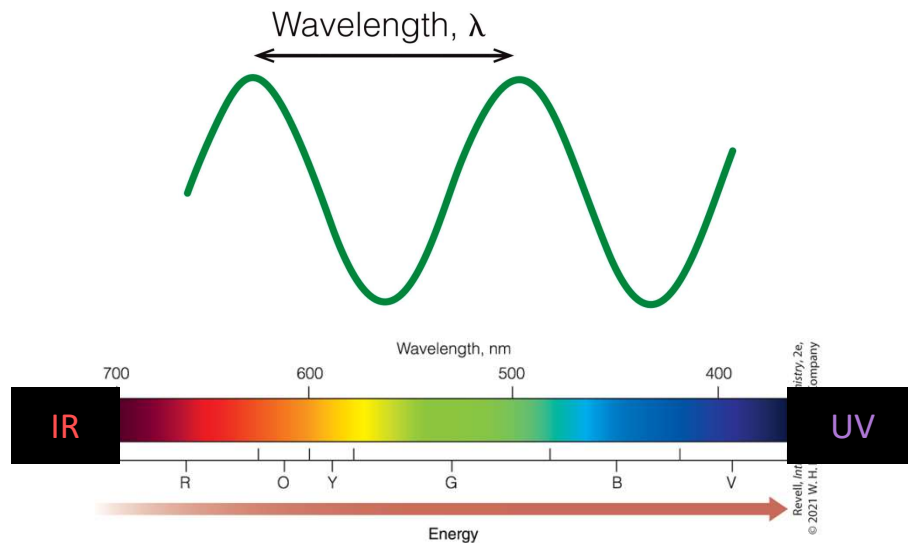
- a form of energy
- travels in waves
- exists in increments called **photons**



## The Electromagnetic Spectrum



## Wavelength



## Describing Electromagnetic Waves

**wavelength ( $\lambda$ )** – The length of one wave

**frequency ( $\nu$ )** – The number of waves per second

1 wave/second = 1 hertz (Hz)

10,000 Hz

10,000/s

10,000  $\text{s}^{-1}$

## Describing Electromagnetic Waves, Continued

$\downarrow$  wavelength  
 $\uparrow$  frequency
 }
*inversely related*

$$c = \lambda \nu$$

*speed of light = wavelength x frequency*

$$\frac{m}{s} = m \times \frac{1}{s}$$

$c$  = speed of light =  $3.00 \times 10^8$  m/s

## Example of Describing Electromagnetic Waves

*A beam of green light has a wavelength of 500 nm.*

*What is the frequency of this light?*

$$c = \lambda \nu$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

$$\lambda = 500 \text{ nm} = 500 \times 10^{-9} \text{ m}$$

$$1 \text{ nm} = 10^{-9} \text{ m}$$

$$\nu = ?$$

$$\frac{c}{\lambda} = \nu$$

$$\frac{3.00 \times 10^8 \text{ ~~m~~/s}}{500 \times 10^{-9} \text{ ~~m~~}} = \nu$$

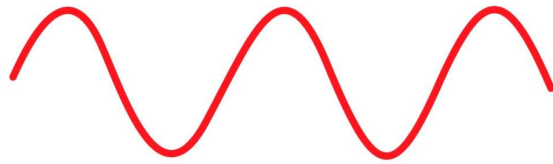
*units: 1/s = Hz*

$$6 \times 10^{14} \text{ Hz} = \nu$$

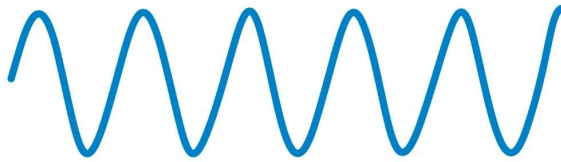


## Frequency and Wavelength

The energy of light depends on its frequency and wavelength.



longer wavelength  
lower frequency  
lower energy



shorter wavelength  
higher frequency  
higher energy



## Energy of a photon:

$$E = h\nu$$

energy

frequency

Planck's constant  
 $= 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$

$$\nu = c/\lambda$$

$$E = hc/\lambda$$

## Example of Photon Energy

A photon has a frequency of  $7.50 \times 10^{14}$  Hz. What is the wavelength of this light? What color is this light? What is the energy of the photon?

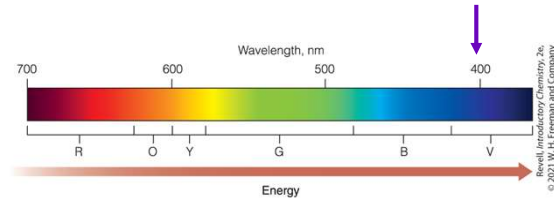
$$c = \lambda \nu$$

$$\frac{c}{\nu} = \lambda$$

$$\frac{3.00 \times 10^8 \text{ m/s}}{7.50 \times 10^{14} \text{ /s}} = \lambda$$

$$4.00 \times 10^{-7} \text{ m} = \lambda$$

$$= 400 \text{ nm} \quad \text{violet}$$

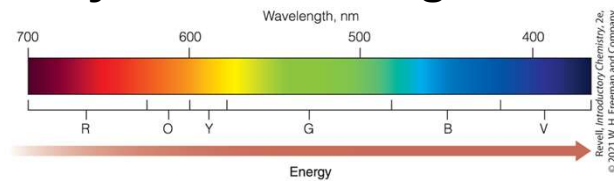


$$E = h\nu$$

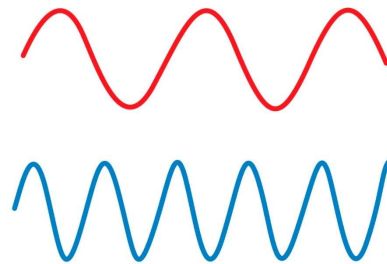
$$E = (6.63 \times 10^{-34} \text{ J}\cdot\text{s})(7.50 \times 10^{14} \text{ /s})$$

$$E = 4.97 \times 10^{-19} \text{ J}$$

## Summary of Electromagnetic Waves



- Light is a form of electromagnetic radiation
- We describe light by its
  - frequency ( $\nu$ )
  - wavelength ( $\lambda$ )
  - energy ( $E$ )
- $c = \lambda \nu$
- $E = h\nu = hc/\lambda$



## Color, Line Spectra, and the Bohr Model



## Flame Tests

observe colors emitted by different metal ions



GIPhotoStock/Science Source  
GIPhotoStock/Science Source

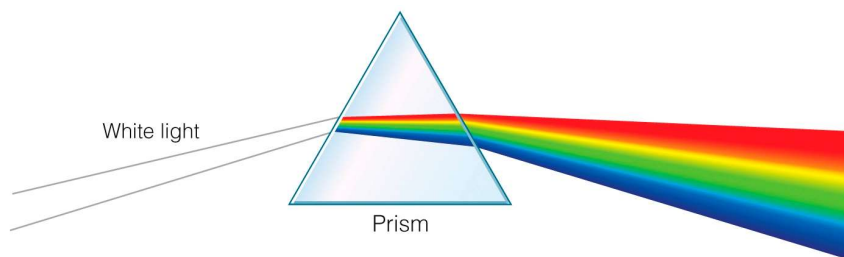
Photo credits: GIPhotoStock/Science Source

**Gas lamps also produce unique colors:**

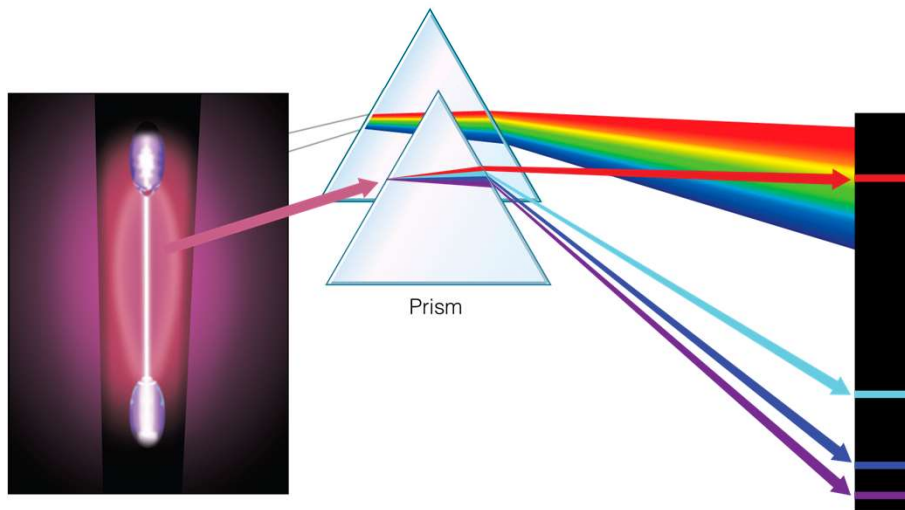


© 2005 Richard Megna/Fundamental  
Photographs, NYC

## Line Spectra



## Line Spectra, Continued



## Examples of Line Spectra

Each element produces a unique line spectrum.

He



Li



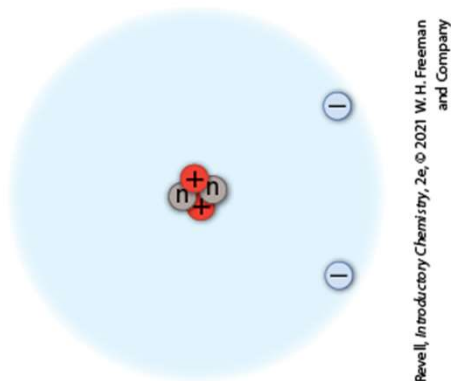
Kr



## Photoelectric Effect

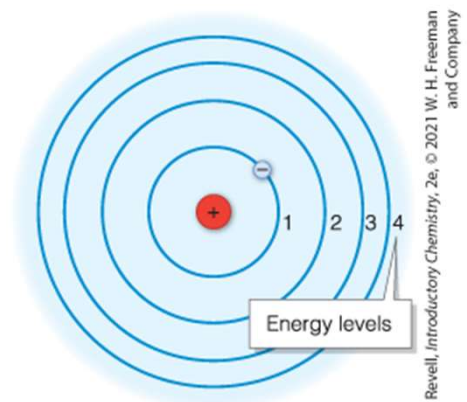
Early 20<sup>th</sup> Century:

- Dense nucleus surrounded by electrons
- *Photoelectric effect*: light causes atoms to eject electrons

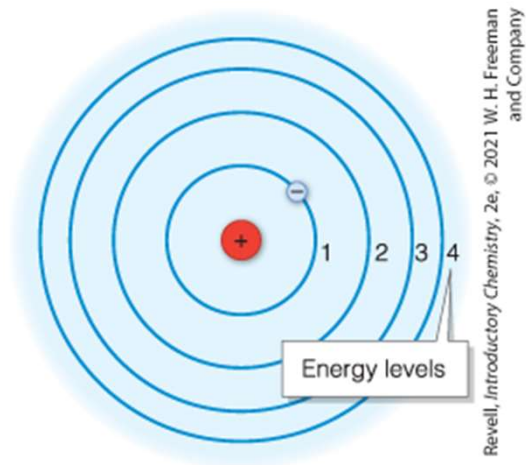


## The Bohr Model (1913)

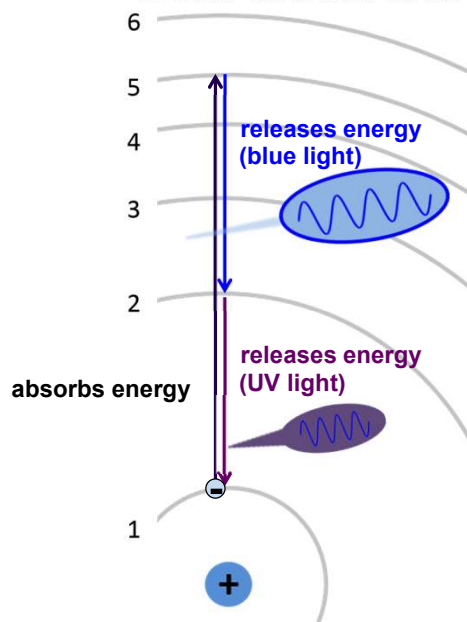
- Electrons orbit the nucleus.
- Only certain orbit energies are “allowed”.
- Electrons can jump between levels.
- Light is absorbed or released when electrons jump.
- *Ground state*: all electrons in lowest possible levels.



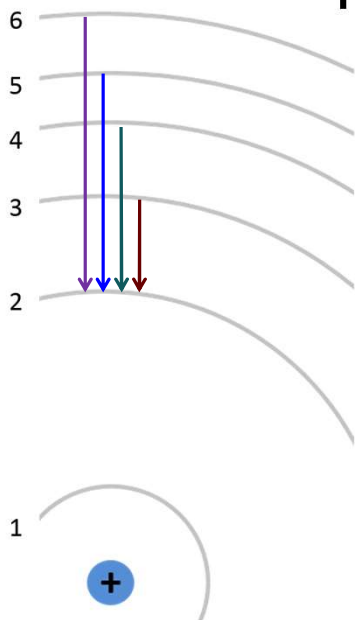
## The Bohr Model, Continued



## Bohr Model and Line Spectra



## The Hydrogen Atom



**TABLE 4.1** Transition in the Hydrogen Line Spectrum

Transition	Color Produced
3 → 2	Red
4 → 2	Light blue
5 → 2	Indigo (deep blue)
6 → 2	Purple(violet)

## Light and Electrons





## Sources of Light



Awais/Shutterstock



Johan Mard/Folio Images/Media Bakery

## Do You Give Off Light?



Monty Rakusen/Getty Images

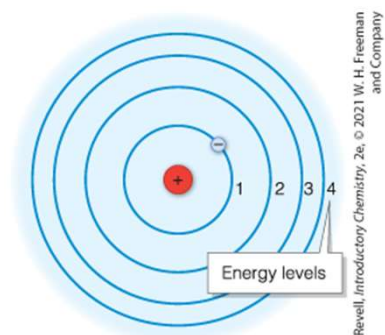
## Summary of the Bohr Model

### Explained

- The hydrogen line spectrum
- Some properties of main group elements

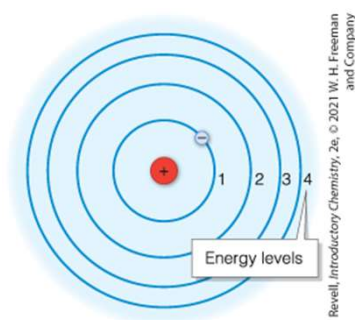
### Did not explain

- More complex line spectra
- Properties of the transition elements

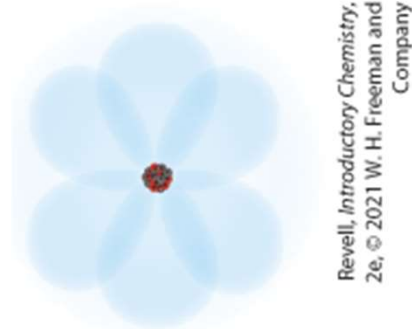


## The Quantum Model and Electron Orbitals

### Bohr Model: 1913



### Quantum Model: 1920s-30s



## Heisenberg's Uncertainty Principle

It is impossible to precisely know the exact velocity and location of a particle.

We describe the shape the blades occupy.



Ted Kinsman/Science Source

Quantum mechanics: describes electrons { most probable locations  
energies

## The wave nature of electrons

*Tiny, fast-moving particles also behave as waves.*

*This explains electron energy levels.*



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Energy 3

Energy 2

Energy 1

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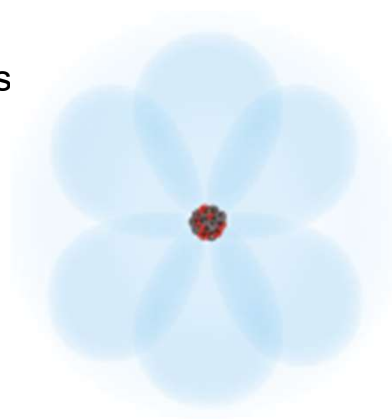
# The Quantum Model

Main Ideas:

- uncertainty principle
- wave nature of electrons

QM describes electrons by

- energy
- probable locations

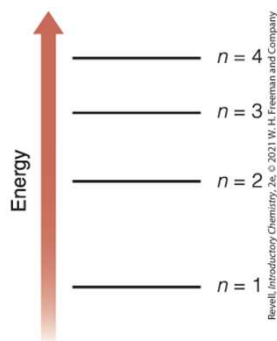


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## Energy Levels and Sublevels, Part 1

1. Electrons occupy different energy levels.

- Level is identified by its **principal quantum number**,  $n$  (1, 2, 3...)
- Higher energy levels can hold more electrons



Level	Electron Capacity
1	2
2	8
3	18
4	32

## Energy Levels and Sublevels, Part 2

2. Each energy level contains one or more **sublevels**.

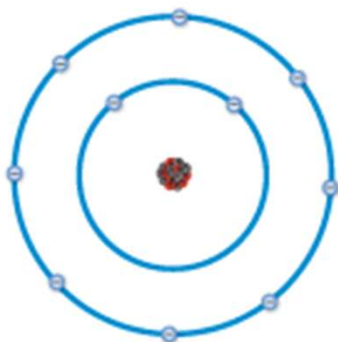
Sublevel
<i>s</i>
<i>p</i>
<i>d</i>
<i>f</i>

## Energy Levels and Sublevels, Part 3

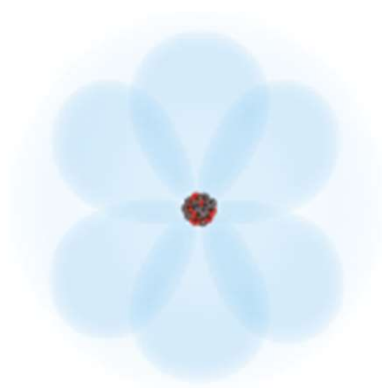
3. Each sublevel contains one or more **orbitals**.

Sublevel	Number of Orbitals
<i>s</i>	1
<i>p</i>	3
<i>d</i>	5
<i>f</i>	7

## The Bohr Model and the Quantum Model



**Bohr model**  
Electrons orbit like planets



**Quantum model**  
Electrons behave like waves  
that occupy different regions

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Company

## Energy Levels and Sublevels, Part 4

4. Each orbital holds up to two electrons.
- Electrons have a magnetic field, called spin.
  - Electrons with opposite spins pair together.



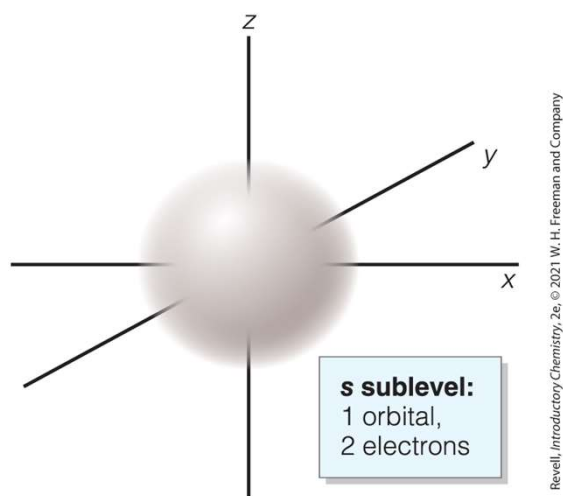
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## Energy Levels and Sublevels, Summary

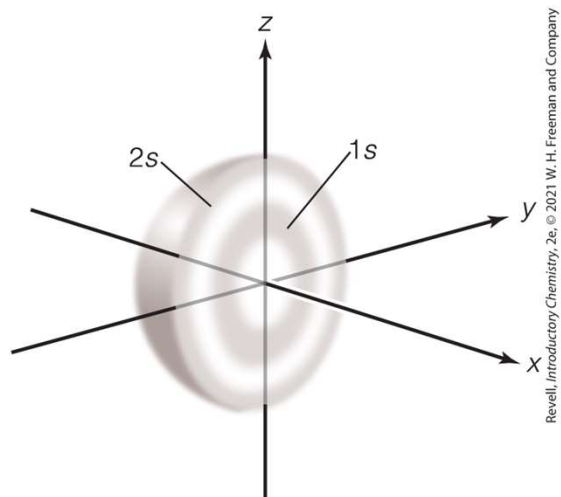
1. Electrons occupy different energy levels.
2. Each level contains sublevels.
3. Each sublevel contains orbitals.
4. Each orbital holds up to two electrons.

Sublevel	Number of Orbitals	Electron Capacity
<i>s</i>	1	2
<i>p</i>	3	6
<i>d</i>	5	10
<i>f</i>	7	14

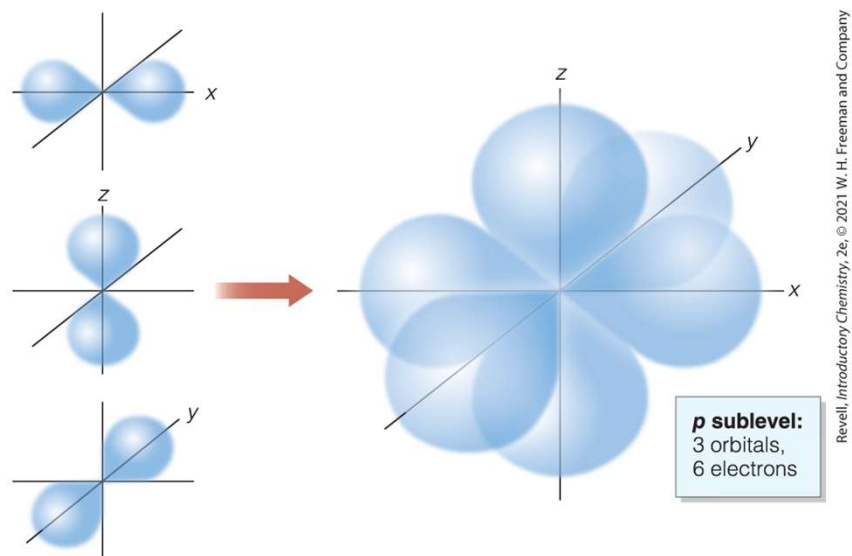
### Level 1: s only



## Level 2: $s + p$ , part 1



## Level 2: $s + p$ , part 2



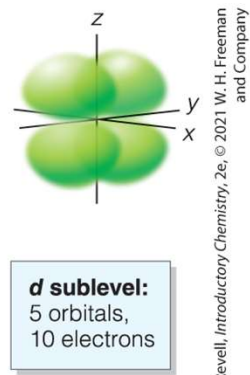
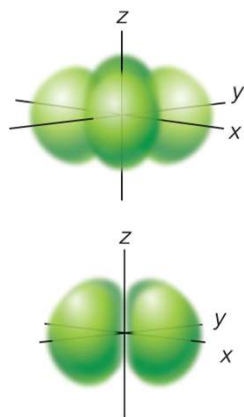
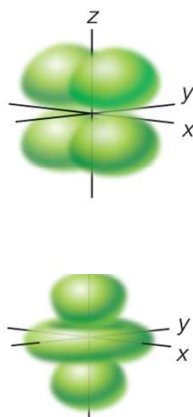


## Level 2: $s + p$ , part 3

Sublevel	Number of Orbitals	Electron Capacity
$s$	1	2
$p$	3	6

**Total: 8**

## Level 3: $s + p + d$ , part 1



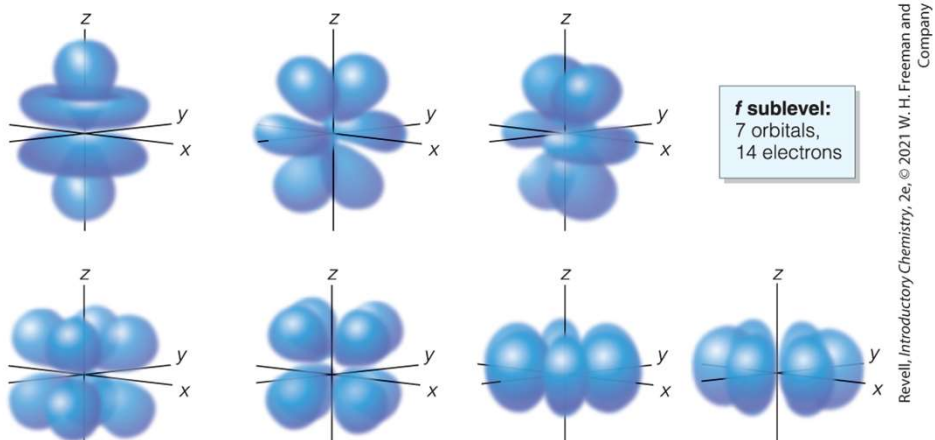
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### Level 3: $s + p + d$ , part 2

Sublevel	Number of Orbitals	Electron Capacity
$s$	1	2
$p$	3	6
$d$	5	10

**Total: 18**

### Level 4: $s + p + d + f$ , part 1



## Level 4: $s + p + d + f$ , part 2

Sublevel	Number of Orbitals	Electron Capacity
$s$	1	2
$p$	3	6
$d$	5	10
$f$	7	14

**Total: 32**

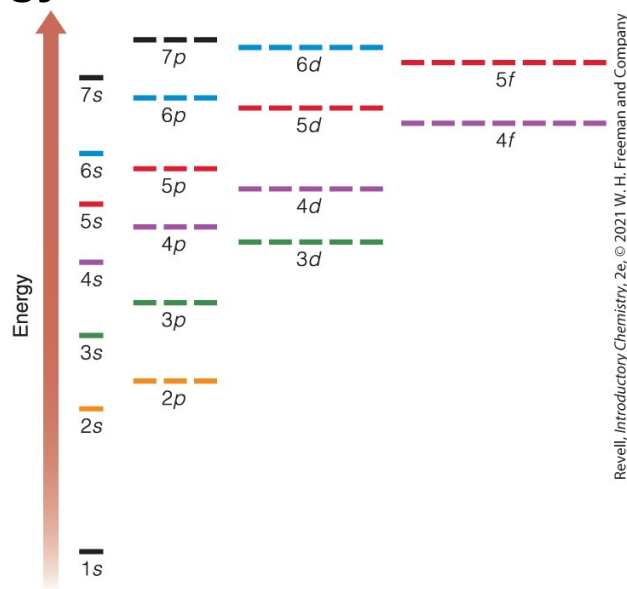
## Summary of Atomic Energy Levels

**TABLE 4.4** Energy Levels, Sublevels, and Electron Capacity

Energy Level	1	2	3	4
<b>Sublevels</b>				$f (14 e^-)$
			$d (10 e^-)$	$d (10 e^-)$
		$p (6 e^-)$	$p (6 e^-)$	$p (6 e^-)$
	$s (2 e^-)$	$s (2 e^-)$	$s (2 e^-)$	$s (2 e^-)$
<b>Electron Capacity</b>	2	8	18	32

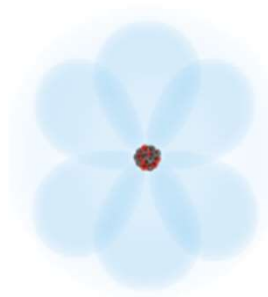
Note : the symbol  $e^-$  means electron.

## Energy Differences Between Levels

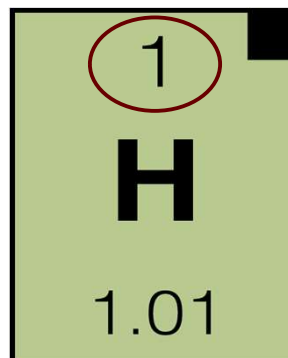


## Describing Electron Configuration

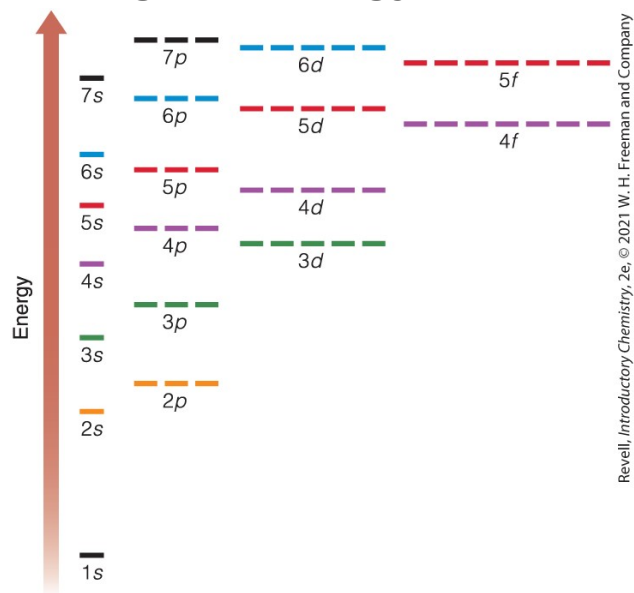
Quantum Model:  
 Energy levels – 1, 2, 3...  
 Energy sublevels – s, p, d, f



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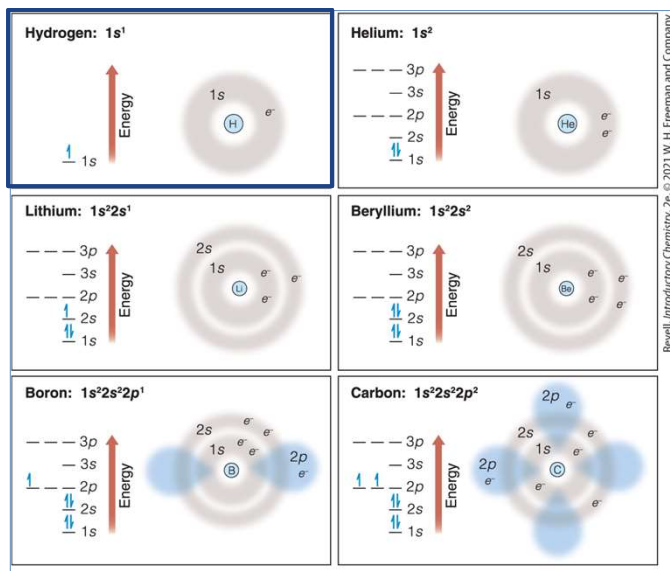


## Filling the Energy Levels



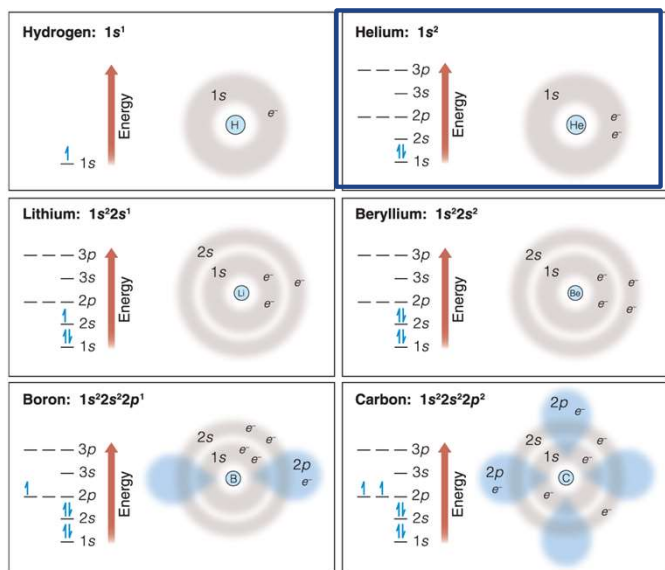
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## Hydrogen:



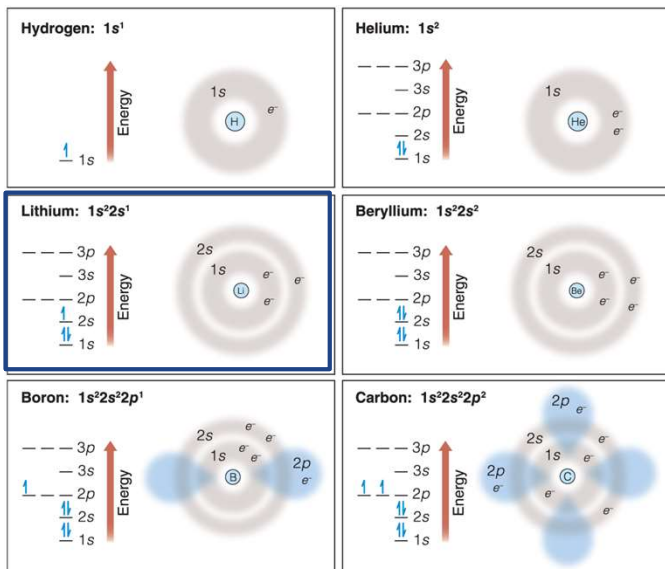
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## Helium:



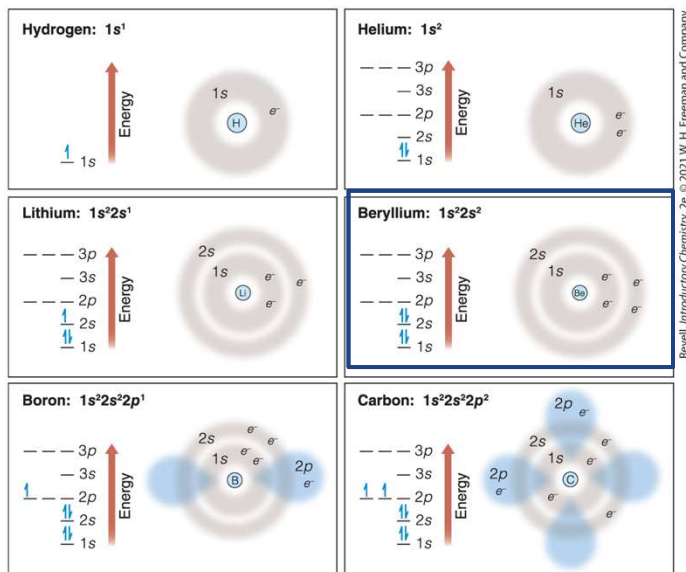
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## Lithium:



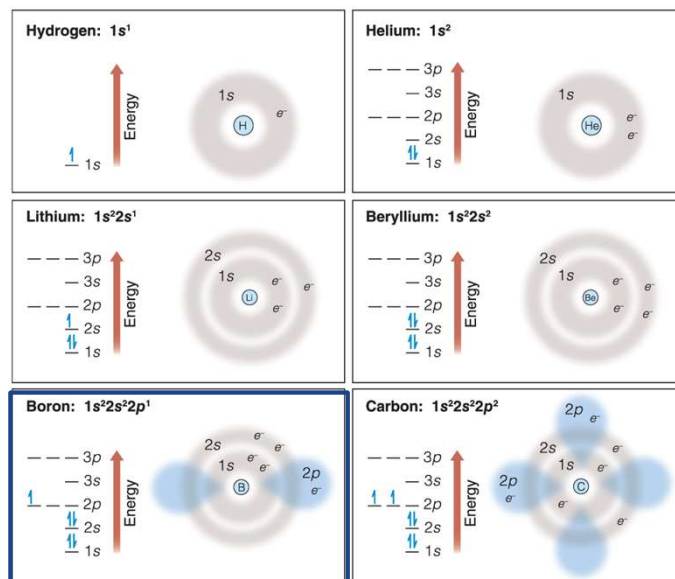
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## Beryllium:



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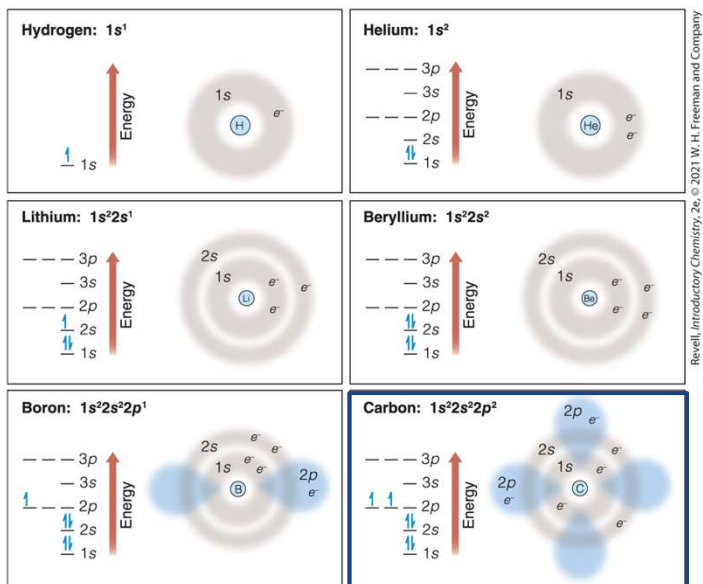
## Boron:



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**Hund's Rule:**

If empty orbitals of the same energy are available, electrons singly occupy orbitals rather than pairing together.

**Carbon:****Electron Configurations of Row 2 Elements**

3	4
<b>Li</b>	<b>Be</b>
6.94	9.01

*Li:*  $1s^2 2s^1$

*Be:*  $1s^2 2s^2$

5	6	7	8	9	10
<b>B</b>	<b>C</b>	<b>N</b>	<b>O</b>	<b>F</b>	<b>Ne</b>
10.81	12.01	14.01	16.00	19.00	20.18

*B:*  $1s^2 2s^2 2p^1$

*C:*  $1s^2 2s^2 2p^2$

*N:*  $1s^2 2s^2 2p^3$

*O:*  $1s^2 2s^2 2p^4$

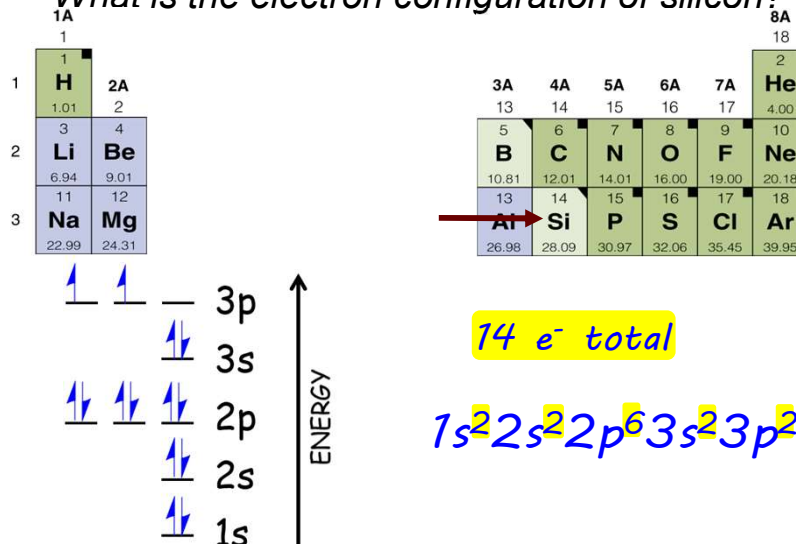
*F:*  $1s^2 2s^2 2p^5$

*Ne:*  $1s^2 2s^2 2p^6$

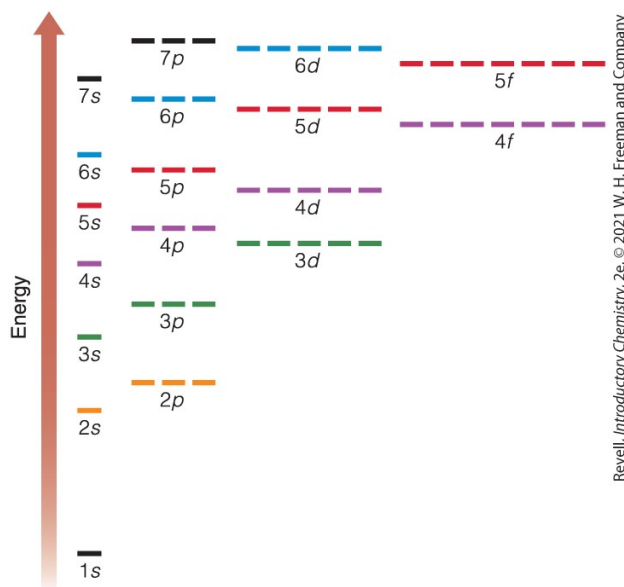


## Example for Silicon

What is the electron configuration of silicon?



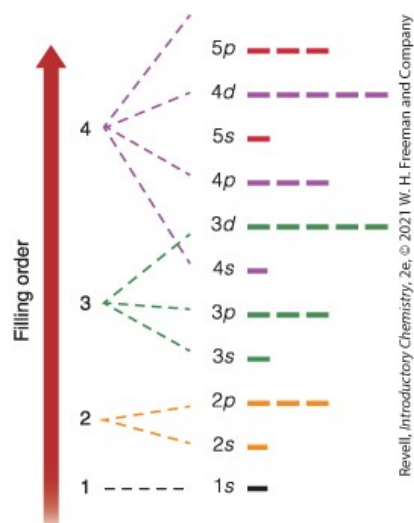
## Energy Diagram and Writing Electron Configurations



## Describing Electron Configuration, Part 2

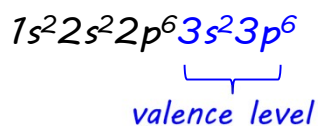
**valence level:** The highest occupied electron energy level

- Up to 8 electrons in valence level

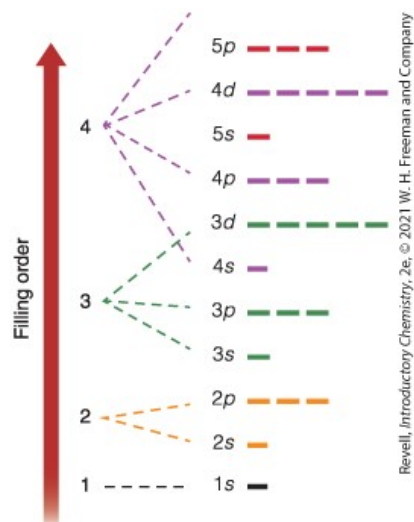
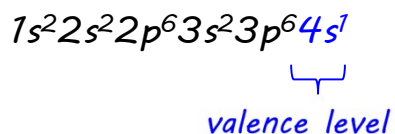


## Describing Electron Configurations, Part 3

Argon: (18 e<sup>-</sup>)

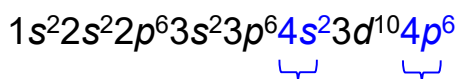
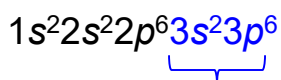
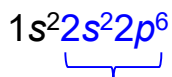


Potassium: (19 e<sup>-</sup>)



## Noble Gases have Filled Valences

2	<b>He</b>
4.00	
10	<b>Ne</b>
20.18	
18	<b>Ar</b>
39.95	
36	<b>Kr</b>
83.80	



### Octet Rule:

An atom is stabilized by having its highest-occupied (valence) energy level filled.

## Electron Configurations for Larger Atoms

	inner electrons	Noble gas notation
<b>Sodium:</b>	$1s^2 2s^2 2p^6 3s^1$	$[\text{Ne}] 3s^1$
<b>Phosphorous:</b>	$1s^2 2s^2 2p^6 3s^2 3p^3$	$[\text{Ne}] 3s^2 3p^3$
<b>Chlorine:</b>	$1s^2 2s^2 2p^6 3s^2 3p^5$	$[\text{Ne}] 3s^2 3p^5$



## Electron Configurations for Larger Atoms, Continued

*not involved with bonding*

inner  
electrons

Titanium:  $[\text{Ar}]4s^23d^2$

outer  
electrons

valence  
+ d, f sublevels  
essential to bonding

## Example of Writing an Electron Configuration

Write the electron configuration for selenium using the noble gas shorthand. Identify the inner electrons, the outer electrons, and the valence electrons.

34
<b>Se</b>
78.97

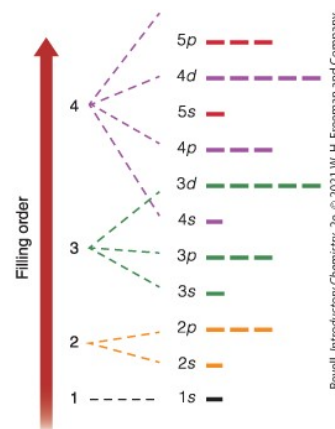
$1s^22s^22p^63s^23p^64s^23d^{10}4p^4$

$[\text{Ar}]$

inner      outer

$[\text{Ar}]4s^23d^{10}4p^4$

valence



## Example, Electron Configuration for Ions - Sodium

11
<b>Na</b>
22.99

*What is the electron configuration of a sodium atom?*

*What is the electron configuration of a sodium ion with a +1 charge?*

species	Symbol	full configuration	noble-gas shorthand
sodium atom	Na	$1s^2 2s^2 2p^6 3s^1$	$[Ne] 3s^1$
sodium ion (+1 charge)	Na <sup>+</sup>	$1s^2 2s^2 2p^6$	$[He] 2s^2 2p^6$ or $[Ne]$

## Example, Electron Configuration for Ions - Oxygen

8
<b>O</b>
16.00

*What is the electron configuration of an oxide ion, which is an oxygen ion with a charge of –2?*

species	symbol	full configuration	noble-gas shorthand
oxygen atom	O	$1s^2 2s^2 2p^4$	$[He] 2s^2 2p^4$
oxide ion (–2 charge)	O <sup>2–</sup>	$1s^2 2s^2 2p^6$	$[He] 2s^2 2p^6$ or $[Ne]$

## Many ions form noble gas configurations

O:  $1s^2 2s^2 2p^4$

Na:  $1s^2 2s^2 2p^6 3s^1$

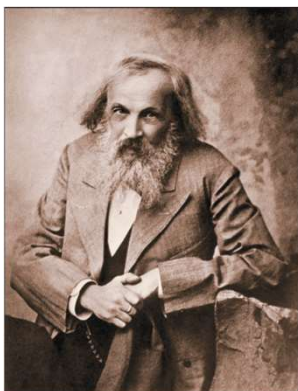
$O^{2-}$ :  $1s^2 2s^2 2p^6$

$Na^+$ :  $1s^2 2s^2 2p^6$

Ne:  $1s^2 2s^2 2p^6$




*These are isoelectronic*

## Electron Configuration and the Periodic Table



ПЕРИОДИЧЕСКАЯ СИСТЕМА ЭЛЕМЕНТОВ															
ГРУППЫ ЭЛЕМЕНТОВ															
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
1 H 1.008	2 He 4.003	3 Li 6.941	4 Be 9.012	5 B 10.81	6 C 12.011	7 N 14.007	8 O 16.00	9 F 18.998	10 Ne 20.183	11 Na 22.990	12 Mg 24.305	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.06
17 Cl 35.453	18 Ar 39.948	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 52.00	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64
33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc 98.906	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411
49 In 114.818	50 Sn 118.710	51 Sb 121.757	52 Te 127.6	53 I 126.905	54 Xe 131.29	55 Cs 132.905	56 Ba 137.327	57 La 138.905	58 Ce 140.12	59 Pr 140.908	60 Nd 144.24	61 Pm 144.913	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25
65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.259	69 Tm 168.930	70 Yb 173.045	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.222	78 Pt 195.084	79 Au 196.967	80 Hg 200.59
81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po 209	85 At 210	86 Rn 222	87 Fr 223	88 Ra 226	89 Ac 227	90 Th 232.0377	91 Pa 231.036	92 U 238.02891	93 Np 237.04817	94 Pu 244.0642	95 Am 243.06138	96 Cm 247.07035
97 Bk 247.07035	98 Cf 251.0832	99 Es 252.083	100 Fm 257.10	101 Md 258.10	102 No 259.10	103 Lr 260.10	104 Rf 261.10	105 Db 262.10	106 Sg 266.10	107 Bh 264.10	108 Hs 277.10	109 Mt 268.10	110 Ds 271.10	111 Rg 272.10	112 Uue 285.10

## Group 1A Electron Configurations

	<div>3</div> <div><b>Li</b></div> <div>6.94</div> <div>[He]2s<sup>1</sup></div>
	<div>11</div> <div><b>Na</b></div> <div>22.99</div> <div>[Ne]3s<sup>1</sup></div>
	<div>19</div> <div><b>K</b></div> <div>39.10</div> <div>[Ar]4s<sup>1</sup></div>

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Left top and middle: SPL/Science Source; bottom: Andrew Lambert Photography/Science Source; right: Philip Evans/Getty Images

**Lithium**  
(3 electrons): [He]2s<sup>1</sup>

**Sodium**  
(11 electrons): [Ne]3s<sup>1</sup>

**Potassium**  
(19 electrons): [Ar]4s<sup>1</sup>

## Group 7A Electron Configurations

**Fluorine:** [He]2s<sup>2</sup>2p<sup>5</sup>

**Chlorine:** [Ne]3s<sup>2</sup>3p<sup>5</sup>

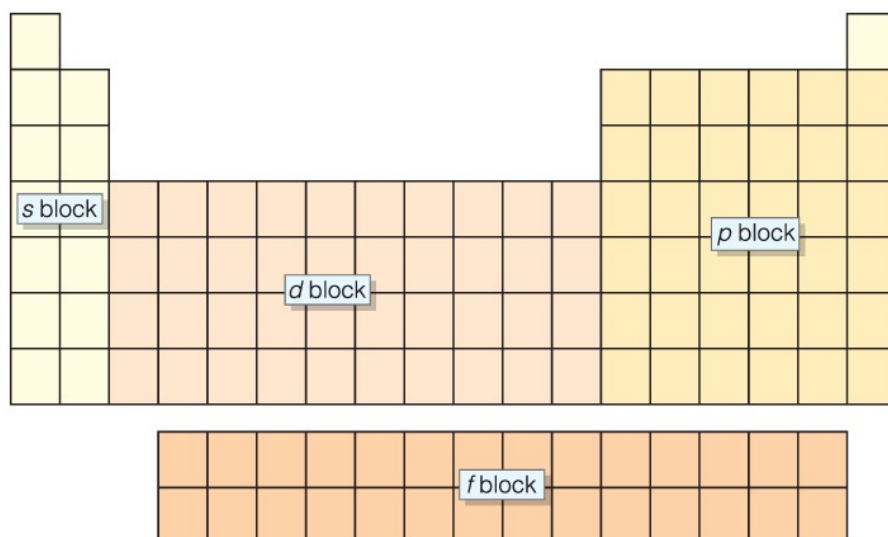
**Bromine:** [Ar]4s<sup>2</sup>3d<sup>10</sup>4p<sup>5</sup>

9	<b>F</b>
19.00	[He]2s <sup>2</sup> 2p <sup>5</sup>
17	<b>Cl</b>
35.45	[Ne]3s <sup>2</sup> 3p <sup>5</sup>
35	<b>Br</b>
79.90	[Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>5</sup>

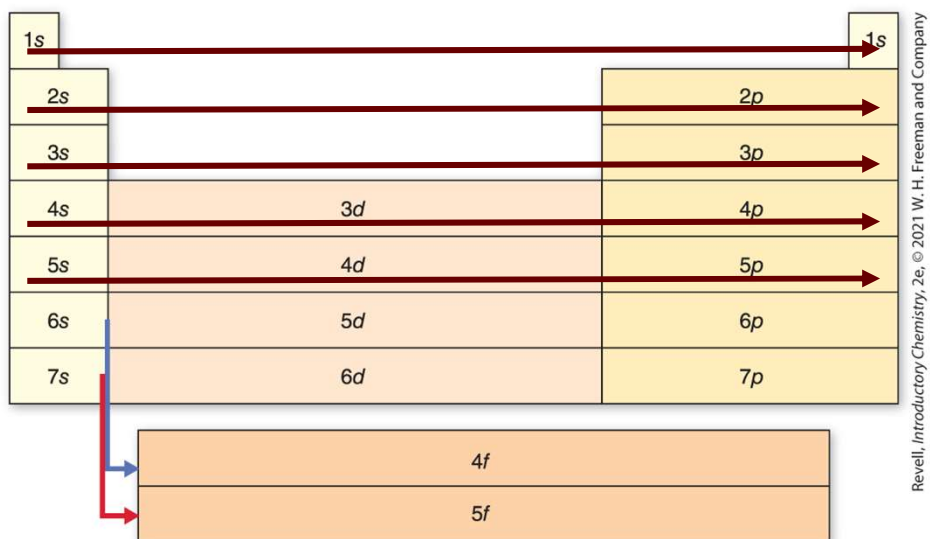




## Four Blocks of the Periodic Table



## Organization of the Periodic Table



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*What is the outermost electron configuration for sulfur?*

*Write the configuration for the highest-energy occupied sublevel for potassium, phosphorus, and iron.*

$N: 1s^2$   
 $P: 3p^3$   
 $Fe: 3d^6$

1s		
2s		2p
3s		3p
4s	3d	4p
5s	4d	5p
6s	5d	6p
7s	6d	7p
	4f	
	5f	

Russell-Saunders Coupling: 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d, 4f, 5s, 5p, 5d, 5f, 6s, 6p, 6d, 7s, 7p, 7d, 7f, 8s, 8p, 8d, 8f, 9s, 9p, 9d, 9f, 10s, 10p, 10d, 10f, 11s, 11p, 11d, 11f, 12s, 12p, 12d, 12f, 13s, 13p, 13d, 13f, 14s, 14p, 14d, 14f, 15s, 15p, 15d, 15f, 16s, 16p, 16d, 16f, 17s, 17p, 17d, 17f, 18s, 18p, 18d, 18f, 19s, 19p, 19d, 19f, 20s, 20p, 20d, 20f, 21s, 21p, 21d, 21f, 22s, 22p, 22d, 22f, 23s, 23p, 23d, 23f, 24s, 24p, 24d, 24f, 25s, 25p, 25d, 25f, 26s, 26p, 26d, 26f, 27s, 27p, 27d, 27f, 28s, 28p, 28d, 28f, 29s, 29p, 29d, 29f, 30s, 30p, 30d, 30f, 31s, 31p, 31d, 31f, 32s, 32p, 32d, 32f, 33s, 33p, 33d, 33f, 34s, 34p, 34d, 34f, 35s, 35p, 35d, 35f, 36s, 36p, 36d, 36f, 37s, 37p, 37d, 37f, 38s, 38p, 38d, 38f, 39s, 39p, 39d, 39f, 40s, 40p, 40d, 40f, 41s, 41p, 41d, 41f, 42s, 42p, 42d, 42f, 43s, 43p, 43d, 43f, 44s, 44p, 44d, 44f, 45s, 45p, 45d, 45f, 46s, 46p, 46d, 46f, 47s, 47p, 47d, 47f, 48s, 48p, 48d, 48f, 49s, 49p, 49d, 49f, 50s, 50p, 50d, 50f, 51s, 51p, 51d, 51f, 52s, 52p, 52d, 52f, 53s, 53p, 53d, 53f, 54s, 54p, 54d, 54f, 55s, 55p, 55d, 55f, 56s, 56p, 56d, 56f, 57s, 57p, 57d, 57f, 58s, 58p, 58d, 58f, 59s, 59p, 59d, 59f, 60s, 60p, 60d, 60f, 61s, 61p, 61d, 61f, 62s, 62p, 62d, 62f, 63s, 63p, 63d, 63f, 64s, 64p, 64d, 64f, 65s, 65p, 65d, 65f, 66s, 66p, 66d, 66f, 67s, 67p, 67d, 67f, 68s, 68p, 68d, 68f, 69s, 69p, 69d, 69f, 70s, 70p, 70d, 70f, 71s, 71p, 71d, 71f, 72s, 72p, 72d, 72f, 73s, 73p, 73d, 73f, 74s, 74p, 74d, 74f, 75s, 75p, 75d, 75f, 76s, 76p, 76d, 76f, 77s, 77p, 77d, 77f, 78s, 78p, 78d, 78f, 79s, 79p, 79d, 79f, 80s, 80p, 80d, 80f, 81s, 81p, 81d, 81f, 82s, 82p, 82d, 82f, 83s, 83p, 83d, 83f, 84s, 84p, 84d, 84f, 85s, 85p, 85d, 85f, 86s, 86p, 86d, 86f, 87s, 87p, 87d, 87f, 88s, 88p, 88d, 88f, 89s, 89p, 89d, 89f, 90s, 90p, 90d, 90f, 91s, 91p, 91d, 91f, 92s, 92p, 92d, 92f, 93s, 93p, 93d, 93f, 94s, 94p, 94d, 94f, 95s, 95p, 95d, 95f, 96s, 96p, 96d, 96f, 97s, 97p, 97d, 97f, 98s, 98p, 98d, 98f, 99s, 99p, 99d, 99f, 100s, 100p, 100d, 100f, 101s, 101p, 101d, 101f, 102s, 102p, 102d, 102f, 103s, 103p, 103d, 103f, 104s, 104p, 104d, 104f, 105s, 105p, 105d, 105f, 106s, 106p, 106d, 106f, 107s, 107p, 107d, 107f, 108s, 108p, 108d, 108f, 109s, 109p, 109d, 109f, 110s, 110p, 110d, 110f, 111s, 111p, 111d, 111f, 112s, 112p, 112d, 112f, 113s, 113p, 113d, 113f, 114s, 114p, 114d, 114f, 115s, 115p, 115d, 115f, 116s, 116p, 116d, 116f, 117s, 117p, 117d, 117f, 118s, 118p, 118d, 118f, 119s, 119p, 119d, 119f, 120s, 120p, 120d, 120f, 121s, 121p, 121d, 121f, 122s, 122p, 122d, 122f, 123s, 123p, 123d, 123f, 124s, 124p, 124d, 124f, 125s, 125p, 125d, 125f, 126s, 126p, 126d, 126f, 127s, 127p, 127d, 127f, 128s, 128p, 128d, 128f, 129s, 129p, 129d, 129f, 130s, 130p, 130d, 130f, 131s, 131p, 131d, 131f, 132s, 132p, 132d, 132f, 133s, 133p, 133d, 133f, 134s, 134p, 134d, 134f, 135s, 135p, 135d, 135f, 136s, 136p, 136d, 136f, 137s, 137p, 137d, 137f, 138s, 138p, 138d, 138f, 139s, 139p, 139d, 139f, 140s, 140p, 140d, 140f, 141s, 141p, 141d, 141f, 142s, 142p, 142d, 142f, 143s, 143p, 143d, 143f, 144s, 144p, 144d, 144f, 145s, 145p, 145d, 145f, 146s, 146p, 146d, 146f, 147s, 147p, 147d, 147f, 148s, 148p, 148d, 148f, 149s, 149p, 149d, 149f, 150s, 150p, 150d, 150f, 151s, 151p, 151d, 151f, 152s, 152p, 152d, 152f, 153s, 153p, 153d, 153f, 154s, 154p, 154d, 154f, 155s, 155p, 155d, 155f, 156s, 156p, 156d, 156f, 157s, 157p, 157d, 157f, 158s, 158p, 158d, 158f, 159s, 159p, 159d, 159f, 160s, 160p, 160d, 160f, 161s, 161p, 161d, 161f, 162s, 162p, 162d, 162f, 163s, 163p, 163d, 163f, 164s, 164p, 164d, 164f, 165s, 165p, 165d, 165f, 166s, 166p, 166d, 166f, 167s, 167p, 167d, 167f, 168s, 168p, 168d, 168f, 169s, 169p, 169d, 169f, 170s, 170p, 170d, 170f, 171s, 171p, 171d, 171f, 172s, 172p, 172d, 172f, 173s, 173p, 173d, 173f, 174s, 174p, 174d, 174f, 175s, 175p, 175d, 175f, 176s, 176p, 176d, 176f, 177s, 17

## Electron Configuration of Aluminum

Write the electron configuration for aluminum.

How many valence electrons does aluminum have?

$[Ne]3s^23p^1$   
3 valence electrons

1A	2A	Main group number						3A	4A	5A	6A	7A	8A
1	2	Valence electrons						3	4	5	6	7	8
													Ne
								Al					

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## Valence Electrons

1A	2A	Main group number						3A	4A	5A	6A	7A	8A
1	2	Valence electrons						3	4	5	6	7	8
									C				
									Si				
									Ge				

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The row indicates the highest occupied electron energy level.

The column gives the outermost electron configuration.

the outermost electron configuration.																	
1	2															3	4
1 H 1s <sup>1</sup>	2 He 1s <sup>2</sup>															3 Li 2s <sup>1</sup>	4 Be 2s <sup>2</sup>
5 Na 3s <sup>1</sup>	6 Mg 3s <sup>2</sup>															9 Al 3s <sup>2</sup> 3p <sup>1</sup>	10 Si 3s <sup>2</sup> 3p <sup>2</sup>
19 K 4s <sup>1</sup>	20 Ca 4s <sup>2</sup>	21 Sc 3d <sup>1</sup> 4s <sup>2</sup>	22 Ti 3d <sup>2</sup> 4s <sup>2</sup>	23 V 3d <sup>3</sup> 4s <sup>2</sup>	24 Cr 3d <sup>5</sup> 4s <sup>1</sup>	25 Mn 3d <sup>5</sup> 4s <sup>2</sup>	26 Fe 3d <sup>6</sup> 4s <sup>2</sup>	27 Co 3d <sup>7</sup> 4s <sup>2</sup>	28 Ni 3d <sup>8</sup> 4s <sup>2</sup>	29 Cu 3d <sup>10</sup> 4s <sup>1</sup>	30 Zn 3d <sup>10</sup> 4s <sup>2</sup>	31 Ga 4s <sup>2</sup> 4p <sup>1</sup>	32 Ge 4s <sup>2</sup> 4p <sup>2</sup>	33 As 4s <sup>2</sup> 4p <sup>3</sup>	34 Se 4s <sup>2</sup> 4p <sup>4</sup>	35 Br 4s <sup>2</sup> 4p <sup>5</sup>	36 Kr 4s <sup>2</sup> 4p <sup>6</sup>
37 Rb 5s <sup>1</sup>	38 Sr 5s <sup>2</sup>	39 Y 4d <sup>1</sup> 5s <sup>2</sup>	40 Zr 4d <sup>2</sup> 5s <sup>2</sup>	41 Nb 4d <sup>4</sup> 5s <sup>1</sup>	42 Mo 4d <sup>5</sup> 5s <sup>1</sup>	43 Tc 4d <sup>5</sup> 5s <sup>2</sup>	44 Ru 4d <sup>7</sup> 5s <sup>1</sup>	45 Rh 4d <sup>8</sup> 5s <sup>1</sup>	46 Pd 4d <sup>10</sup> 5s <sup>0</sup>	47 Ag 4d <sup>10</sup> 5s <sup>1</sup>	48 Cd 4d <sup>10</sup> 5s <sup>2</sup>	49 In 5s <sup>2</sup> 5p <sup>1</sup>	50 Sn 5s <sup>2</sup> 5p <sup>2</sup>	51 Sb 5s <sup>2</sup> 5p <sup>3</sup>	52 Te 5s <sup>2</sup> 5p <sup>4</sup>	53 I 5s <sup>2</sup> 5p <sup>5</sup>	54 Xe 5s <sup>2</sup> 5p <sup>6</sup>
55 Cs 6s <sup>1</sup>	56 Ba 6s <sup>2</sup>	57 La 5d <sup>1</sup> 6s <sup>2</sup>	72 Hf 5d <sup>2</sup> 6s <sup>2</sup>	73 Ta 5d <sup>3</sup> 6s <sup>2</sup>	74 W 5d <sup>4</sup> 6s <sup>2</sup>	75 Re 5d <sup>5</sup> 6s <sup>2</sup>	76 Os 5d <sup>6</sup> 6s <sup>2</sup>	77 Ir 5d <sup>7</sup> 6s <sup>2</sup>	78 Pt 5d <sup>9</sup> 6s <sup>1</sup>	79 Au 5d <sup>10</sup> 6s <sup>1</sup>	80 Hg 5d <sup>10</sup> 6s <sup>2</sup>	81 Tl 6s <sup>2</sup> 6p <sup>1</sup>	82 Pb 6s <sup>2</sup> 6p <sup>2</sup>	83 Bi 6s <sup>2</sup> 6p <sup>3</sup>	84 Po 6s <sup>2</sup> 6p <sup>4</sup>	85 At 6s <sup>2</sup> 6p <sup>5</sup>	86 Rn 6s <sup>2</sup> 6p <sup>6</sup>
87 Fr 7s <sup>1</sup>	88 Ra 7s <sup>2</sup>	89 Ac 6d <sup>1</sup> 7s <sup>2</sup>	104 Rf 6d <sup>2</sup> 7s <sup>2</sup>	105 Db 6d <sup>3</sup> 7s <sup>2</sup>	106 Sg 6d <sup>4</sup> 7s <sup>2</sup>	107 Bh 6d <sup>5</sup> 7s <sup>2</sup>	108 Hs 6d <sup>6</sup> 7s <sup>2</sup>	109 Mt 6d <sup>7</sup> 7s <sup>2</sup>	110 Ds 6d <sup>9</sup> 7s <sup>1</sup>	111 Rg 6d <sup>10</sup> 7s <sup>1</sup>	112 Cn 6d <sup>10</sup> 7s <sup>2</sup>	113 Nh 7s <sup>2</sup> 7p <sup>1</sup>	114 Fl 7s <sup>2</sup> 7p <sup>2</sup>	115 Mc 7s <sup>2</sup> 7p <sup>3</sup>	116 Lv 7s <sup>2</sup> 7p <sup>4</sup>	117 Ts 7s <sup>2</sup> 7p <sup>5</sup>	118 Og 7s <sup>2</sup> 7p <sup>6</sup>
58	59	60	61	62	63	64	65	66	67	68	69	70	71				
Ce 4f <sup>1</sup>	Pr 4f <sup>2</sup>	Nd 4f <sup>3</sup>	Pm	Sm 4f <sup>6</sup>	Eu 4f <sup>7</sup>	Gd 4f <sup>7</sup> 5d <sup>1</sup>	Tb 4f <sup>9</sup>	Dy 4f <sup>10</sup>	Ho 4f <sup>11</sup>	Er 4f <sup>12</sup>	Tm 4f <sup>13</sup>	Yb 4f <sup>14</sup>	Lu 4f <sup>14</sup> 5d <sup>1</sup>				
90	91	92	93	94	95	96	97	98	99	100	101	102	103				
Th 5f <sup>0</sup>	Pa 5f <sup>2</sup>	U 5f <sup>3</sup>	Np 5f <sup>4</sup>	Pu 5f <sup>6</sup>	Am 5f <sup>7</sup>	Cm 5f <sup>7</sup> 6d <sup>1</sup>	Bk 5f <sup>9</sup>	Cf 5f <sup>10</sup>	Es 5f <sup>11</sup>	Fm 5f <sup>12</sup>	Md 5f <sup>13</sup>	No 5f <sup>14</sup>	Lr 5f <sup>14</sup> 6d <sup>1</sup>				

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 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 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 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1043 1044 10

# Chapter 5 – Chemical Bonds and Compounds

Introductory  
**CHEMISTRY**

Second Edition

**Kevin Revell**

## Lewis Symbols and the Octet Rule

### Valence electrons

- electrons in highest occupied energy level
- *s* and *p* sublevels
- generally up to 8 electrons

Group	1A	2A		3A	4A	5A	6A	7A	8A
Valence electrons	1	2		3	4	5	6	7	8
Configuration	$s^1$	$s^2$		$s^2p^1$	$s^2p^2$	$s^2p^3$	$s^2p^4$	$s^2p^5$	$s^2p^6$
	H								He
	Li	Be		B	C	N	O	F	Ne
	Na	Mg		Al	Si	P	S	Cl	Ar

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## Lewis Symbols Show Valence Electrons

Lewis dot symbols

- Represent valence electrons as dots around atomic symbol

	Li•	Be••		•B•	•C•	•N•	•O•	•F•	•Ne•
Group	1A	2A		3A	4A	5A	6A	7A	8A
Valence electrons	1	2		3	4	5	6	7	8
Configuration	$s^1$	$s^2$		$s^2p^1$	$s^2p^2$	$s^2p^3$	$s^2p^4$	$s^2p^5$	$s^2p^6$
	H								He
	Li	Be		B	C	N	O	F	Ne
	Na	Mg		Al	Si	P	S	Cl	Ar

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# The Octet Rule

**Octet Rule:** An atom is stabilized by having its valence energy level filled.

Li•    Be•    B•    •C•    •N•    :O•    :F•    :Ne:

Noble gases fulfill the octet rule.

Other atoms fulfill the octet rule by:

- gaining or losing electrons (ions).
- sharing electrons.

Li•       $\overset{\cdot}{\underset{\cdot}{\text{Be}}}$        $\overset{\cdot}{\underset{\cdot}{\text{B}}}$ •       $\cdot\overset{\cdot}{\underset{\cdot}{\text{C}}}\cdot$        $\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{N}}}\cdot$        $\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{O}}}\cdot$        $\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{F}}}\cdot$        $\cdot\overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{Ne}}}\cdot$

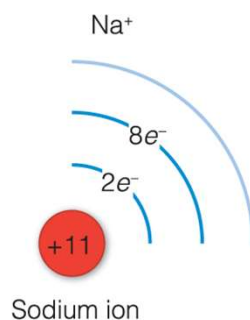
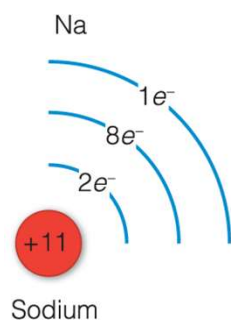
Other atoms fulfill the octet rule by:

- gaining or losing electrons (ions).
- sharing electrons.

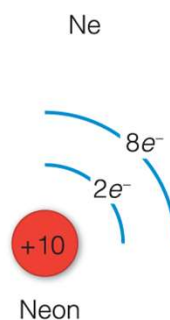
[illegible][illegible]

## Cations – positively charged ions

Main group metals fulfill the octet rule by forming cations



Fulfills octet rule



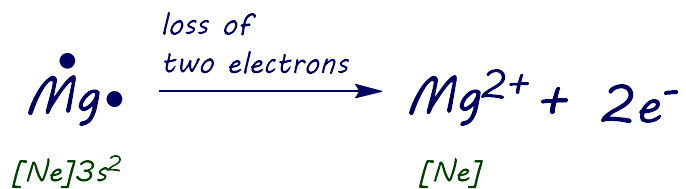
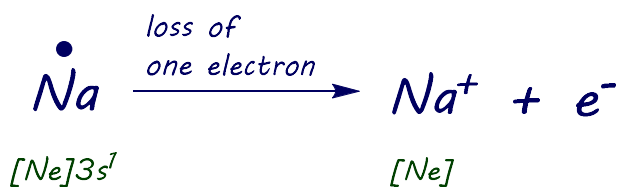
Fulfills octet rule

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## Lewis Structures Show Cation Formation

+1	+2
H <sup>+</sup>	
Li <sup>+</sup>	Be <sup>2+</sup>
Na <sup>+</sup>	Mg <sup>2+</sup>
K <sup>+</sup>	Ca <sup>2+</sup>
Rb <sup>+</sup>	Sr <sup>2+</sup>

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*Name the following cations:*

$\text{Pb}^{4+}$   
*lead(IV)*

The diagram shows a simplified periodic table grid. Elements are represented by their symbols and common oxidation states:

- Green boxes (+3):** Al<sup>3+</sup>, Sn<sup>2+</sup>, Sn<sup>4+</sup>, Pb<sup>2+</sup>, Pb<sup>4+</sup>.
- Purple boxes (+2):** Cr<sup>2+</sup>, Mn<sup>2+</sup>, Fe<sup>2+</sup>, Co<sup>2+</sup>, Cu<sup>2+</sup>, Zn<sup>2+</sup>, Ag<sup>+</sup>.
- Light blue boxes (+1):** Cr<sup>3+</sup>, Mn<sup>3+</sup>, Fe<sup>3+</sup>, Co<sup>3+</sup>.

Red circles are drawn around the following elements:

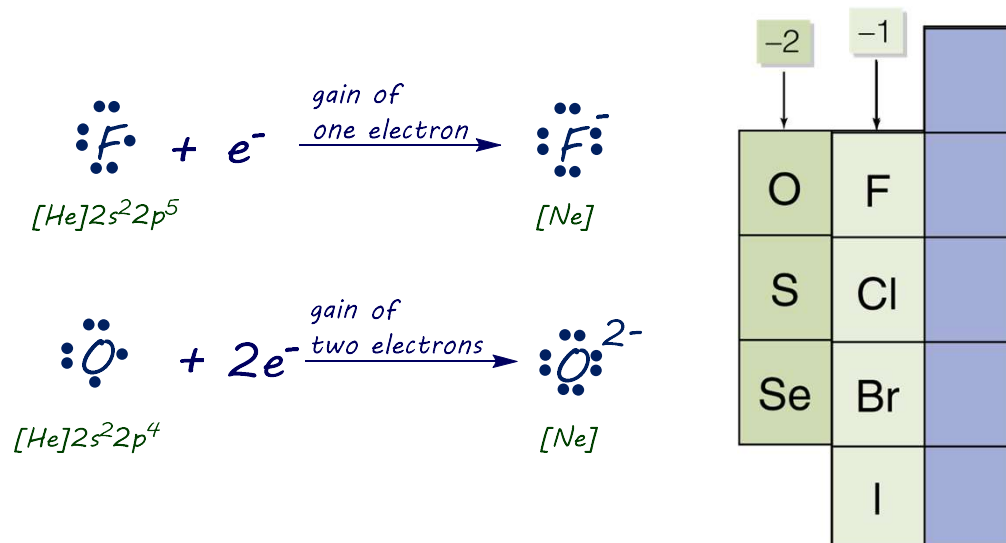
- Copper (Cu) in its +2 state.
- Lead (Pb) in its +2 state.

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N	O	F	
P	S	Cl	
	Se	Br	
		I	

## Anions Fulfill the Octet Rule, Part 1

Most nonmetals fulfill the octet rule by gaining electrons.



## Anions Fulfill the Octet Rule, Part 2

Most nonmetals fulfill the octet rule by gaining electrons.

	5A	6A	7A	8A
	-3	-2	-1	
	N <sup>3-</sup>	O <sup>2-</sup>	F <sup>-</sup>	
	P <sup>3-</sup>	S <sup>2-</sup>	Cl <sup>-</sup>	
			Br <sup>-</sup>	
			I <sup>-</sup>	

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## Naming Anions: change ending to *-ide*

Atom	Anion Symbol	Anion Name
chlorine	$\text{Cl}^-$	chloride
oxygen	$\text{O}^{2-}$	oxide
sulfur	$\text{S}^{2-}$	sulfide
nitrogen	$\text{N}^{3-}$	nitride

## Polyatomic ions: groups of atoms with a charge, part 1

$\text{NH}_4^+$ Ammonium			
$\text{NO}_3^-$	Nitrate	$\text{SO}_4^{2-}$	Sulfate
$\text{NO}_2^-$	Nitrite	$\text{SO}_3^{2-}$	Sulfite
$\text{CO}_3^{2-}$	Carbonate	$\text{HSO}_4^-$	Bisulfate (Hydrogen sulfate)
$\text{HCO}_3^-$	Bicarbonate (Hydrogen carbonate)	$\text{ClO}_4^-$	Perchlorate
$\text{PO}_4^{3-}$	Phosphate	$\text{ClO}_3^-$	Chlorate
$\text{HPO}_4^{2-}$	Hydrogen phosphate	$\text{ClO}_2^-$	Chlorite
$\text{C}_2\text{H}_3\text{O}_2^-$	Acetate	$\text{ClO}^-$	Hypochlorite
$\text{OH}^-$	Hydroxide	$\text{CrO}_4^{2-}$	Chromate
$\text{CN}^-$	Cyanide	$\text{Cr}_2\text{O}_7^{2-}$	Dichromate
$\text{O}_2^{2-}$	Peroxide	$\text{MnO}_4^-$	Permanganate

## Polyatomic ions: groups of atoms with a charge, part 2

**Oxyanions** – contain oxygen

Usually named as element root + *-ate*



## Polyatomic ions: groups of atoms with a charge, part 3

More than one oxyanion:

*-ate*      more oxygen atoms

*-ite*      fewer oxygen atoms



## Polyatomic ions: groups of atoms with a charge, part 4

More than one oxyanion:

**-ate** more oxygen atoms

**-ite** fewer oxygen atoms



## Things to Know

[illegible]

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### Polyatomic atoms

NH <sub>4</sub> <sup>+</sup> Ammonium			
NO <sub>3</sub> <sup>-</sup>	Nitrate	SO <sub>4</sub> <sup>2-</sup>	Sulfate
CO <sub>3</sub> <sup>2-</sup>	Carbonate	SO <sub>3</sub> <sup>2-</sup>	Sulfite
HCO <sub>3</sub> <sup>-</sup>	Bicarbonate (Hydrogen carbonate)	HSO <sub>4</sub> <sup>-</sup>	Bisulfate (Hydrogen sulfate)
NO <sub>2</sub> <sup>-</sup>	Nitrite	ClO <sub>4</sub> <sup>-</sup>	Perchlorate
PO <sub>4</sub> <sup>3-</sup>	Phosphate	ClO <sub>3</sub> <sup>-</sup>	Chlorate
HPO <sub>4</sub> <sup>2-</sup>	Hydrogen phosphate	ClO <sub>2</sub> <sup>-</sup>	Chlorite
C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup>	Acetate	ClO <sup>-</sup>	Hypochlorite
OH <sup>-</sup>	Hydroxide	CrO <sub>4</sub> <sup>2-</sup>	Chromate
CN <sup>-</sup>	Cyanide	Cr <sub>2</sub> O <sub>7</sub> <sup>2-</sup>	Dichromate
O <sub>2</sub> <sup>2-</sup>	Peroxide	MnO <sub>4</sub> <sup>-</sup>	Permanganate

[illegible]

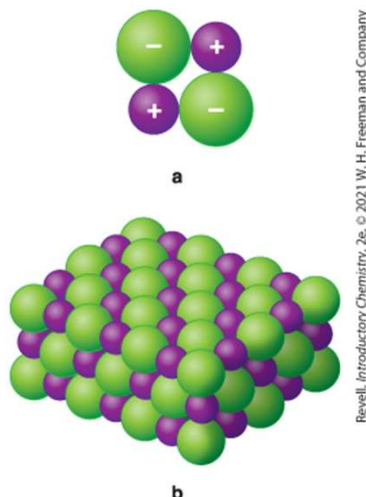
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**ionic compound** – composed of charged ions

50

## Ionic Compound Structure

**ionic lattice** – an array of positive and negative ions.

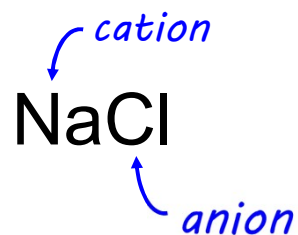
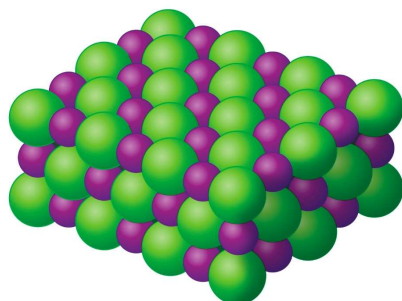


## Chemical Formulas

Show the type and amount of each element present

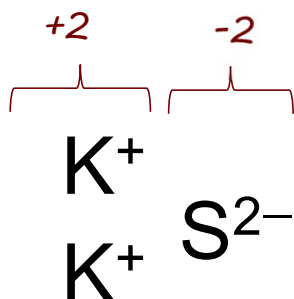
**Empirical formula:** The smallest whole-number ratio of atoms

**Formula unit:** The smallest number of ions necessary to form a compound

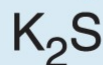


## Ionic Compounds

*Write the formula for a compound composed of potassium and sulfide ions.*



Total charge = 0

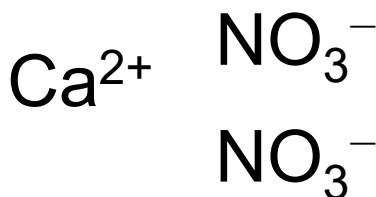


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positive charges must equal the negative charges.

## Compounds with Polyatomic Ions

*Write the formula for a compound composed of calcium and nitrate ions.*



Total charge = 0



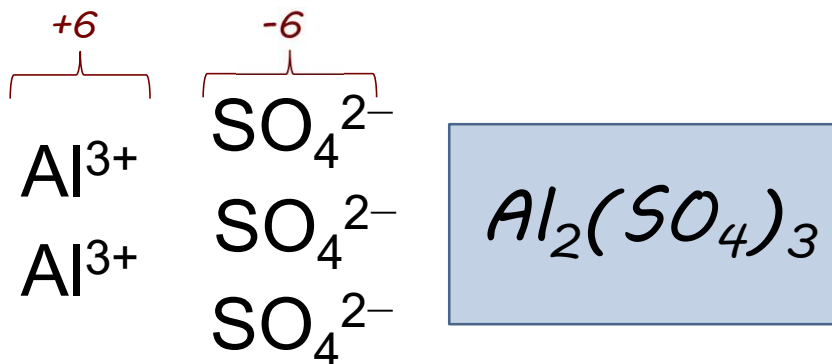
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Company

positive charges must equal the negative charges.



## Compounds with Polyatomic Ions, Continued

Write the formula for a compound composed of aluminum and sulfate ions.



positive charges must equal the negative charges.

## Naming Ionic Compounds, Part 1

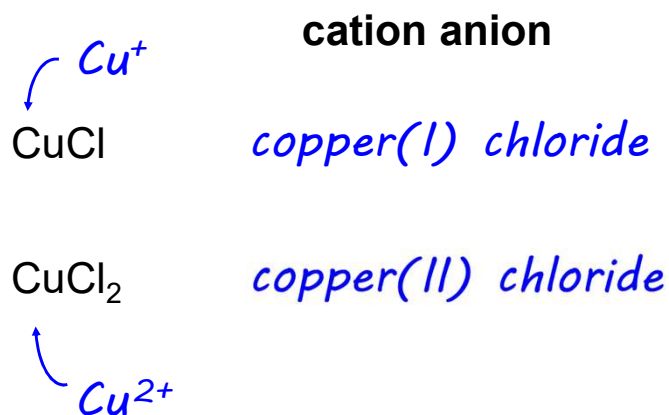
cation anion

NaCl      *sodium chloride*

MgCl<sub>2</sub>      *magnesium chloride*

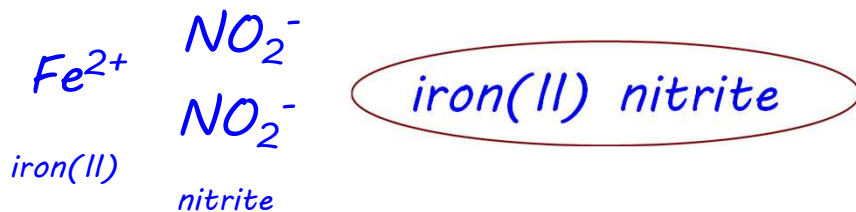
MgSO<sub>4</sub>      *magnesium sulfate*

## Naming Ionic Compounds, Part 2



## Example, Naming Ionic Compounds

1. Name the compound  $\text{Fe}(\text{NO}_2)_2$ .

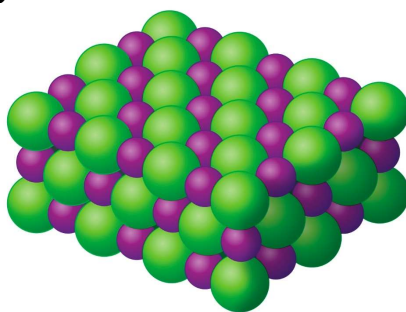


2. Write the empirical formula for ammonium sulfide.



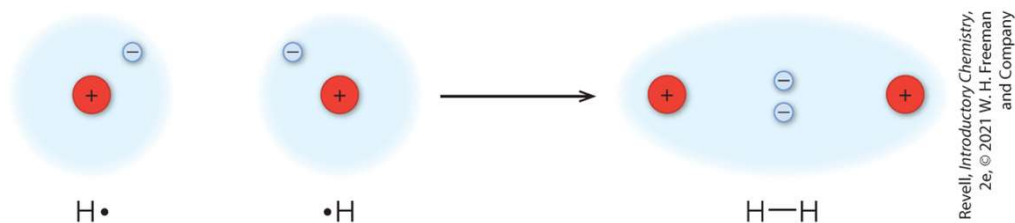
## Summary, Ionic Compounds

- Ionic bonds occur between oppositely charged ions
- In ionic compounds, total charge = 0
- Named as “cation anion”
- Formula  $\Leftrightarrow$  Name



## Covalent Bonding, Part 1

**covalent bond** – electrons shared between two atoms



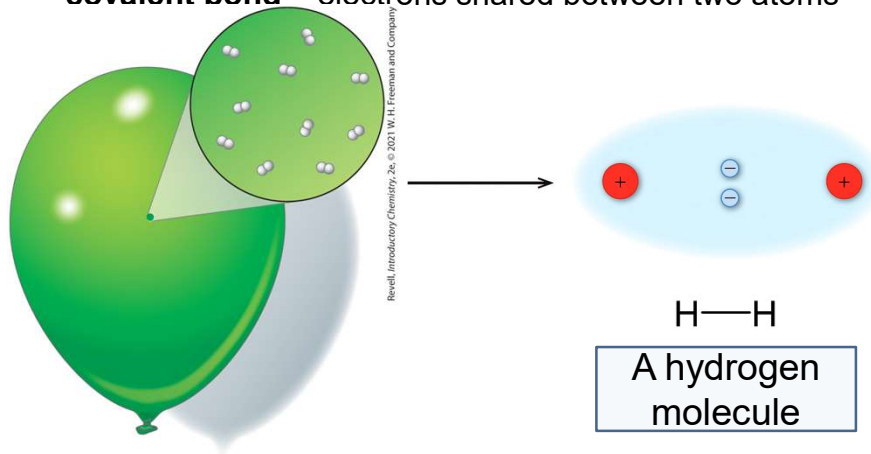
A hydrogen  
molecule

By sharing electrons, each hydrogen completes its valence level.

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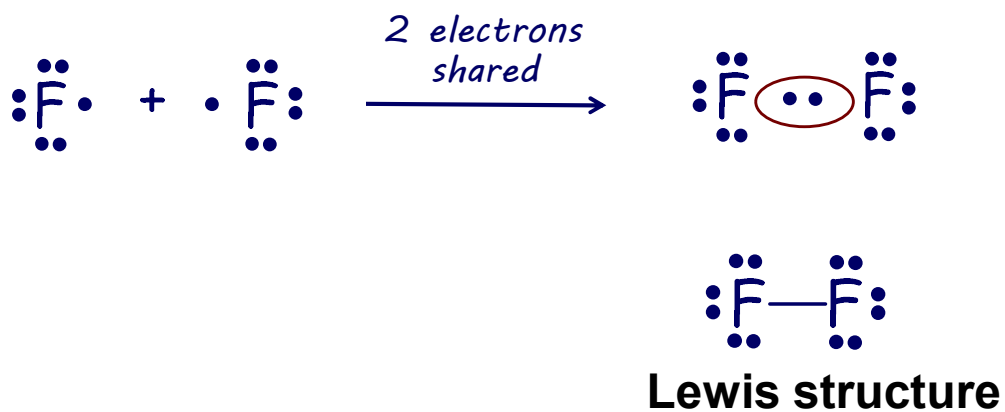
## Covalent Bonding, Part 2

covalent bond – electrons shared between two atoms



By sharing electrons, each hydrogen completes its valence level.

## Covalent Bonding, Part 3



## Seven Elements Form Diatomic Molecules

## The Magnificent Seven

### Elements that form Diatomic Molecules

Hydrogen:  $H_2$

Nitrogen:  $N_2$

Oxygen:  $O_2$

Fluorine:  $F_2$

Chlorine:  $\text{Cl}_2$

Bromine:  $\text{Br}_2$

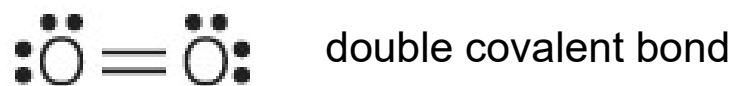
Iodine:  $I_2$

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## Seven Elements Form Diatomic Molecules, Continued

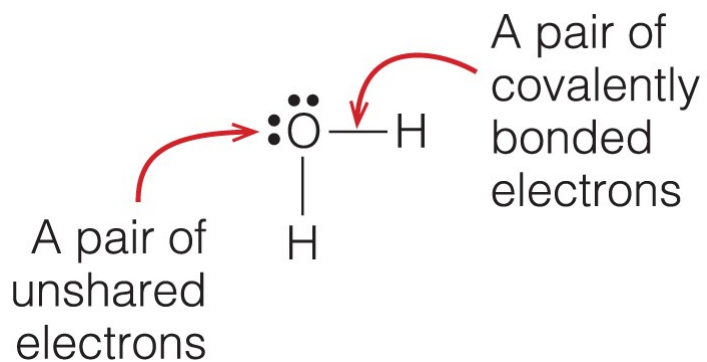
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## Double and Triple Bonds in Lewis Structures



## Covalent Compounds

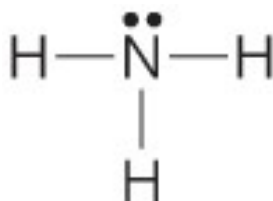
Covalent compounds fulfill the octet rule by sharing electrons.



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## Electrons in Lewis Structures

*In this structure, how many electrons does the nitrogen atom share through covalent bonds? How many of the valence nitrogen electrons are not shared? Does this nitrogen atom have a complete octet?*



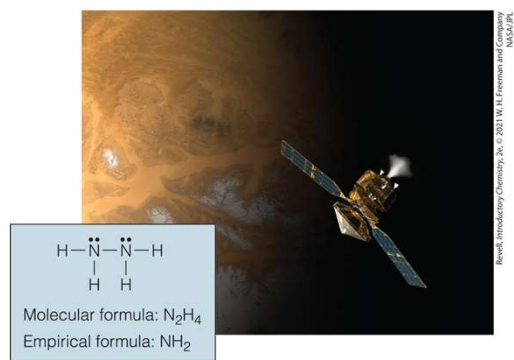
*Nitrogen has 6 shared electrons  
and 2 unshared electrons*

---

*8 electrons - a complete octet*

## Covalent Compounds, Continued

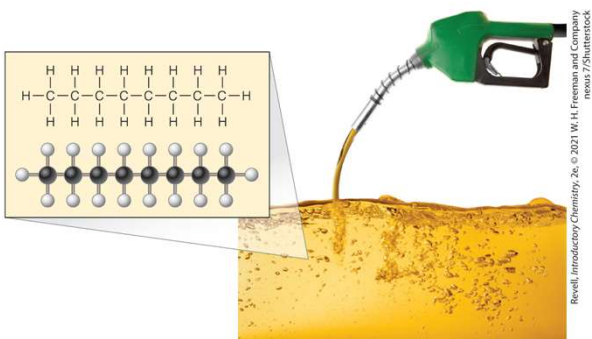
**molecular formula** – gives the number of atoms in the molecule



Empirical Formula:  $\text{NH}_2$

Molecular Formula:  $\text{N}_2\text{H}_4$

## Covalent Compound Structures



Covalent compounds often have complex structures.

Compound name	Formula
Phosphorus monoxide	PO
Diphosphorus trioxide	P <sub>2</sub> O <sub>3</sub>
Diphosphorus tetroxide	P <sub>2</sub> O <sub>4</sub>
Tetraphosphorus decoxide	P <sub>4</sub> O <sub>10</sub>

## Naming Binary Covalent Compounds

Atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

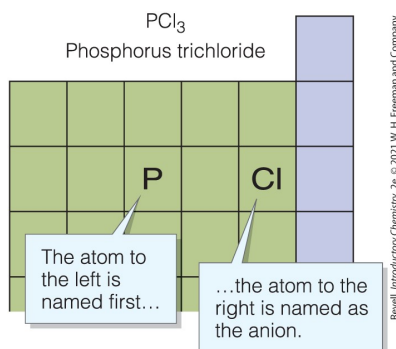
\* omit for first element



phosphorus trichloride



phosphorus pentachloride





## Using Greek Prefixes

“pent” or “penta”

$\text{PCl}_5$     phosphorus pentachloride

$\text{P}_2\text{O}_5$     diphosphorus pentoxide

Remove “a” if anion begins with a vowel.

## Practice Naming Covalent Compounds

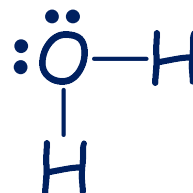
*Nitrogen and oxygen form two covalent compounds,  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$ . Name each of these compounds.*

$\text{NO}_2$     nitrogen dioxide

$\text{N}_2\text{O}_4$     dinitrogen tetroxide

## Summary of Covalent Compounds

- In covalent bonds, atoms share electrons
- Covalent bonds form between nonmetals
- Most covalent compounds form discrete molecules
- We describe molecules using
  - Lewis structures
  - Molecular formulas
- Naming binary covalent compounds
  - Leftmost element first
  - Second element named as anion
  - Prefixes indicate the number of atoms present



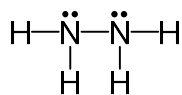
## Distinguishing Ionic and Covalent Compounds

To fulfill their valence, atoms

- gain or lose electrons (ions)
- share electrons (covalent bonds)

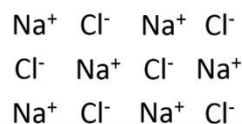
### Covalent compounds

- share electrons
- between nonmetal atoms
- usually form molecules
- *molecular formula*



### Ionic compounds

- oppositely-charged ions
- don't form molecules
- *formula unit* or *empirical formula*



## Properties of Ionic and Covalent Compounds

Limestone  
( $\text{CaCO}_3$ )



Olive Oil



## Identifying and Naming Compounds

### Covalent compounds

- all nonmetals

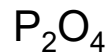
### Ionic compounds

- metal + nonmetal
- contains polyatomic ions

*Identify these compounds as ionic or covalent, and name each one:*



*ionic*  
*magnesium fluoride*



*covalent*  
*diphosphorus tetroxide*



*ionic*  
*iron(III) nitrate*



*covalent*  
*sulfur hexachloride*

# Aqueous Solutions: How Ionic and Covalent Compounds Differ

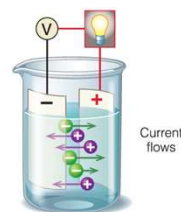
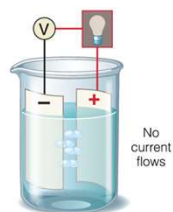
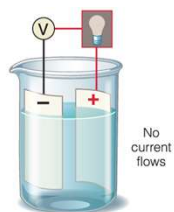
**aqueous solution** A homogeneous mixture, in which the main component is water

**soluble** Able to dissolve



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## Electrolyte Solutions Conduct Electricity



a



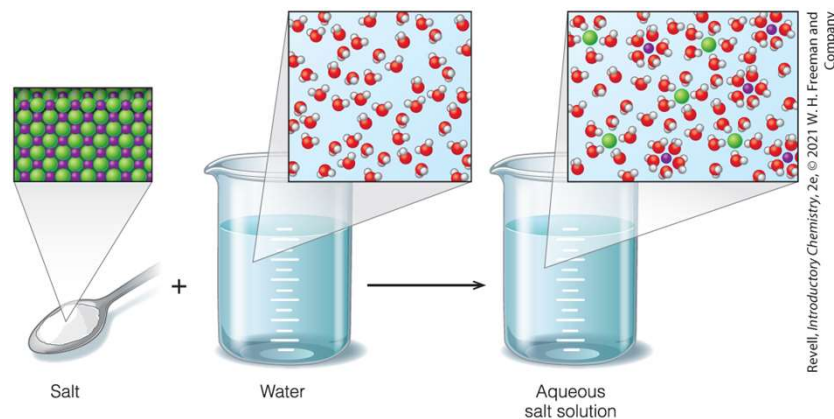
b



c

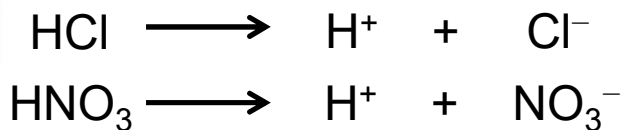
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**dissociation** Ions are pulled apart in an aqueous solution



## Acids

covalent compounds that produce  $\text{H}^+$  ions in aqueous solution



Common Acids

Formula	Name	Formula	Name
$\text{HF}$	hydrofluoric acid	$\text{HNO}_3$	nitric acid
$\text{HCl}$	hydrochloric acid	$\text{HNO}_2$	nitrous acid
$\text{HBr}$	hydrobromic acid	$\text{H}_2\text{SO}_4$	sulfuric acid
$\text{HI}$	hydroiodic acid	$\text{H}_3\text{PO}_4$	phosphoric acid
$\text{H}_2\text{CO}_3$	carbonic acid	$\text{HC}_2\text{H}_3\text{O}_2$	acetic acid

## Binary Acids

HF	hydrofluoric acid
HCl	hydrochloric acid
HBr	hydrobromic acid
HI	hydroiodic acid

## Oxyacids

form  $\text{H}^+$  and oxyanion

1. *-ate*  $\rightarrow$  *-ic acid*

$\text{NO}_3^-$	nitrate	$\text{HNO}_3$	nitric acid
$\text{CO}_3^{2-}$	carbonate	$\text{H}_2\text{CO}_3$	carbonic acid
$\text{SO}_4^{2-}$	sulfate	$\text{H}_2\text{SO}_4$	sulfuric acid
$\text{PO}_4^{3-}$	phosphate	$\text{H}_3\text{PO}_4$	phosphoric acid

## Oxyacids, Continued

form  $\text{H}^+$  and oxyanion

2. *-ite*  $\rightarrow$  *-ous acid*

$\text{NO}_2^-$  nitrite

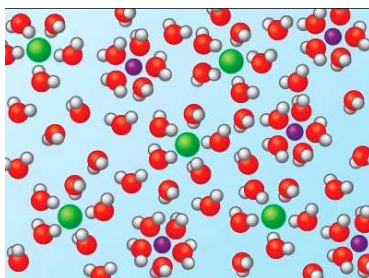
$\text{HNO}_2$  nitrous acid

$\text{ClO}_2^-$  chlorite

$\text{HClO}_2$  chlorous acid

## Summary, Electrolytes

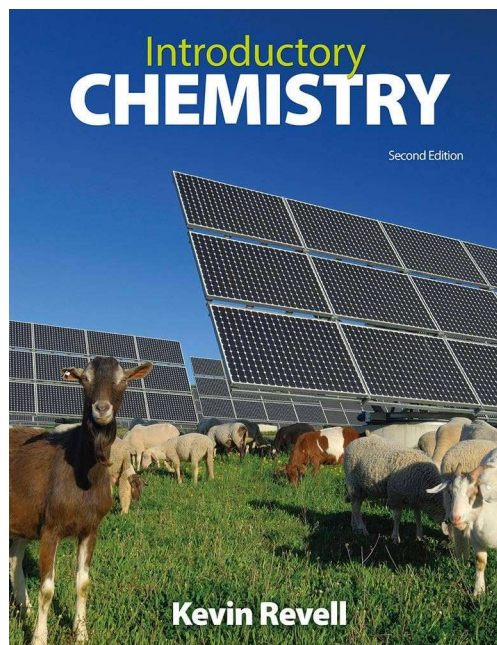
electrolytes {  
ionic compounds  
acids (form  $\text{H}^+$  ions in water)



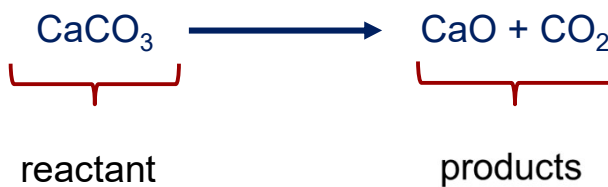
Introductory Chemistry  
Chem 103

## Chapter 6 – Chemical Reactions

Lecture Slides

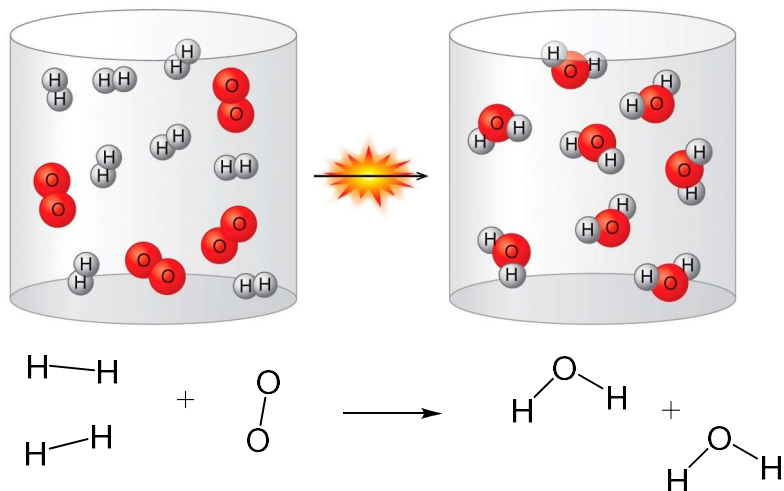


### Chemical Equations

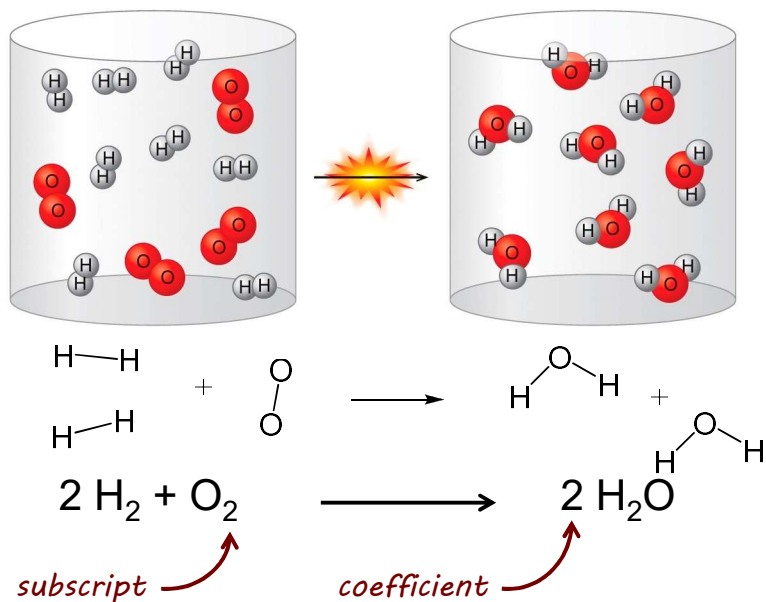




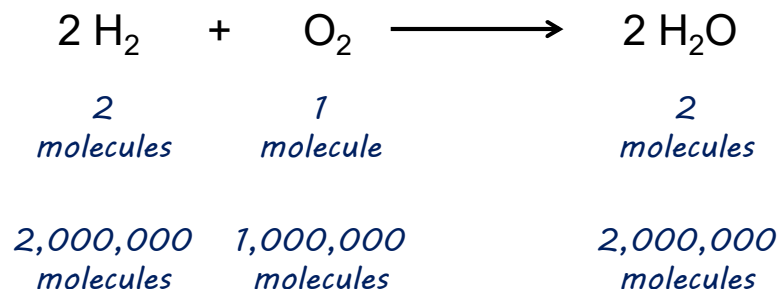
## Chemical Equations Show Ratios of Substances



## Chemical Equations Show Ratios of Substances, Continued



## The Ratios In a Chemical Reaction Are Constant

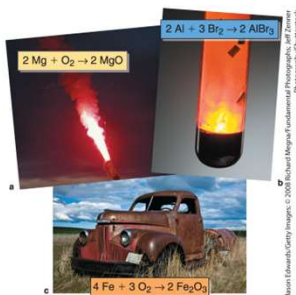


*In a **balanced equation**, the number and type of each atom are the same on both sides of the arrow.*

*Properly balanced – smallest whole-number ratio*

## Balancing Equations

*In a **balanced equation**, the number and type of each atom are the same on both sides of the arrow.*



## Practice Balancing Equations



~~4~~ ~~1~~ Fe

~~4~~ ~~2~~ Fe

Fe



~~6~~ ~~2~~ O

~~6~~ ~~3~~ O

O

1. Identify number and type on each side.
2. Add coefficients to balance atoms.
3. Do not change subscripts.

## Practice Balancing Equations, Continued



Al - 2

O - 3

C - ~~1~~ 3

Cl - ~~2~~ 6

Al - ~~1~~ 2

O - ~~1~~ 3

C - ~~1~~ 3

Cl - ~~3~~ 6



Balance elemental forms last.

## Strategies for Balancing Equations

balance polyatomic ions



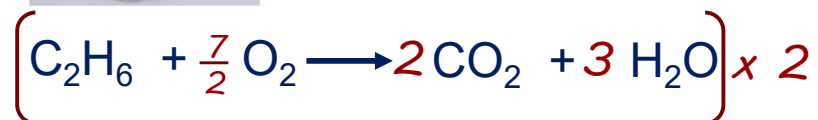
nitrate:  $\text{NO}_3^-$

hydroxide:  $\text{OH}^-$

## Strategies for Balancing Equations, Continued



use a fractional coefficient for diatomic molecules



need 7 oxygen atoms!



## Equations with Phase Notations

**phase notations:** show phase or state of reaction components

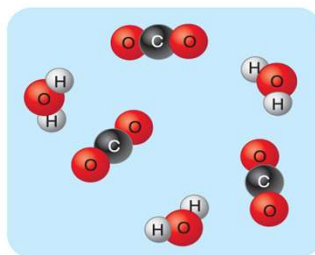
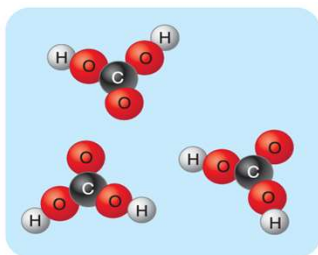


TABLE 6.1 Phase Symbols

Symbol	Meaning
(s)	Solid
(l)	Liquid
(g)	Gas
(aq)	Aqueous solution (dissolved in water)

## Aqueous Solutions

**(aq)** – indicates the substance is dissolved in water



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## Chemical Equations Can Show Changes of State



Zoom Team/Shutterstock

## Classifying Reactions, Part 1



Niloo/Shutterstock



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Jasni/Shutterstock



## Classifying Reactions, Part 2



## Classifying Reactions, Part 3

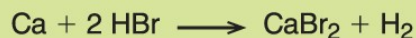
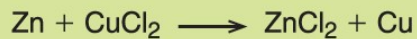
### Decomposition:

*One forms two or more*



### Single Displacement:

*One element replaces another*



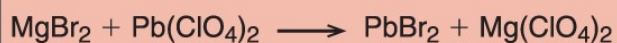
### Synthesis (Combination):

*Two form one*



### Double Displacement:

*Two ions replace each other*



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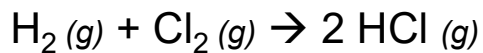
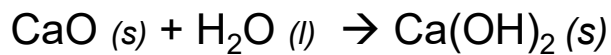
## Decomposition Reactions



**Decomposition:**  
*One forms two or more*



## Synthesis Reactions

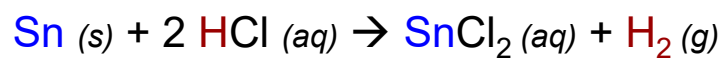


**Synthesis (Combination):**  
*Two form one*



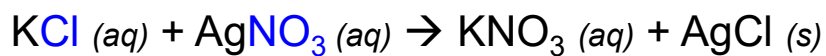


## Single Displacement Reactions



**Single Displacement:**  
*One element replaces another*

## Double Displacement Reactions

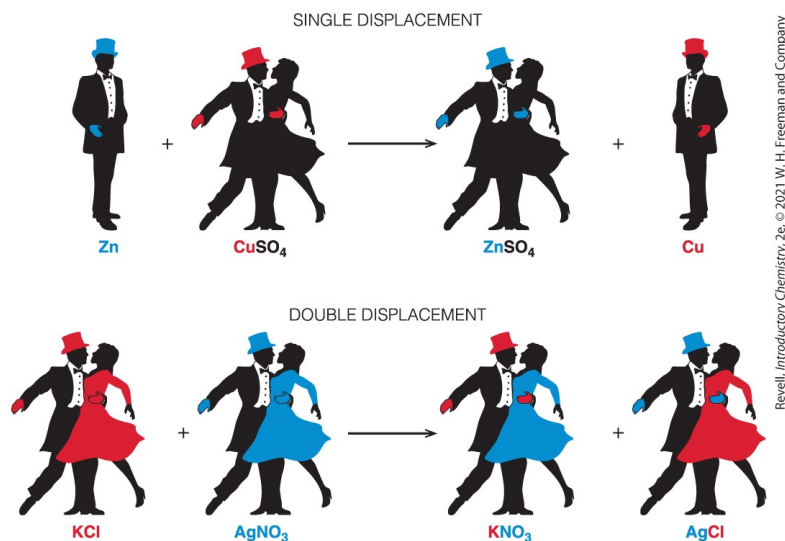


The anions "swap" positions



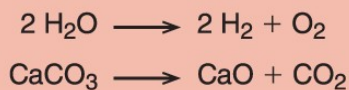
**Double Displacement**  
*Two ions replace each other*

## Single and Double Displacement Reactions



## Classifying Reactions Summary

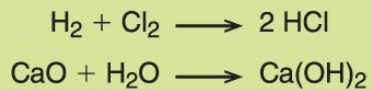
**Decomposition:**  
*One forms two or more*



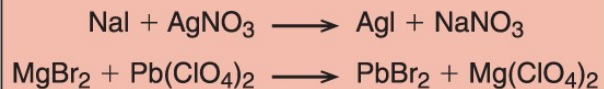
**Single Displacement:**  
*One element replaces another*



**Synthesis (Combination):**  
*Two form one*



**Double Displacement:**  
*Two ions replace each other*



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## Metal + Nonmetal → Ionic Compound



**reduction** – gain of electrons

Diagram illustrating the formation of an ionic bond between Calcium (Ca) and Sulfur (S):

- Calcium (Ca) has 1 valence electron.
- Sulfur (S) has 6 valence electrons.
- The reaction shows Calcium losing 2 electrons to form  $\text{Ca}^{2+}$ .
- Sulfur gains 2 electrons to form  $\text{S}^{2-}$ .
- The resulting ions are  $\text{Ca}^{2+}$  and  $\text{S}^{2-}$ .


## Reactions between Metals and Nonmetals Example 2

$$\text{Mg (s)} + \text{Cl}_2 \text{ (g)} \rightarrow \text{MgCl}_2 \text{ (s)}$$

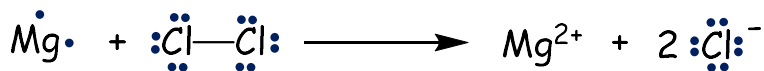
$$\text{Mg} \cdot + \cdot \ddot{\text{Cl}} - \ddot{\text{Cl}} \cdot \longrightarrow \text{Mg}^{2+} + 2 \cdot \ddot{\text{Cl}} \cdot$$

*Mg loses two electrons*

*each Cl gains one electron*



Charles D. Williams Science Source



each Cl gains  
one electron



# Metals and Nonmetals Form Specific, Stable Ions.

Monatomic atoms																	
H <sup>+</sup>																	
Li <sup>+</sup>	Be <sup>2+</sup>												N <sup>3-</sup>	O <sup>2-</sup>	F <sup>-</sup>		
Na <sup>+</sup>	Mg <sup>2+</sup>											Al <sup>3+</sup>		P <sup>3-</sup>	S <sup>2-</sup>	Cl <sup>-</sup>	
K <sup>+</sup>	Ca <sup>2+</sup>				Cr <sup>2+</sup>	Mn <sup>2+</sup>	Fe <sup>2+</sup>	Co <sup>2+</sup>		Cu <sup>+</sup>	Zn <sup>2+</sup>					Br <sup>-</sup>	
Rb <sup>+</sup>	Sr <sup>2+</sup>				Cr <sup>3+</sup>	Mn <sup>3+</sup>	Fe <sup>3+</sup>	Co <sup>3+</sup>		Cu <sup>2+</sup>							
										Ag <sup>+</sup>			Sn <sup>2+</sup>			I <sup>-</sup>	
													Sn <sup>4+</sup>				
													Pb <sup>2+</sup>				
													Pb <sup>4+</sup>				

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Monatomic atoms																	
H <sup>+</sup>																	
Li <sup>+</sup>	Be <sup>2+</sup>													N <sup>3-</sup>	O <sup>2-</sup>	F <sup>-</sup>	
Na <sup>+</sup>	Mg <sup>2+</sup>											Al <sup>3+</sup>		P <sup>3-</sup>	S <sup>2-</sup>	Cl <sup>-</sup>	
K <sup>+</sup>	Ca <sup>2+</sup>				Cr <sup>2+</sup>	Mn <sup>2+</sup>	Fe <sup>2+</sup>	Co <sup>2+</sup>		Cu <sup>+</sup>	Zn <sup>2+</sup>					Br <sup>-</sup>	
					Cr <sup>3+</sup>	Mn <sup>3+</sup>	Fe <sup>3+</sup>	Co <sup>3+</sup>		Cu <sup>2+</sup>							
Rb <sup>+</sup>	Sr <sup>2+</sup>									Ag <sup>+</sup>			Sn <sup>2+</sup>			I <sup>-</sup>	
													Sn <sup>4+</sup>				
													Pb <sup>2+</sup>				
													Pb <sup>4+</sup>				

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## Reactions Between Metals and Nonmetals Practice

*What compound is formed when aluminum metal reacts with chlorine gas? Write a balanced equation for this reaction.*



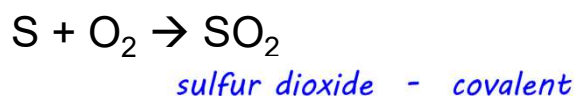
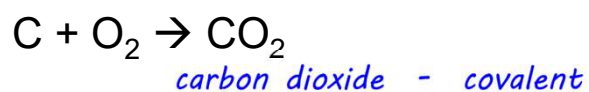
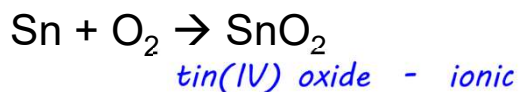
## Reactions Between Metals and Nonmetals, More Practice

*When tin metal reacts with bromine, it is oxidized to the tin(IV) ion, while bromine is reduced to form bromide ions. Write a balanced equation for this reaction.*



## Combustion Reactions

reactions in which oxygen gas combines with elements or compounds to produce oxides.



**Hydrocarbons** compounds composed of hydrogen and carbon

**TABLE 6.2** Common Hydrocarbons

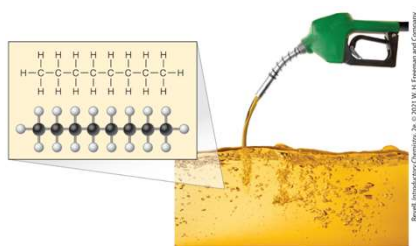
Formula	Name	Use
CH <sub>4</sub>	Methane	Natural gas
C <sub>2</sub> H <sub>2</sub>	Acetylene	Torches for cutting and welding
C <sub>2</sub> H <sub>4</sub>	Ethylene	Manufacture of plastic
C <sub>3</sub> H <sub>8</sub>	Propane	Natural gas component; used for heating and power
C <sub>4</sub> H <sub>10</sub>	Butane	Lighter fluid
C <sub>6</sub> H <sub>6</sub>	Benzene	Solvent; precursor for many pharmaceutical compounds
C <sub>8</sub> H <sub>18</sub>	Octane	Component of gasoline



francisreporter/Getty Images

## Combustion of Hydrocarbons

hydrocarbon + oxygen  $\rightarrow$  carbon dioxide + water



## The Combustion of Sulfur Produces Sulfur Oxides

### Sulfur Oxides

(SO<sub>x</sub>)

SO

SO<sub>2</sub>

SO<sub>3</sub>

SO<sub>4</sub>

S<sub>2</sub>O<sub>7</sub>



### Combustion Reactions Practice

*Write a balanced equation for the combustion of calcium metal.*



### Combustion Reactions, More Practice

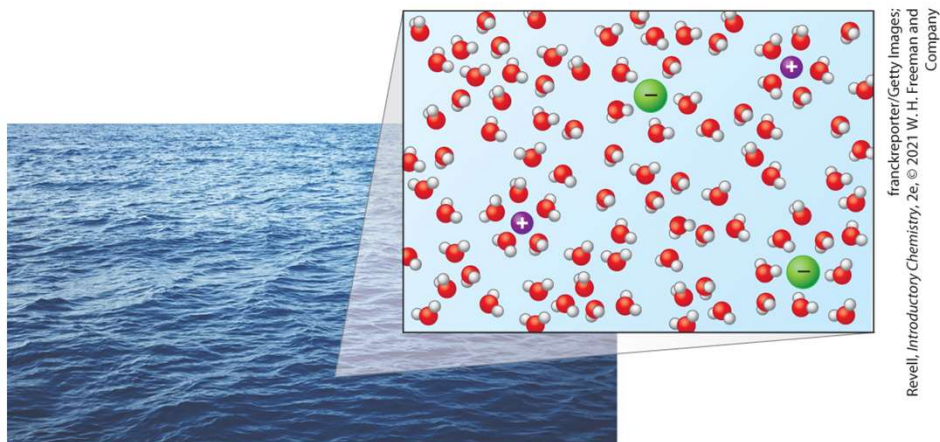
*Write a balanced equation for the combustion of propane gas, a common fuel used for home heating, cooking, etc. The formula for propane is  $\text{C}_3\text{H}_8$ .*





## Reactions in Aqueous Solution

Ionic compounds **dissociate** when dissolved in water.

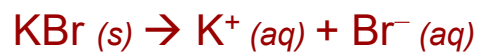


## Comparing Molecular and Ionic Equations

**molecular equation** – shows ions together as compounds

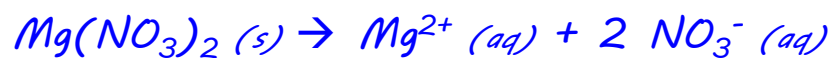


**ionic equation** – shows dissociated ions as separate species



## Writing Ionic Equations Practice

Show this process as an ionic equation:



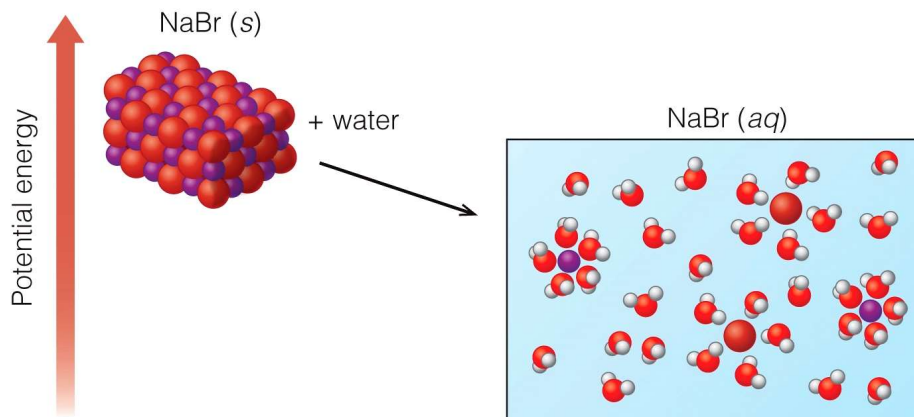
## Predicting Solubility

Many ionic compounds are **insoluble** in water.



Turtle Rock Scientific/Science Source

## Predicting Solubility, Continued



## Factors affecting solubility

- Charge on Ions
- Size of Ions
- How tightly ions pack together

### Soluble

NaCl ( $\text{Na}^+$  and  $\text{Cl}^-$ )  
 $\text{KNO}_3$  ( $\text{K}^+$  and  $\text{NO}_3^-$ )  
 $\text{NH}_4\text{Br}$  ( $\text{NH}_4^+$  and  $\text{Br}^-$ )

### Insoluble

$\text{Fe}_2\text{O}_3$  ( $\text{Fe}^{3+}$  and  $\text{O}^{2-}$ )  
 $\text{PbS}$  ( $\text{Pb}^{2+}$  and  $\text{S}^{2-}$ )  
 $\text{BaCO}_3$  ( $\text{Ba}^{2+}$  and  $\text{CO}_3^{2-}$ )

## Solubility Rules:

- Halogens ( $F^-$ ,  $Br^-$ ,  $Cl^-$ ,  $I^-$ ) are soluble
  - Unless bonded to  $Ag^+$  or  $Pb^{2+}$

### Soluble

KF  
ZnCl<sub>2</sub>  
FeBr<sub>2</sub>  
CuI

### Insoluble

AgF  
AgCl  
PbBr<sub>2</sub>  
PbI<sub>2</sub>

## Solubility Rules, Continued

**TABLE 6.3 Solubility Rules**

Compounds Containing These Ions Are Nearly Always Soluble	
→ Alkali metals	$Li^+$ , $Na^+$ , $K^+$ , $Rb^+$
→ Ammonium	$NH_4^+$
→ Large -1 oxyanions	$NO_3^-$ , $ClO_3^-$ , $ClO_4^-$ , $C_2H_3O_2^-$
Compounds Containing These Ions Are Usually Soluble	
→ Halides (except $Pb^{2+}$ , $Ag^+$ )	$F^-$ , $Cl^-$ , $Br^-$ , $I^-$
→ Sulfate (except $Ba^{2+}$ , $Ca^{2+}$ , $Pb^{2+}$ , $Ag^+$ )	$SO_4^{2-}$
Not Soluble	
→ Most other ions	

## Solubility Tables

		Ammonium	Sodium	Potassium	Silver	Magnesium	Calcium	Barium	Iron(II)	Zinc	Copper(II)	Lead(II)	Iron(III)	Aluminum
		NH <sub>4</sub> <sup>+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Ag <sup>+</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	Ba <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Cu <sup>2+</sup>	Pb <sup>2+</sup>	Fe <sup>3+</sup>	Al <sup>3+</sup>
Nitrate	NO <sub>3</sub> <sup>-</sup>													
Chlorate	ClO <sub>3</sub> <sup>-</sup>													
Perchlorate	ClO <sub>4</sub> <sup>-</sup>													
Acetate	C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup>													
Chloride	Cl <sup>-</sup>													
Bromide	Br <sup>-</sup>													
Iodide	I <sup>-</sup>													
Sulfate	SO <sub>4</sub> <sup>2-</sup>													
Hydroxide	OH <sup>-</sup>													
Sulfite	SO <sub>3</sub> <sup>2-</sup>													
Carbonate	CO <sub>3</sub> <sup>2-</sup>													
Phosphate	PO <sub>4</sub> <sup>3-</sup>													

Legend: Soluble (Yellow), Insoluble (Blue)

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Ex.:

CaCl<sub>2</sub>  
*soluble*

Mg(OH)<sub>2</sub>  
*insoluble*

## Determine Solubility

Determine whether the following compounds are soluble or insoluble in water:

Na<sub>3</sub>PO<sub>4</sub>  
*soluble*

AlCl<sub>3</sub>  
*soluble*

CaCO<sub>3</sub>  
*insoluble*

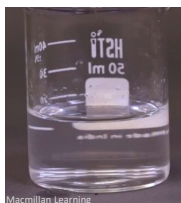
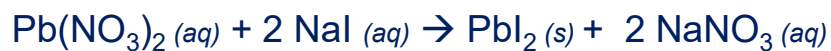
TABLE 6.3 Solubility Rules

Compounds Containing These Ions Are Nearly Always Soluble	
Alkali metals	Li <sup>+</sup> , Na <sup>+</sup> , K <sup>+</sup> , Rb <sup>+</sup>
Ammonium	NH <sub>4</sub> <sup>+</sup>
Large -1 oxyanions	NO <sub>3</sub> <sup>-</sup> , ClO <sub>3</sub> <sup>-</sup> , ClO <sub>4</sub> <sup>-</sup> , C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup>
Compounds Containing These Ions Are Usually Soluble	
Halides (except Pb <sup>2+</sup> , Ag <sup>+</sup> )	F <sup>-</sup> , Cl <sup>-</sup> , Br <sup>-</sup> , I <sup>-</sup>
Sulfate (except Ba <sup>2+</sup> , Ca <sup>2+</sup> , Pb <sup>2+</sup> , Ag <sup>+</sup> )	SO <sub>4</sub> <sup>2-</sup>
Not Soluble	
Most other ions	

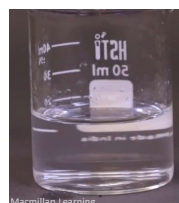
## Precipitation Reactions

**precipitation reaction** two aqueous solutions produce an insoluble product

**precipitate** the solid product formed in the reaction

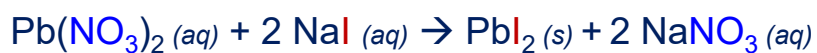


$\text{Pb}(\text{NO}_3)_2 (\text{aq})$



$\text{NaI} (\text{aq})$

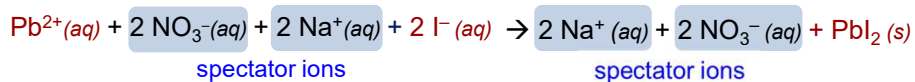
## Precipitation Reactions Are Double Displacement Reactions



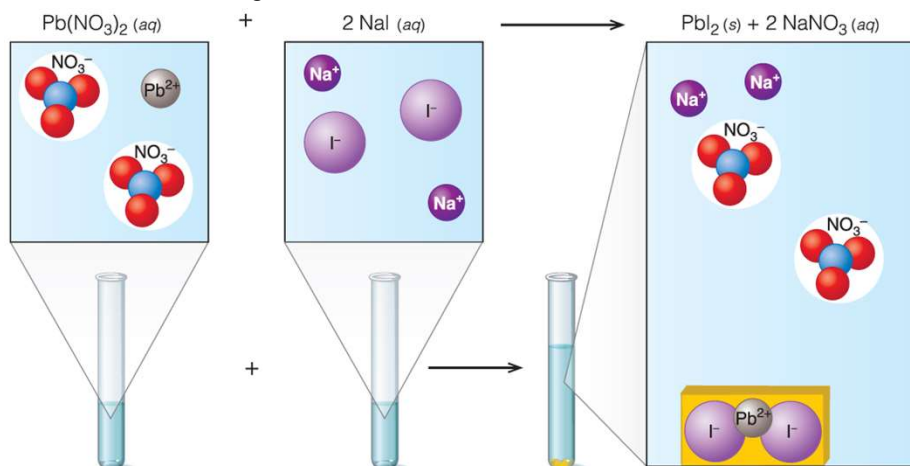
*The anions "swap" positions*



## How Precipitation Reactions Occur



Driving force - formation of the solid

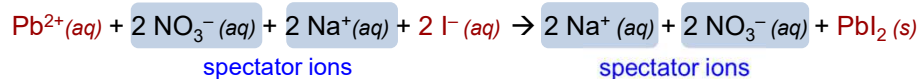


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## Comparing Complete and Net Ionic Equations

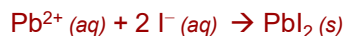
Complete ionic equation

shows all ions present



Net ionic equation

Only include ions involved in the precipitation

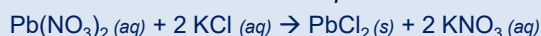


## Writing Precipitation Reactions

Three ways to show a precipitation reaction:

### Molecular Equation

*shows neutral compounds*



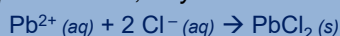
### Complete Ionic Equation

*shows all ions present*



### Net Ionic Equation

*Omits spectator ions; only shows ions that react.*



Use solubility rules to predict precipitation reactions.

## Precipitation Reactions Practice

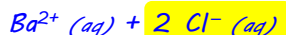


When aqueous silver acetate is combined with aqueous barium chloride, a white precipitate forms. Write balanced complete ionic, net ionic, and molecular equations to show the reaction that takes place. Include phase symbols.

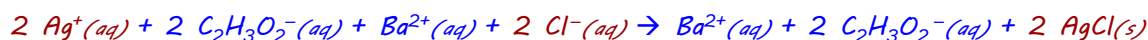
silver acetate solution:



barium chloride solution:



### Complete ionic equation



### Net ionic equation



### Molecular equation





## Summary of Precipitation Reactions

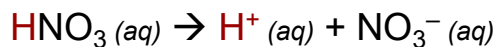
- Soluble ionic compounds dissociate in water.
- Some ionic compounds are insoluble in water.
- Solubility rules predict the solubility of compounds.
- Precipitation reaction: two solutions combine to produce an insoluble product.
- We describe reactions in solution using
  - molecular equations
  - complete ionic equations
  - net ionic equations

## Reactions in Aqueous Solution

**acids** compounds that produce  $\text{H}^+$  ions in aqueous solution

**TABLE 6.4** Common Acids

Formula	Name
$\text{HF}$	Hydrofluoric acid
$\text{HCl}$	Hydrochloric acid
$\text{HBr}$	Hydrobromic acid
$\text{HI}$	Hydroiodic acid
$\text{H}_2\text{CO}_3$	Carbonic acid
$\text{HNO}_3$	Nitric acid
$\text{HNO}_2$	Nitrous acid
$\text{H}_2\text{SO}_4$	Sulfuric acid
$\text{H}_3\text{PO}_4$	Phosphoric acid
$\text{HC}_2\text{H}_3\text{O}_2$	Acetic acid



## Reactions in Aqueous Solution, Continued

**bases** compounds that produce  $\text{OH}^-$  ions in aqueous solution

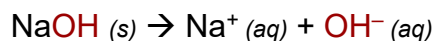
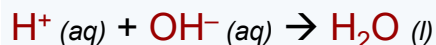


TABLE 6.5 Common Hydroxide Base

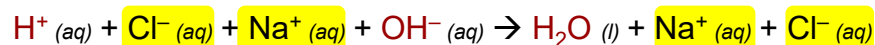
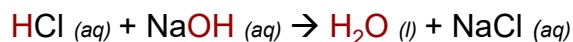
Formula	Name
$\text{LiOH}$	Lithium hydroxide
$\text{NaOH}$	Sodium hydroxide
$\text{KOH}$	Potassium hydroxide
$\text{Ba}(\text{OH})_2$	Barium hydroxide

## Neutralization Reactions

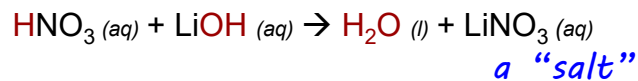
Acids and bases undergo **neutralization reactions**.



*Ex.: hydrochloric acid reacts with sodium hydroxide*

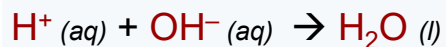


*Ex.: nitric acid reacts with lithium hydroxide*



## Neutralization Reactions, Continued

Acid-base neutralization is a **double displacement reaction**.



The formation of water is the driving force for the reaction.

## Acid-Base Reactions Practice

Write a balanced equation to show the reaction of sulfuric acid with sodium hydroxide. Include phase symbols.

