

CHEM103

General Chemistry

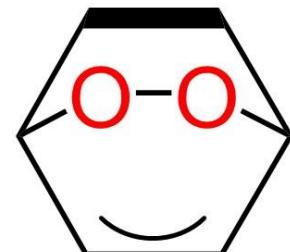
Chapter 7: Periodic Properties of the Elements



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Education, Inc.

Department of Chemistry
SUSTech



Assignment 6

Homework 6

Due date: 24th Oct. (Wed)

Review on Chapter 6

Arrangement of Electrons of an Atom in Atomic Orbitals

Light: Quantized Energy, Photoelectric Effect, Photon, Wave-Particle Duality, Bohr Model, Matter Wave, Uncertainty Principle

Quantum Mechanics: Schrödinger (Wave) Equation, Wave Function, Electron Density

Electrons & Orbitals: Quantum Numbers, Electron Shell, Spin, Pauli Exclusion Principle, Hund's Rule, Electron Configurations

Outline of Chapter 7

Development/History of Periodic Table

Periodic Trends:

Effective Nuclear Charge: Shielding
Sizes of Atoms & Ions: (non-) bonding atomic radius;
Ionization Energy
Electron Affinity

Properties of Metal, Nonmetals, and Metalloids

H	Development of Periodic Table														He		
Li	Be									B	C	N	O	F	Ne		
Na	Mg									Al	Si	P	S	Cl	Ar		
K	Ca	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
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn						

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

Ancient Times

(9 elements)

Middle Ages–1700

(6 elements)

1735–1843

(42 elements)

1843–1886

(18 elements)

1894–1918

(11 elements)

1923–1961

(17 elements)

1965–

(9 elements)

Dmitrij Ivanovič Mendeleev (Russian chemist and inventor) and Lothar Meyer (German chemist) independently came to the same conclusion about how elements should be grouped.

Development of Periodic Table

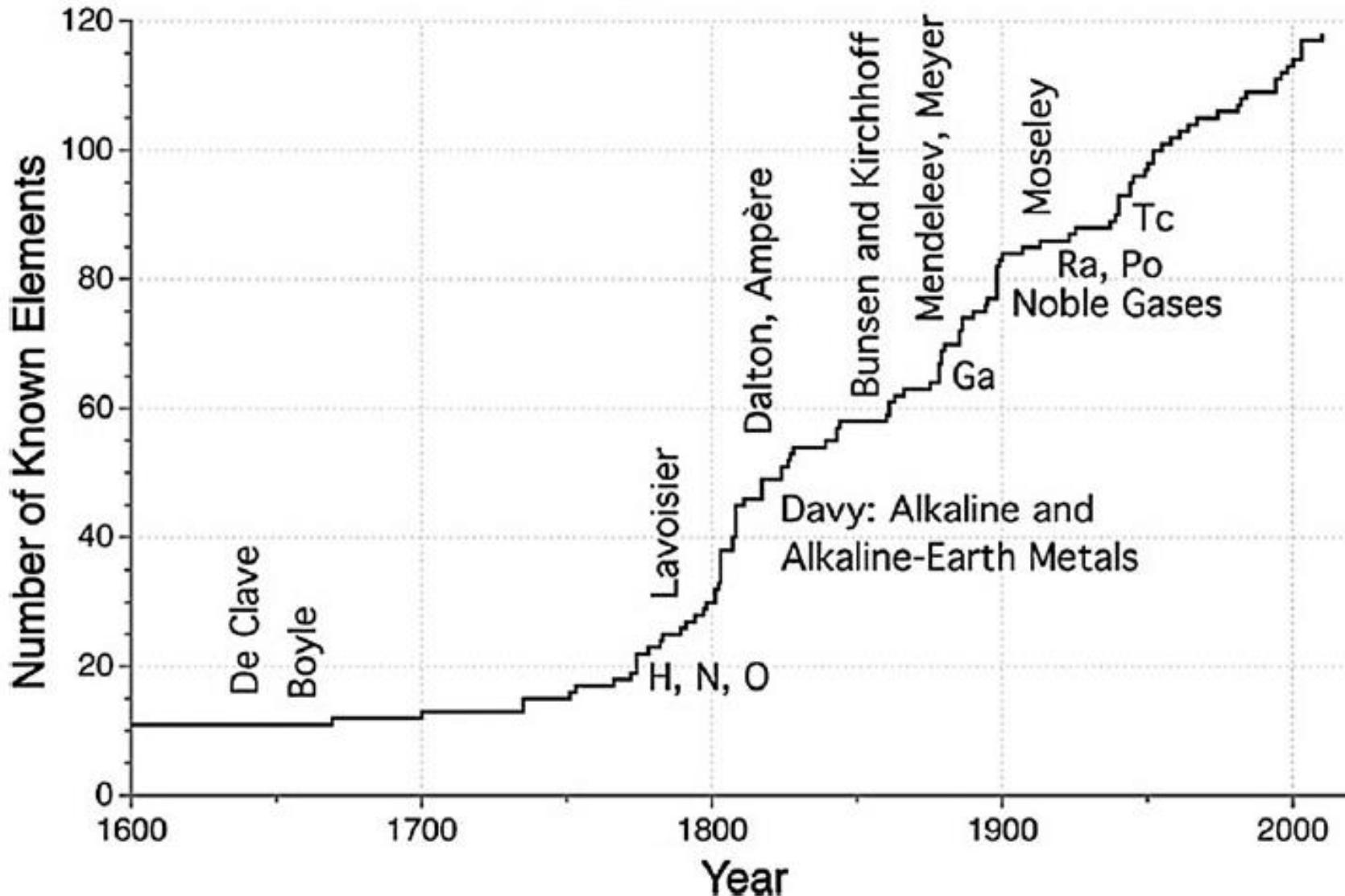


Figure 1. A plot of the number of elements discovered per year.
Adapted with permission from ref. [4].

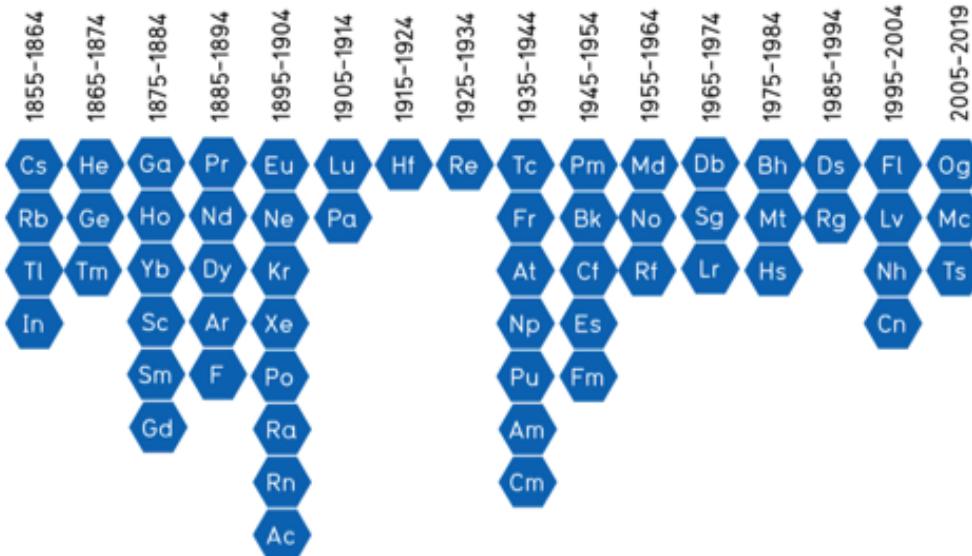
In Te R Na Ti O N Al Y E Ar O F T He

PERIODIC TABLE OF THE ELEMENTS

15 P Er 16 I 17 O Di C 18 Ta 19 B Le



2019 International Year of the Periodic Table Timeline of Elements



Celebrating the discovery of elements

A collaborative University of Waterloo project

uwaterloo.ca/chemistry/timeline-of-elements



UNIVERSITY OF WATERLOO
FACULTY OF SCIENCE

Mendeleev's 1871 Periodic Table

Rielen	Gruppe I. R ⁺ 0	Gruppe II. R0	Gruppe III. R ⁺ 0 ²	Gruppe IV. RH ⁴ R0 ²	Gruppe V. RH ³ R ⁺ 0 ³	Gruppe VI. RH ² R0 ³	Gruppe VII. RH R ⁺ 0 ¹	Gruppe VIII. — R0 ⁴
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=86	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	— — — —
12	—	—	—	Th=231	—	U=240	—	— — — —

On 6 March 1869, Mendeleev made a formal presentation to the entitled “*The Dependence between the Properties of the Atomic Weights of the Elements*”, which described elements according to both **atomic weight** and **valence**.

Table 7.1 Comparison of the Properties of Eka-Silicon Predicted by Mendeleev with the Observed Properties of Germanium

Property	Mendeleev's Predictions for Eka-Silicon (made in 1871)	Observed Properties of Germanium (discovered in 1886)
Atomic weight	72	72.59
Density (g/cm ³)	5.5	5.35
Specific heat (J/g-K)	0.305	0.309
Melting point (°C)	High	947
Color	Dark gray	Grayish white
Formula of oxide	XO ₂	GeO ₂
Density of oxide (g/cm ³)	4.7	4.70
Formula of chloride	XCl ₄	GeCl ₄
Boiling point of chloride (°C)	A little under 100	84

Mendeleev predicted the discovery of germanium (which he called eka-silicon) as an element with an atomic weight between that of zinc & arsenic, but with chemical properties similar to those of silicon.

Extra Info:

Figure 9. A modern-shaped Mendeleev's Table of 1871, with eka-elements printed in red e.g., eAl, and some predictive empty boxes marked in red. Boron (B) is duplicated in grey besides Be; this unusual position intends to show its relationship with eka-boron (eB, which would later be discovered and named Sc). The e-elements and

<u>Predictions</u>	<u>Discoveries</u>
Eka-Aluminum	Gallium
AW	(discovered in 1875 by Lecoq)
Density	69.9
Atomic Volume	5.96
	11.7
Eka-Boron	Scandium
AW	(discovered in 1879 by Nilson)
	43.79

Eka-Aluminum

AW	68
Density	6.0
Atomic Volume	11.5

Eka-Boron

44

Gallium

(discovered in 1875 by Lecoq)	69.9
	5.96
	11.7

Scandium

(discovered in 1879 by Nilson)	43.79
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Elements & Country of Discovery

Credit given to both where joint or independently discovered. IUPAC recognised only.

113: Japan; 115, 117 & 118: Russia & US

The Latest Periodic Table

1 H hydrogen 1.08 [1.0078, 1.0082]	2 He helium 4.0026
3 Li lithium 6.94 [6.938, 6.997]	4 Be beryllium 9.0122
11 Na sodium 22.990 [24.004, 24.307]	12 Mg magnesium 24.305 [24.04, 24.307]
19 K potassium 39.098 40.078(4)	20 Ca calcium 44.956 40.078(4)
37 Rb rubidium 85.468 87.62	21 Sc scandium 44.956 47.867
55 Cs cesium 132.91 137.33	22 Ti titanium 50.942 51.996
87 Fr francium —	23 V vanadium 51.996 54.938
88 Ra radium —	24 Cr chromium 54.938 55.845(2)
57-71 Ba barium lanthanoids 137.33	25 Mn manganese 95.95 178.49(2)
104 Rf rutherfordium actinoids —	26 Fe iron 101.07(2) 58.933
105 Db dubnium actinoids —	27 Co cobalt 102.91 58.693
106 Sg seaborgium actinoids —	28 Ni nickel 106.42 63.546(3)
107 Bh bohrium actinoids —	29 Cu copper 107.87 65.38(2)
108 Hs hassium actinoids —	30 Zn zinc 112.41 69.723
109 Mt meitnerium actinoids —	31 Ga gallium 114.82 72.630(8)
110 Ds darmstadtium actinoids —	32 Ge germanium 118.71 74.922
111 Rg roentgenium actinoids —	33 As arsenic 121.76 78.971(8)
112 Cn copeimium actinoids —	34 Se selenium 127.60(3) 79.904 [79.901, 79.907]
113 Nh nihonium actinoids —	35 Br bromine 126.90 83.798(2)
114 Fl flerovium actinoids —	36 Kr krypton 131.29 83.798(2)
115 Mc moscovium actinoids —	37 Xe xenon 126.90 83.798(2)
116 Lv livermorium actinoids —	38 I iodine 127.60(3) 79.904 [79.901, 79.907]
117 Ts tennessine actinoids —	39 Rn radon 131.29 83.798(2)
57 La lanthanum 138.91	58 Ce cerium 140.12
89 Ac actinium 232.04	59 Pr praseodymium 140.91
90 Th thorium 231.04	60 Nd neodymium 144.24
91 Pa protactinium 238.03	61 Pm promethium 150.36(2)
92 U uranium 238.03	62 Sm samarium 151.96
93 Np neptunium —	63 Eu europium 157.25(3)
94 Pu plutonium —	64 Gd gadolinium 158.93
95 Am americium —	65 Tb terbium 162.50
96 Cm curium —	66 Dy dysprosium 164.93
97 Bk berkelium —	67 Ho holmium 167.28
98 Cf californium —	68 Er erbium 168.93
99 Es einsteinium —	69 Tm thulium 173.05
100 Fm fermium —	70 Yb ytterbium 174.97
101 Md mendelevium —	71 Lu lutetium —

57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium —	62 Sm samarium 150.36(2)	63 Eu europium 151.96	64 Gd gadolinium 157.25(3)	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.28	69 Tm thulium 168.93	70 Yb ytterbium 173.05	71 Lu lutetium 174.97
89 Ac actinium 232.04	90 Th thorium 231.04	91 Pa protactinium 238.03	92 U uranium 238.03	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —

Useful interactive ones: <https://www.ptable.com>
<https://pubchem.ncbi.nlm.nih.gov/periodic-table>

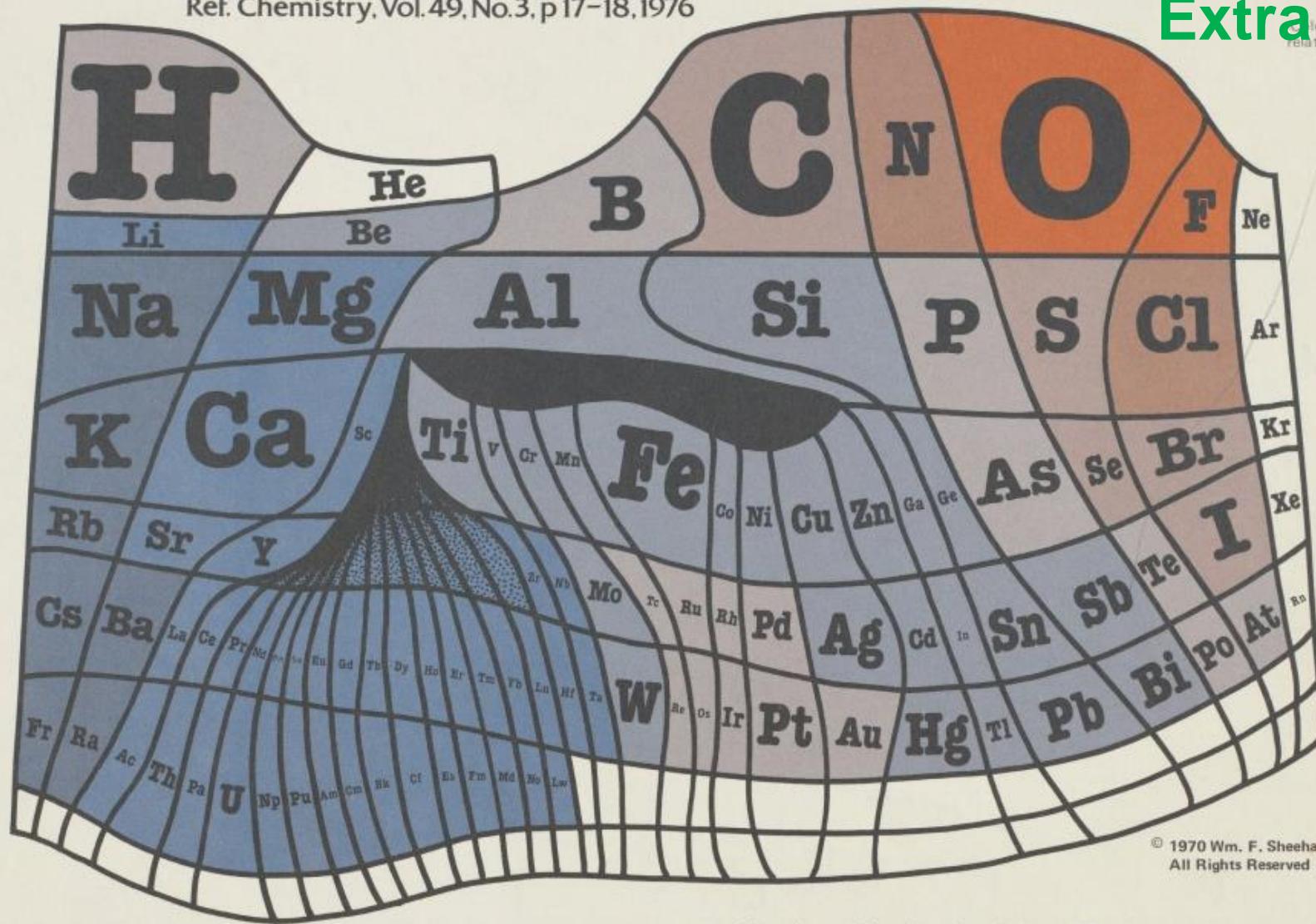
NATIONAL UNION OF
IND APPLIED CHEMISTRY

The Elements According to Relative Abundance

A Periodic Chart by Prof. Wm. F. Sheehan, University of Santa Clara, CA 95053
Ref. Chemistry, Vol. 49, No. 3, p 17-18, 1976

Extra Info:

largest
relative electro-
negativity



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Roughly, the size of an element's own niche ("I almost wrote square") is proportioned to its abundance on Earth's surface, and in addition, certain chemical similarities (e.g., Be and Al, or B and Si) are suggested by the positioning of neighbors. The chart emphasizes that in real life a chemist will probably meet O, Si, Al, . . . and that he better do something about it. Periodic tables based upon elemental abundance would, of course, vary from planet to planet. . . W.F.S.

NOTE: TO ACCOMMODATE ALL ELEMENTS SOME DISTORTIONS WERE NECESSARY, FOR EXAMPLE SOME ELEMENTS DO NOT OCCUR NATURALLY.

ESSENTIAL ELEMENTS FOR HUMANS

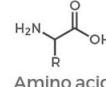
There are 118 elements in the periodic table, but which of them are essential for human life? Here we zero in on the ones we can't live without and the roles they play.

Extra Info:



^a Includes Ca, P, K, S, Na, Cl, Mg, B, Cr, Co, Cu, F, I, Fe, Mn, Mo, Se, Si, Sn, V, and Zn.

BUILDING BLOCKS



These elements (except phosphorus) are found in amino acids, the building blocks of proteins. With the exception of sulfur, they all also combine to make up DNA, our genetic code.

ENZYMES



Metal ions help many enzymes in the body function. Enzymes have many important roles in the body, including in respiration, digestion, metabolism, and the immune system.

NERVES AND CONTROL



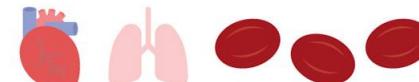
Sodium, potassium, and calcium ions play roles in transmitting nerve signals. Chloride ions regulate fluid in and out of cells. The body uses iodine to make hormones that regulate metabolism.

BONES AND TEETH



Bones and teeth are mainly calcium phosphate. Calcium is essential for the growth of healthy teeth and bones. Without manganese, bones are spongier and break more easily.

BLOOD



Iron in hemoglobin carries oxygen from the lungs to the body's cells. And it carries carbon dioxide back to the lungs. Cobalt, found in vitamin B-12, is essential for making red blood cells.

RESPIRATION AND ENERGY



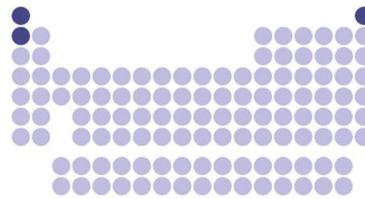
Our cells use the oxygen we breathe for respiration. Respiration produces adenosine triphosphate (ATP, shown), a molecular energy source for our cells.

THE ORIGINS OF THE ELEMENTS

The 118 elements in the periodic table don't all have the same backstory. Here, we examine how different elements were created, according to physicists and chemists.

Extra Info:

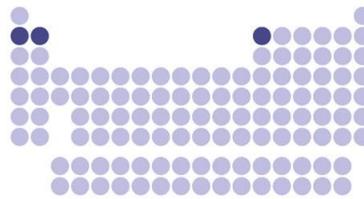
THE BIG BANG



H He Li

The lightest elements were made by nuclear reaction chains between 10 s and 20 min after the big bang. Hydrogen and helium in particular were made in large amounts.

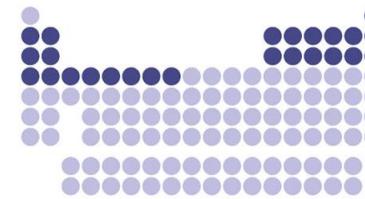
COSMIC RAYS



Li Be B

When cosmic rays hit the nuclei of elements like carbon or nitrogen, they cause those elements to fragment into lighter elements like lithium, beryllium, and boron.

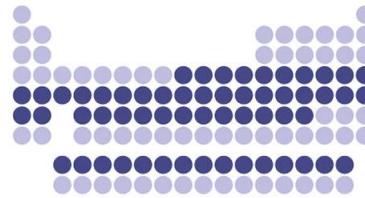
FUSION IN STARS



He → Fe

Fusion reactions inside stars generate the energy that stars radiate. They produce elements from helium up to iron. Creating heavier elements isn't possible through fusion.

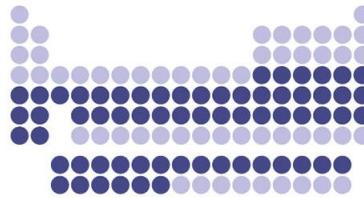
THE S-PROCESS



Co → Bi

The slow neutron-capture process (s-process) occurs in aging stars over thousands of years. Atoms capture neutrons and undergo β decay to produce new element isotopes.

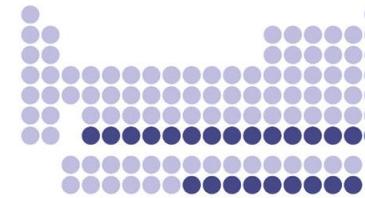
THE R-PROCESS



Ga → Pu

In the rapid neutron-capture process (r-process), atoms capture many neutrons at once and undergo β decay to form new element isotopes. It occurs in neutron star collisions.

SYNTHETIC ELEMENTS



Am → Og

The heaviest elements have been created artificially on Earth in nuclear reactors or particle accelerators. These elements are unstable and decay into lighter elements rapidly.

Note: Elements are highlighted where isotopes of that element are created by the process discussed. Not all isotopes created are stable.

Periodic Trends

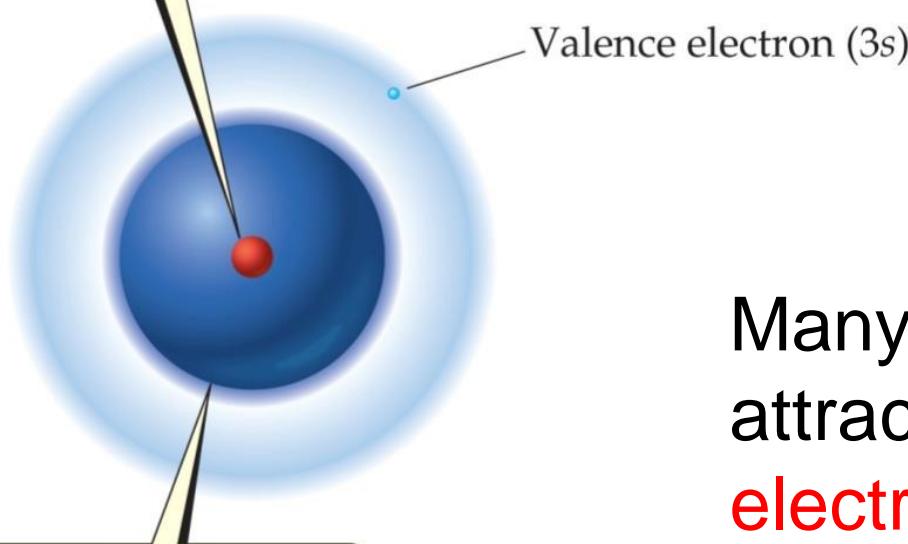
Periodicity

- Periodicity: the **repetitive** pattern of a **property** for elements based on atomic number.
- For example:
 - Sizes of atoms and ions;
 - Ionization energy (I.E.);
 - Electron affinity (E.A.);
 - Chemical property.

Atomic number	1	2	3	4	- - -	9	10	11	12	- - -	17	18	19	20	- - -
Symbol	H	He	Li	Be	- - -	F	Ne	Na	Mg	- - -	Cl	Ar	K	Ca	- - -
	Nonreactive gas		Soft, reactive metal			Nonreactive gas		Soft, reactive metal			Nonreactive gas		Soft, reactive metal		

Sodium nucleus contains
11 protons ($11+$)

Effective Nuclear Charge (Z_{eff})



Many properties depend on attractions between **valence electrons** & the nucleus.

Ten core electrons ($1s^2 2s^2 2p^6$)
screen the nucleus from the
valence electron ($10-$)

- In a many-electron atom, **electrons** are simultaneously both **attracted** to the **nucleus** & **repelled** by **the other electrons**.
- **Effective nuclear charge** (force): one electron (either valence electron or core electron) experiences **net effect of the attractions** & **repulsions**.

The effective nuclear charge, Z_{eff} :

$$Z_{\text{eff}} = Z - S$$

where Z is the atomic number & S is a *screening* (屏蔽) *constant*, (can be **simply** approximated by the number of its **core/inner electrons**).

e.g. Z_{eff} for one of the **valence electrons**:

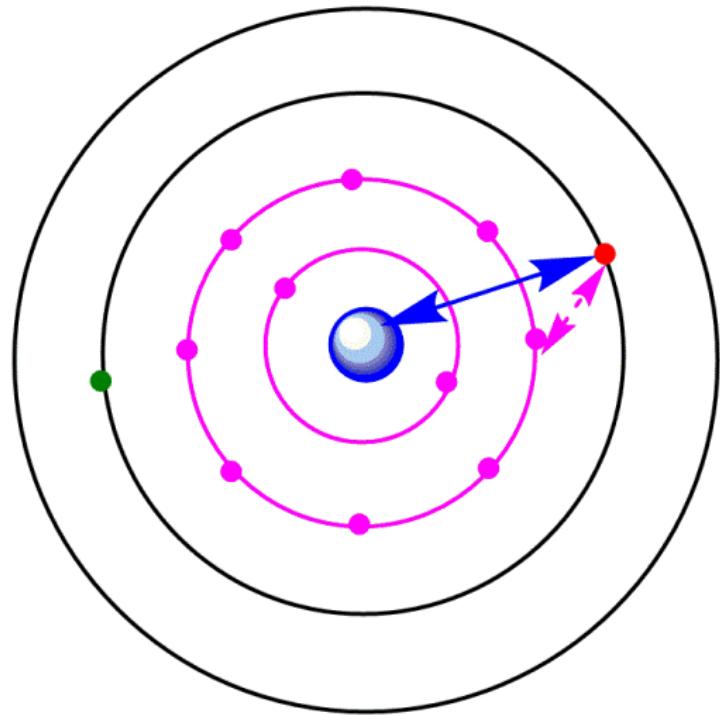
$$\text{Si} \quad 1s^2 2s^2 2p^6 3s^2 3p^2 \quad Z_{\text{eff}} \sim 14 - 10 = 4$$

$$\text{P} \quad 1s^2 2s^2 2p^6 3s^2 3p^3 \quad Z_{\text{eff}} \sim 15 - 10 = 5$$

$$\text{S} \quad 1s^2 2s^2 2p^6 3s^2 3p^4 \quad Z_{\text{eff}} \sim 16 - 10 = 6$$

$$Z_{\text{eff}} = Z - S$$

S is usually close to the number of its **core/inner electrons**.



Mg:

12 protons
12 electrons

Z_{eff} for the red electron

(net attraction with the protons)

$$\sim 12 - 10 = 2$$

(12)protons-(1)electron attraction

(10)core electrons-(1)electron repulsion (**major**)

(1)valence electrons-(1)electron repulsion (**minor**)

1. Any of one **3s** electrons ($n = 3$): $Z_{\text{eff}} \sim 2$

2. Any of one **second-shell** electrons ($n = 2$; 2s or 2p):

$$Z_{\text{eff}} \sim 12 - 2 \sim 10$$

3. Any of one **first-shell (1s)** electrons ($n = 1$):

$$Z_{\text{eff}} \sim 12 - 0 \sim 12$$

Screening Constant: **Slater's Rules**

1. Electrons in **higher groups (higher energy level, $>n$)** do **not** shield those in lower groups ($\leq n$).
2. For **ns or np valence electrons** :
 - a. Electrons in the **same ns or np group (same energy level, n)** contribute **0.35**, except the 1s, where **0.30** works better.
 - b. Electrons in the **$n-1$ group** contribute **0.85**.
 - c. Electrons in the **$n-2$ or lower groups** contribute **1.00**.
3. For **nd and nf valence electrons**:
 - a. Electrons in the **same nd or nf group** contribute **0.35**.
 - b. Electrons in **groups to the left** contribute **1.00**.

$$Z_{\text{eff}} = Z - S$$

e.g. Oxygen $1s^2 2s^2 2p^4$
 $(1s^2)(2s^2 2p^4)$

For each of the $2p$ electron,

$$\begin{aligned} Z_{\text{eff}} &= Z - S \\ &= 8 - (2 \times 0.85) - (5 \times 0.35) = 4.55 \\ &\quad \mathbf{1s^2} \qquad \mathbf{2s^2 2p^3} \end{aligned}$$

$$Z_{\text{eff}} = Z - S$$

e.g. Nickel

$$\begin{aligned} & 1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2 \\ & (1s^2)(2s^2 2p^6)(3s^2 3p^6)(3d^8)(4s^2) \end{aligned}$$

For each of the **3d** electron,

$$Z_{\text{eff}} = Z - S$$

$$= 28 - (18 \times 1.00) - (7 \times 0.35) = 7.55$$



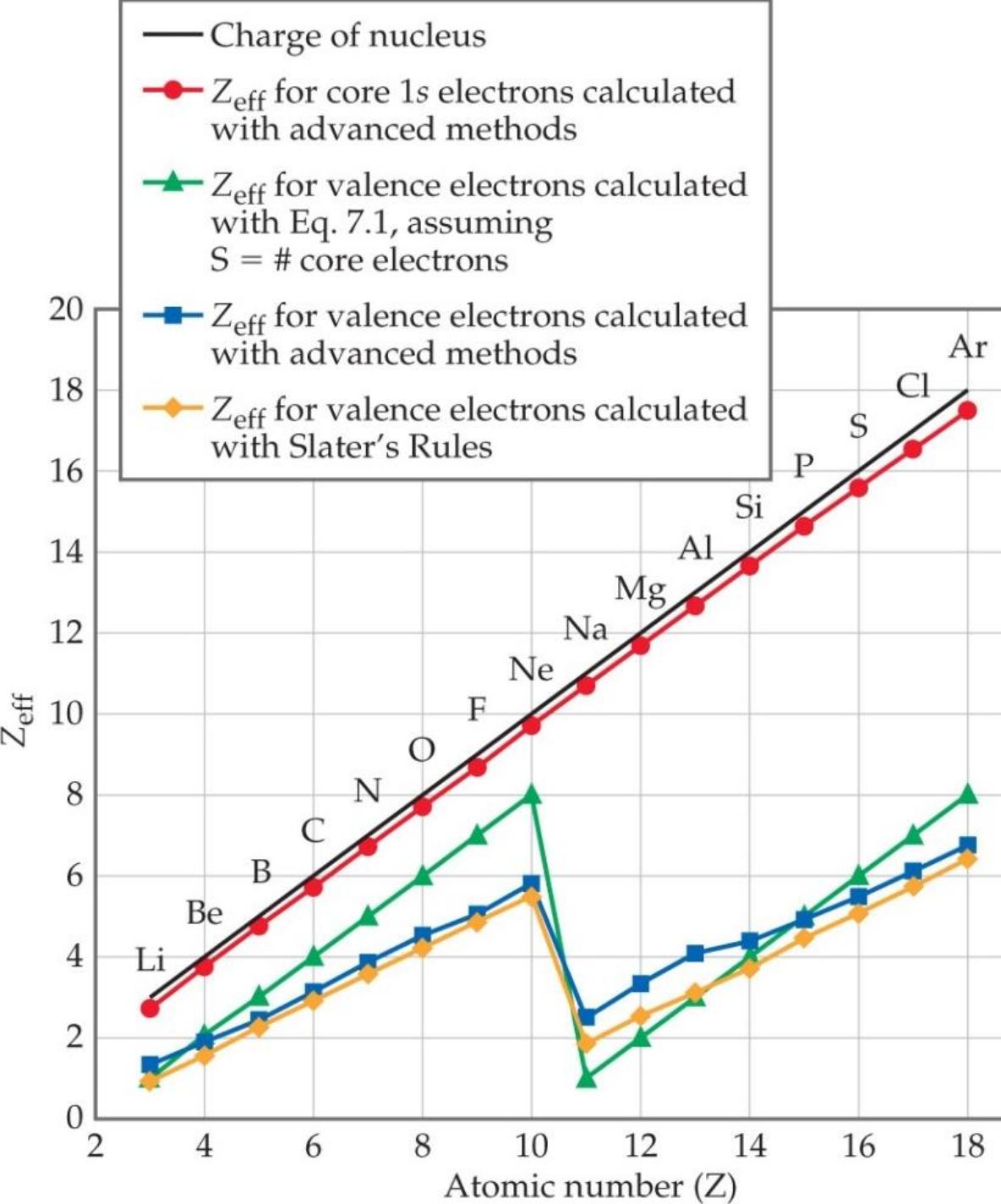
For each of the **4s** electron,

$$Z_{\text{eff}} = Z - S$$

$$= 28 - (10 \times 1.00) - (16 \times 0.85) - (1 \times 0.35)$$

$$= 4.05$$





1. Z_{eff} increases from left to right of the periodic table (number of proton increases).

2. Z_{eff} slightly increases down a group (more diffuse electron cloud is less able to screen the valence electrons).

Size of an Atom

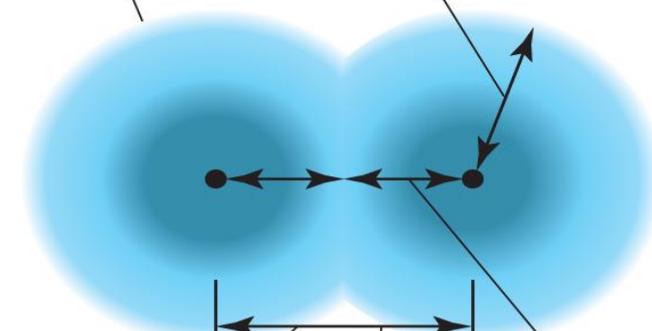
Bonding atomic radius

(covalent radius): **one half** of the **distance between covalently bonded nuclei within a molecule.**

Nonbonding atomic radius (or van der Waals 范德华 radius): **half** of the **shortest distance separating two nonbonding nuclei during a collision of atoms/molecules.**

Electron distribution in molecule

Nonbonding atomic radius



Distance between nuclei

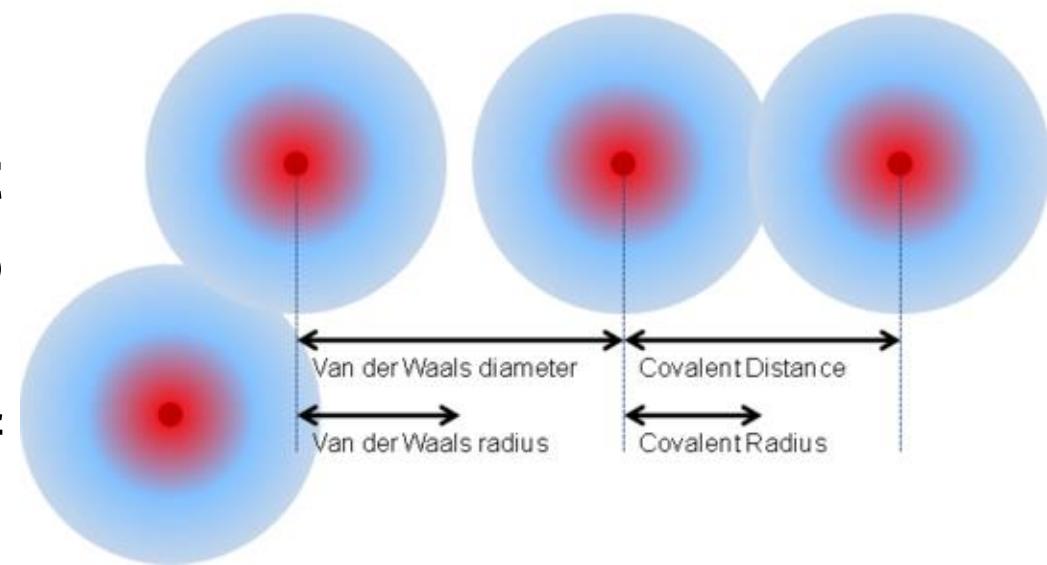
Bonding atomic radius, $\frac{1}{2}d$

Van der Waals diameter

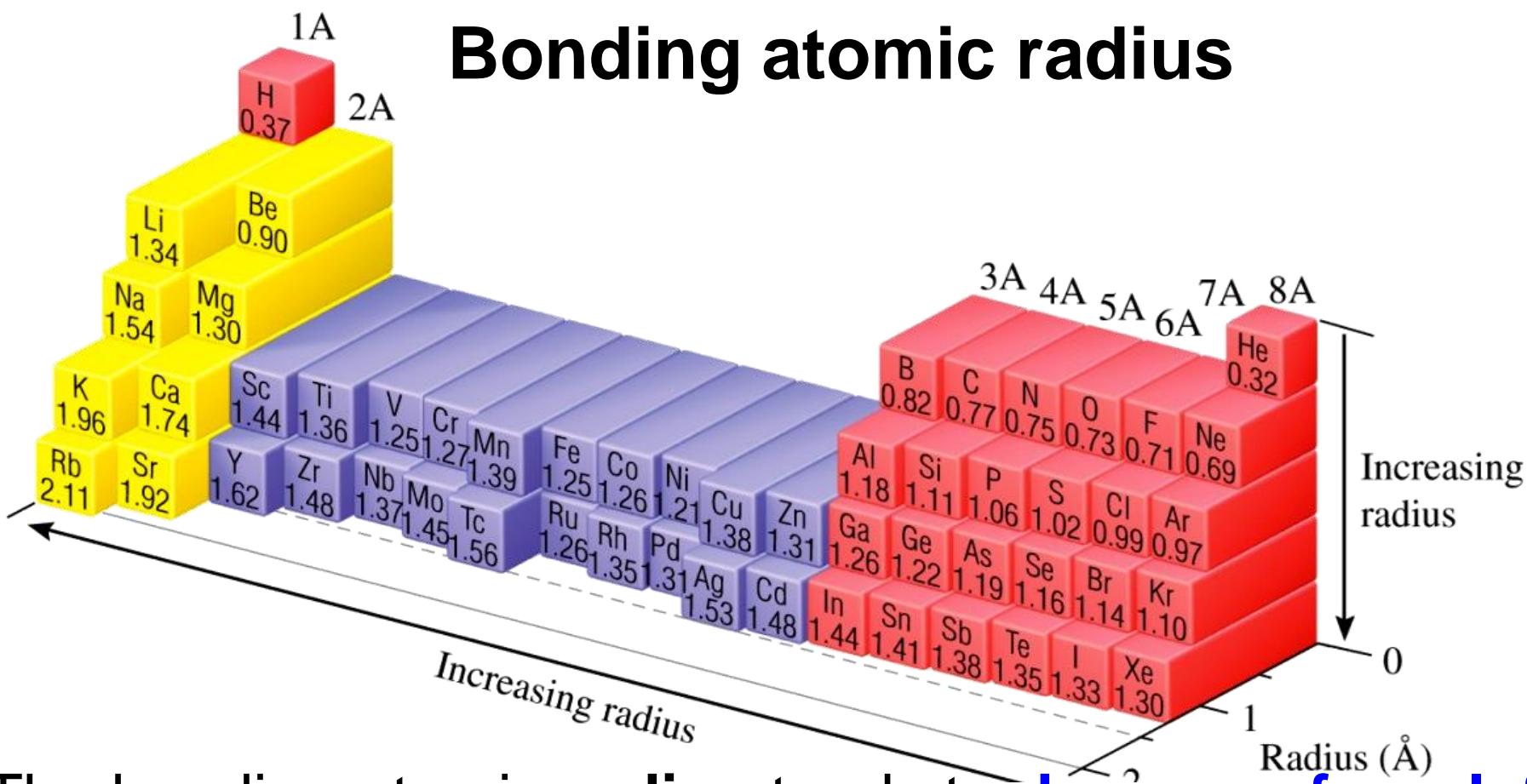
Van der Waals radius

Covalent Distance

Covalent Radius



Bonding atomic radius



The bonding atomic **radius** tends to **decrease from left to right** across a row (due to **increasing Z_{eff}**).

They **increase from top to bottom** of a column (due to the **increasing n value; NOT minor Z_{eff} effect!**).

Electrostatic attraction of one electron & nucleus:

$$k^*Q_1^*Q_2/d = k^*(-1)^*Z_{\text{eff}}/d$$

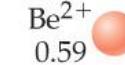
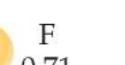
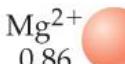
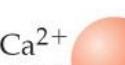
Group 1A

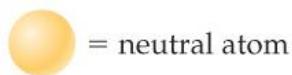
Group 2A

Group 3A

Group 6A

Group 7A

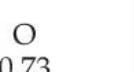
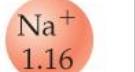
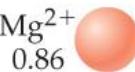
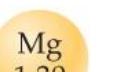
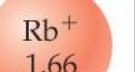
Li^+ 0.90 	Be^{2+} 0.59 	B^{3+} 0.41 	O^{2-} 1.26 	F^- 1.19 
Li 1.34 	Be 0.90 	B 0.82 	O 0.73 	F 0.71 
Na^+ 1.16 	Mg^{2+} 0.86 	Al^{3+} 0.68 	S^{2-} 1.70 	Cl^- 1.67 
Na 1.54 	Mg 1.30 	Al 1.18 	S 1.02 	Cl 0.99 
K^+ 1.52 	Ca^{2+} 1.14 	Ga^{3+} 0.76 	Se^{2-} 1.84 	Br^- 1.82 
K 1.96 	Ca 1.24 	Ga 1.26 	Se 1.16 	Br 1.14 
Rb^+ 1.66 	Sr^{2+} 1.32 	In^{3+} 0.94 	Te^{2-} 2.07 	I^- 2.06 
Rb 2.11 	Sr 1.92 	In 1.44 	Te 1.35 	I 1.33 

 = cation = anion = neutral atom

Sizes of Ions

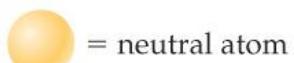
Ionic size (ionic radius) depends on

1. Z_{eff} ;
2. the number of electrons;
3. the orbitals (n value or type of the orbital).

Group 1A	Group 2A	Group 3A	Group 6A	Group 7A
Li ⁺ 0.90  Li 1.34 	Be ²⁺ 0.59  Be 0.90 	B ³⁺ 0.41  B 0.82 	O ²⁻ 1.26  O 0.73 	F ⁻ 1.19  F 0.71 
Na ⁺ 1.16  Na 1.54 	Mg ²⁺ 0.86  Mg 1.30 	Al ³⁺ 0.68  Al 1.18 	S ²⁻ 1.70  S 1.02 	Cl ⁻ 1.67  Cl 0.99 
K ⁺ 1.52  K 1.96 	Ca ²⁺ 1.14  Ca 1.24 	Ga ³⁺ 0.76  Ga 1.26 	Se ²⁻ 1.84  Se 1.16 	Br ⁻ 1.82  Br 1.14 
Rb ⁺ 1.66  Rb 2.11 	Sr ²⁺ 1.32  Sr 1.92 	In ³⁺ 0.94  In 1.44 	Te ²⁻ 2.07  Te 1.35 	I ⁻ 2.06  I 1.33 

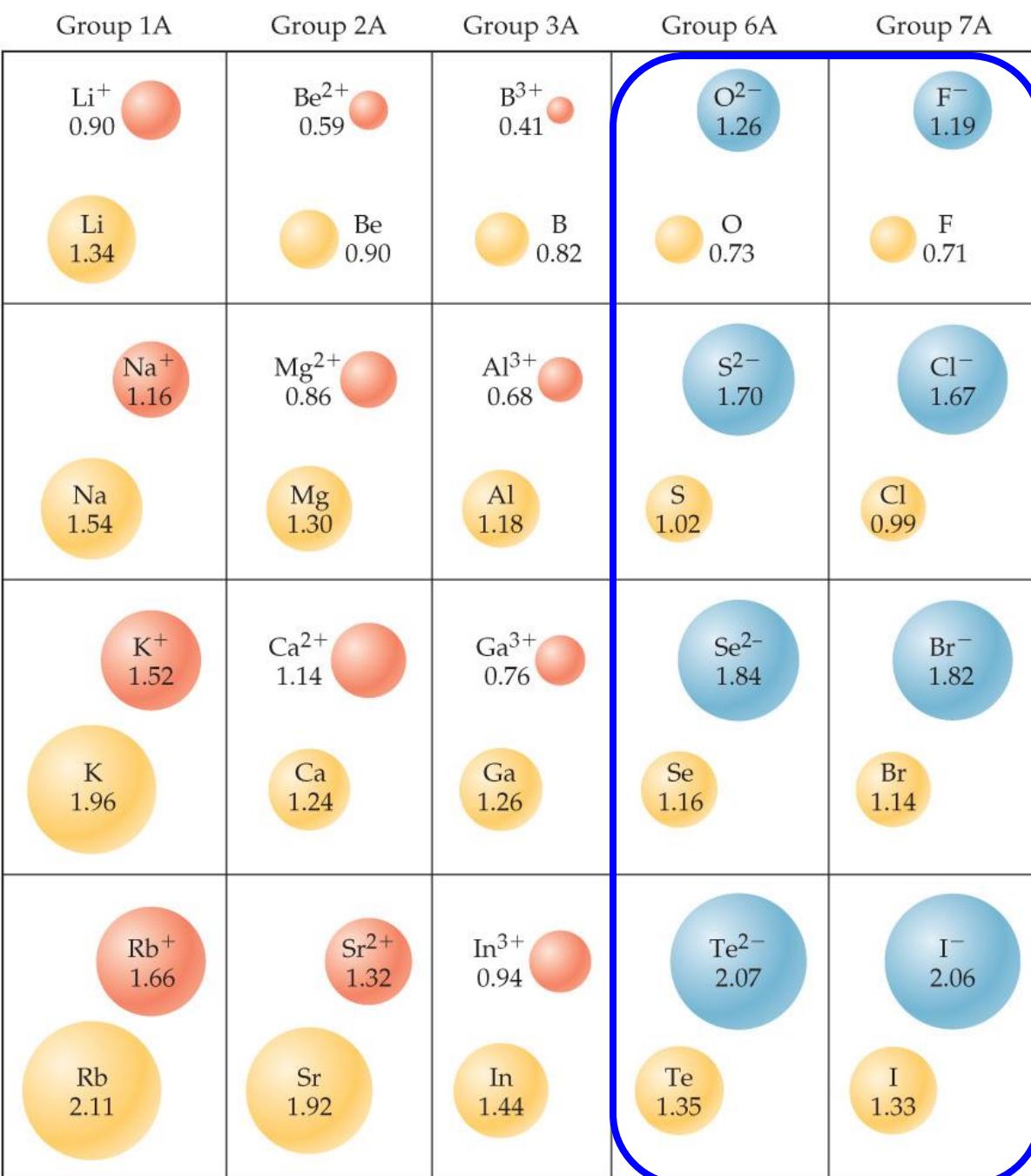
 = cation

 = anion

 = neutral atom

$$Z_{\text{eff}} = Z - S$$

Cations are smaller than their parent neutral atoms: one (or many) outermost electron(s) is(are) removed &, thus, **repulsions between electrons are reduced.**



 = cation

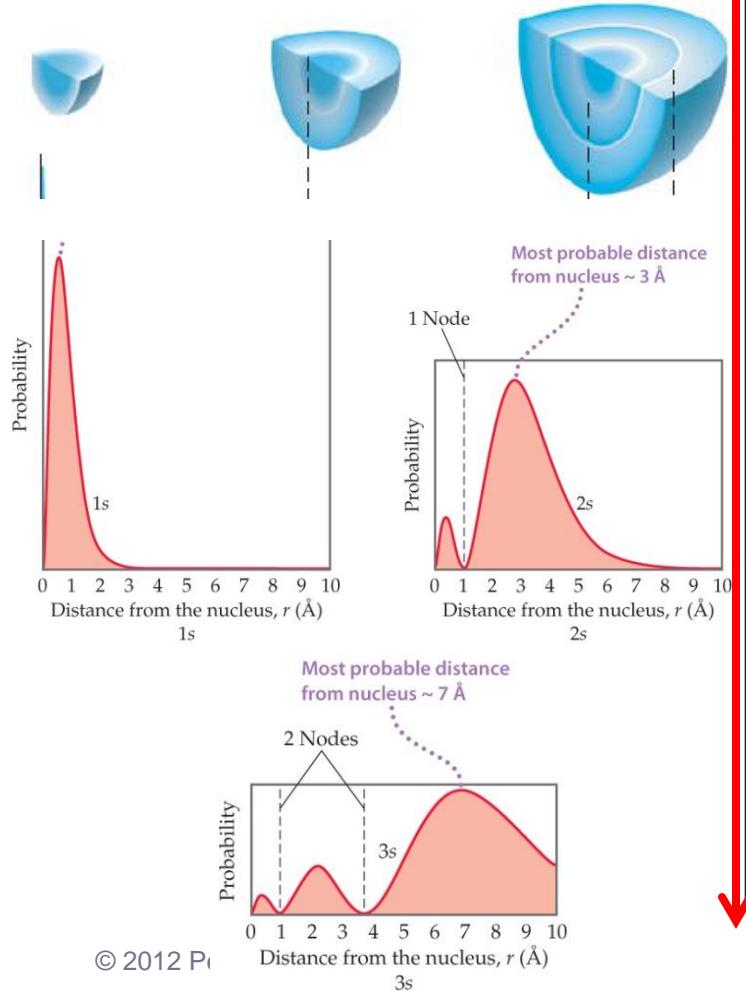
 = anion

 = neutral atom

$$Z_{\text{eff}} = Z - S$$

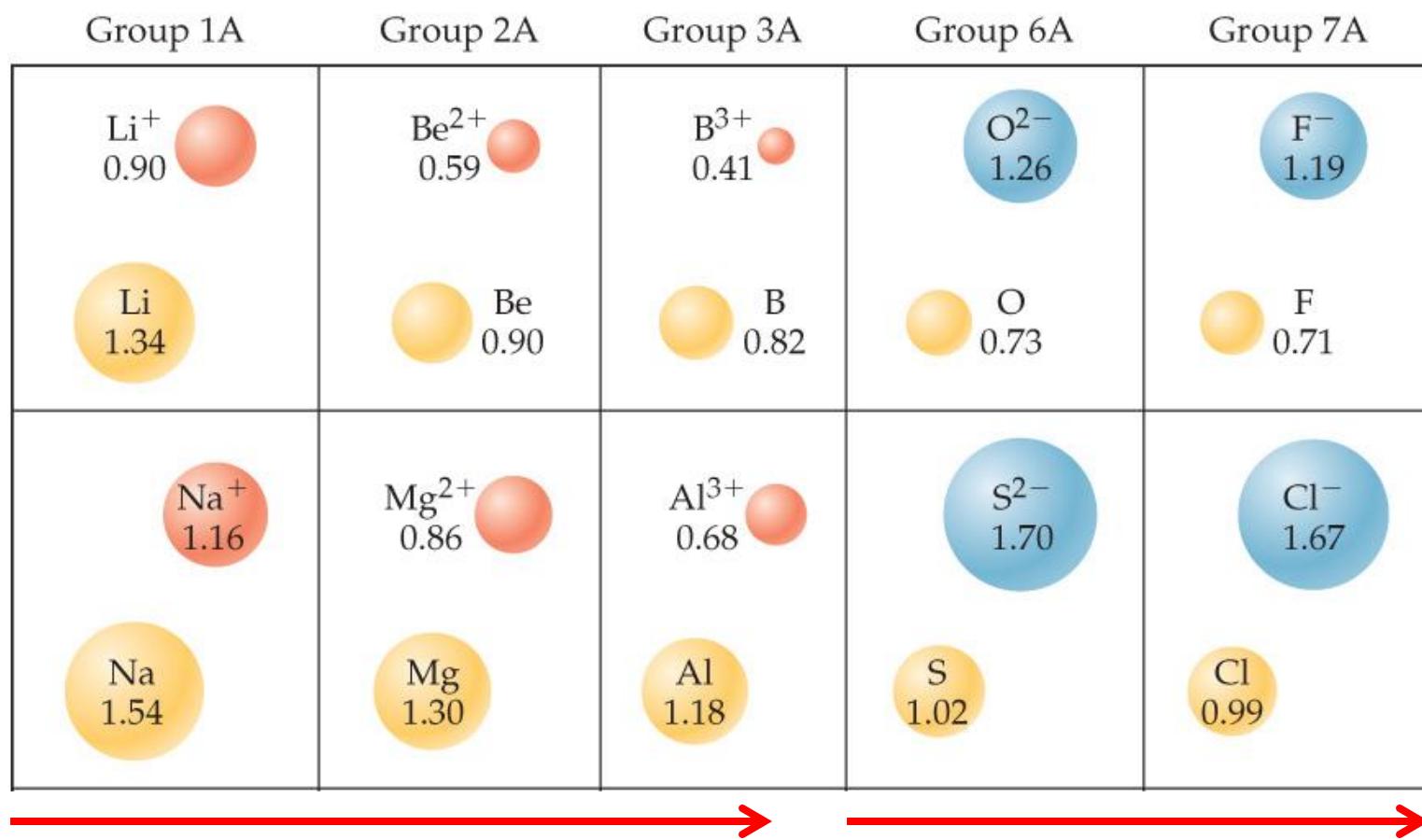
Anions are larger than their parent atoms: electron(s) is(are) added &, thus, repulsions between electrons are increased.

Ions **increase** in size when down a group, due to the increasing *n* value.



Group 1A	Group 2A	Group 3A	Group 6A	Group 7A
Li^+ 0.90 Li 1.34 	Be^{2+} 0.59 Be 0.90 	B^{3+} 0.41 B 0.82 	O^{2-} 1.26 O 0.73 	F^- 1.19 F 0.71
Na^+ 1.16 Na 1.54 	Mg^{2+} 0.86 Mg 1.30 	Al^{3+} 0.68 Al 1.18 	S^{2-} 1.70 S 1.02 	Cl^- 1.67 Cl 0.99
K^+ 1.52 K 1.96 	Ca^{2+} 1.14 Ca 1.24 	Ga^{3+} 0.76 Ga 1.26 	Se^{2-} 1.84 Se 1.16 	Br^- 1.82 Br 1.14
Rb^+ 1.66 Rb 2.11 	Sr^{2+} 1.32 Sr 1.92 	In^{3+} 0.94 In 1.44 	Te^{2-} 2.07 Te 1.35 	I^- 2.06 I 1.33

Legend: = cation; = anion; = neutral atom



- In an **isoelectronic** (等电子的) **series**, ions have the **same number of electrons**. e.g. 1) O^{2-} , F^- , Na^+ , Mg^{2+} , Al^{3+} ; 2) Li^+ , Be^{2+} , B^{3+} ; 3) S^{2-} , Cl^-
 - Ionic size decreases with increasing nuclear charge (the more positive, the stronger attraction with electrons).
- $Z_{\text{eff}} = Z - S$

Extra Info:

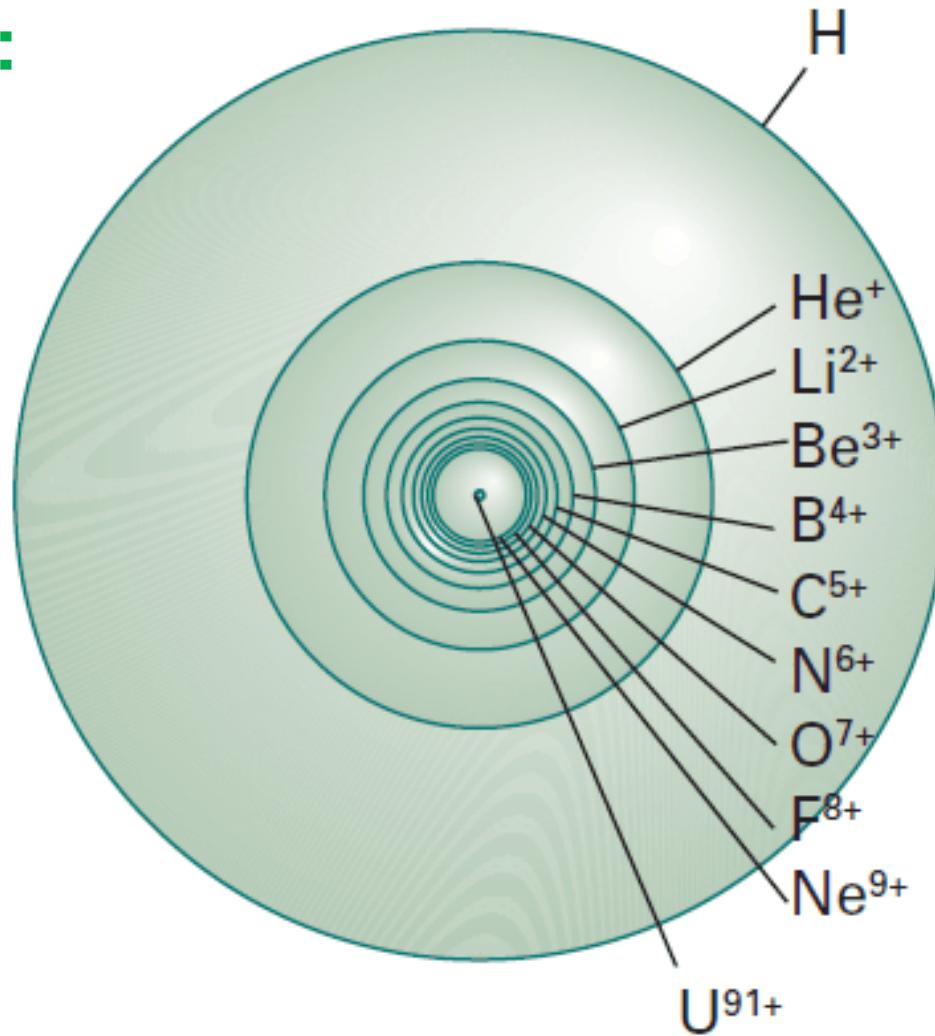
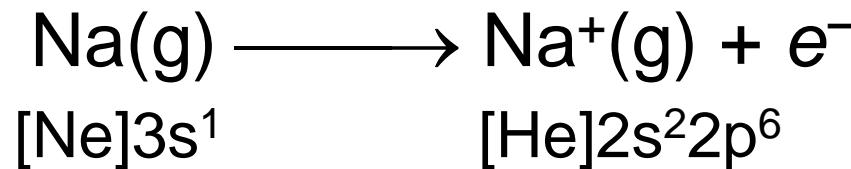


Fig. 9.14 A representation of the most probable radii of a variety of one-electron atoms and ions.

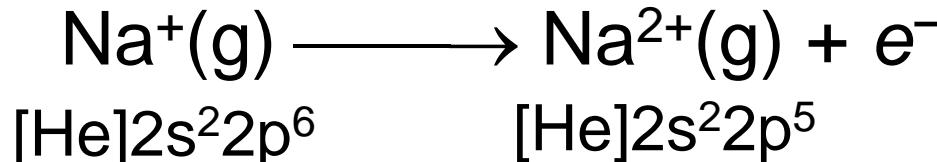
Ionization Energy (IE, 电离能)

Ionization energy: the minimum amount of **energy** required to **remove an electron** from the **ground state** of a **gaseous** atom or ion.



The **first** ionization energy: energy required to **remove the first electron**.

The **second** ionization energy: energy required to **remove the second electron**.

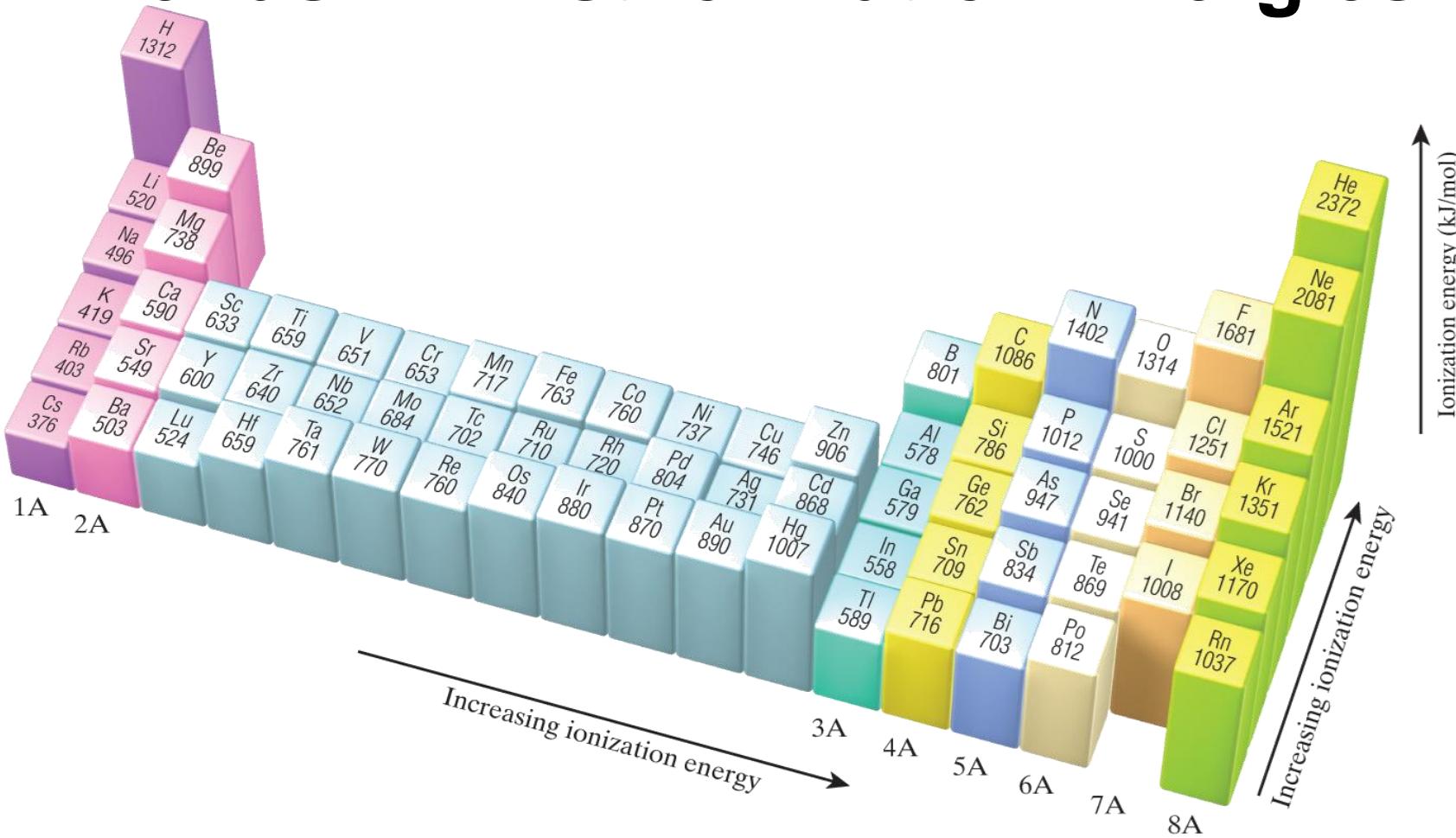


- Requires **more energy** to remove each **successive** (连续的) **electron** ($I_1 < I_2 < I_3 < I_4$).
- After **all valence electrons** are removed, the ionization energy increases **significantly** (**removal of core electrons**, much closer to the nucleus & stronger attraction; break stable noble-gas configuration).

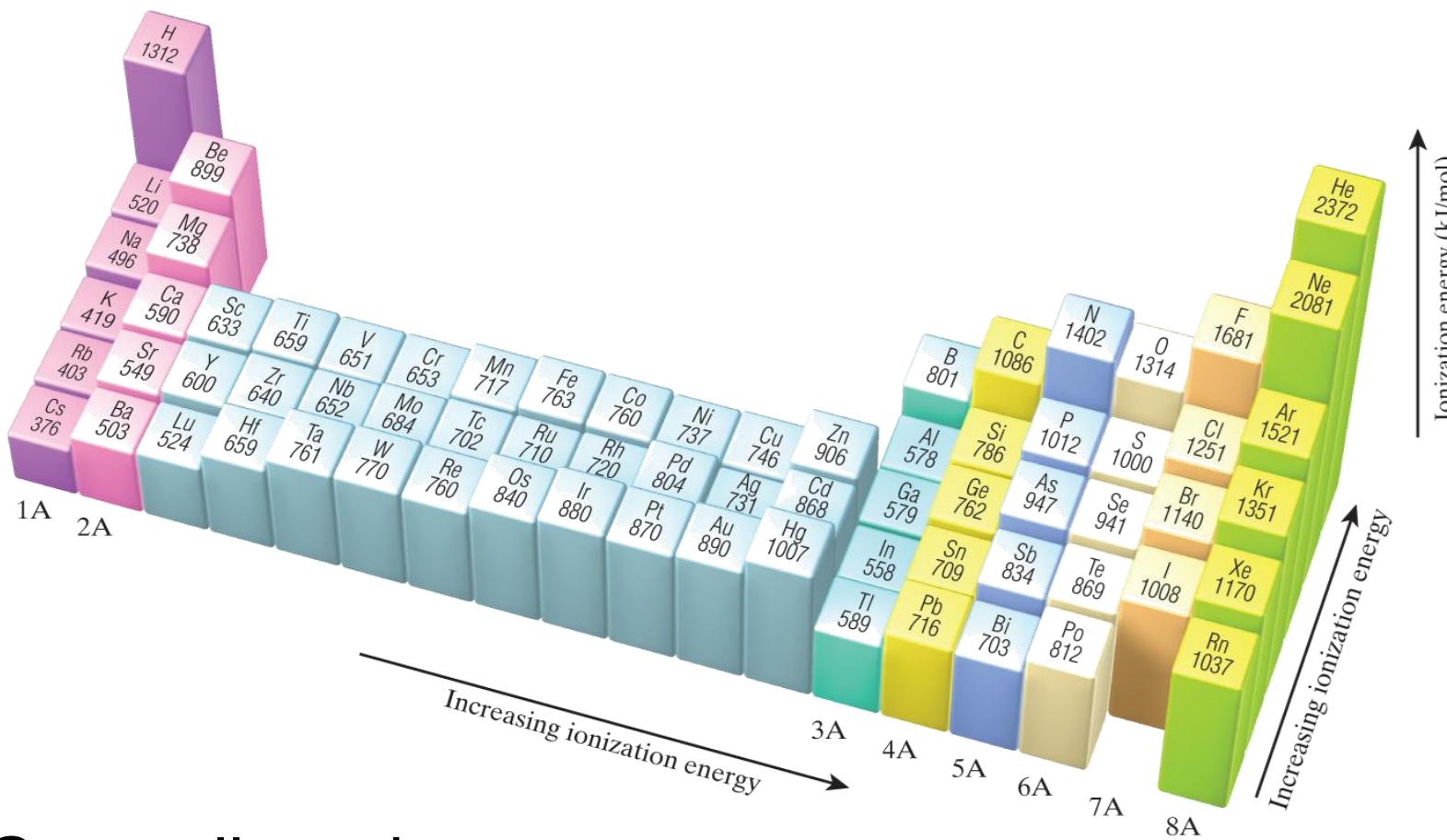
Table 7.2 Successive Values of Ionization Energies, I , for the Elements Sodium through Argon (kJ/mol)

Element	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Na	496	4562					(inner-shell electrons)
Mg	738	1451	7733				
Al	578	1817	2745	11,577			
Si	786	1577	3232	4356	16,091		
P	1012	1907	2914	4964	6274	21,267	
S	1000	2252	3357	4556	7004	8496	27,107
Cl	1251	2298	3822	5159	6542	9362	11,018
Ar	1521	2666	3931	5771	7238	8781	11,995

Trends in First Ionization Energies

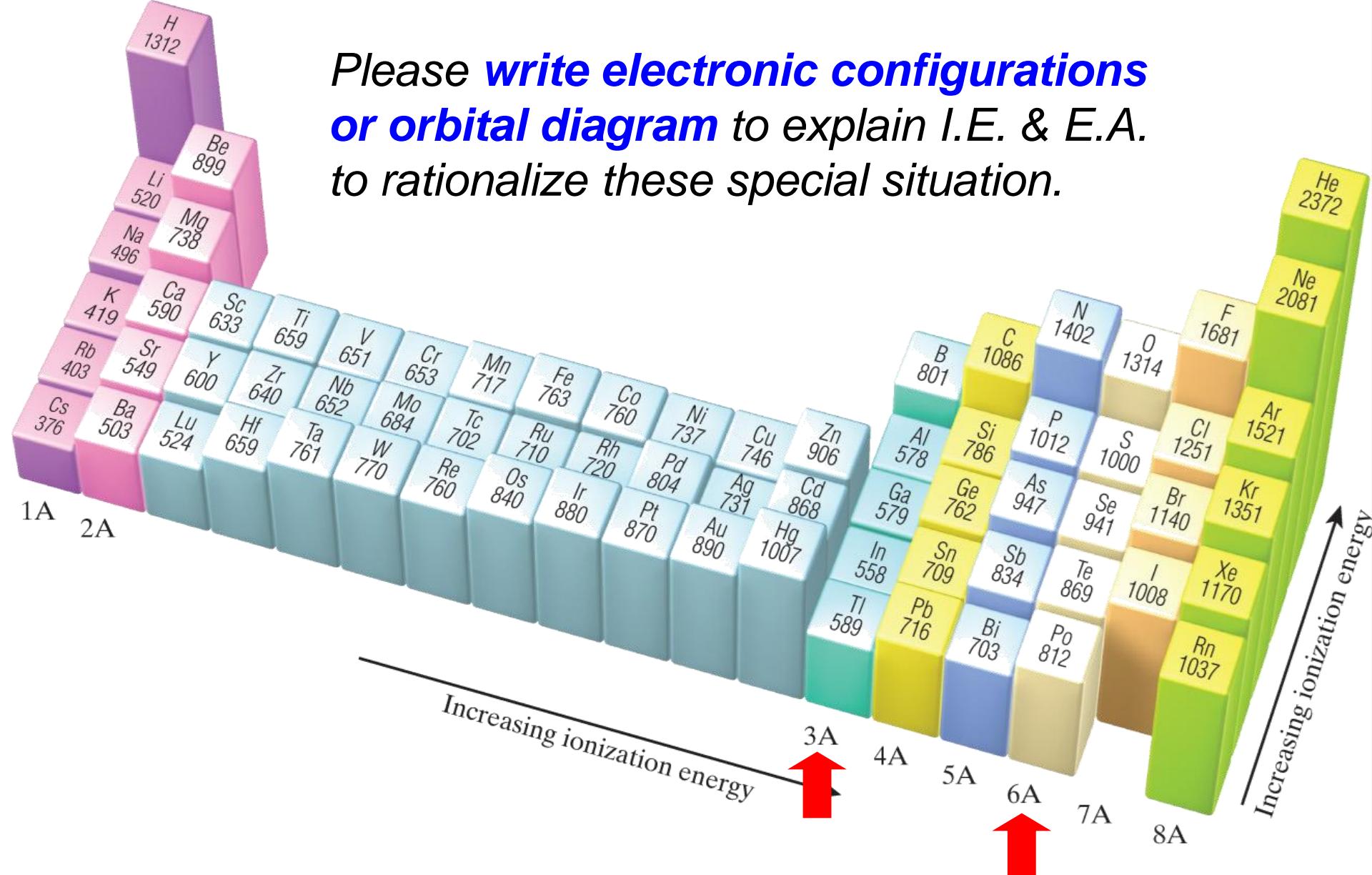


- When **down a group (larger n value)**, less energy is required to remove the first electron: the valence electrons are **further** from the nucleus (**weaker attraction**).

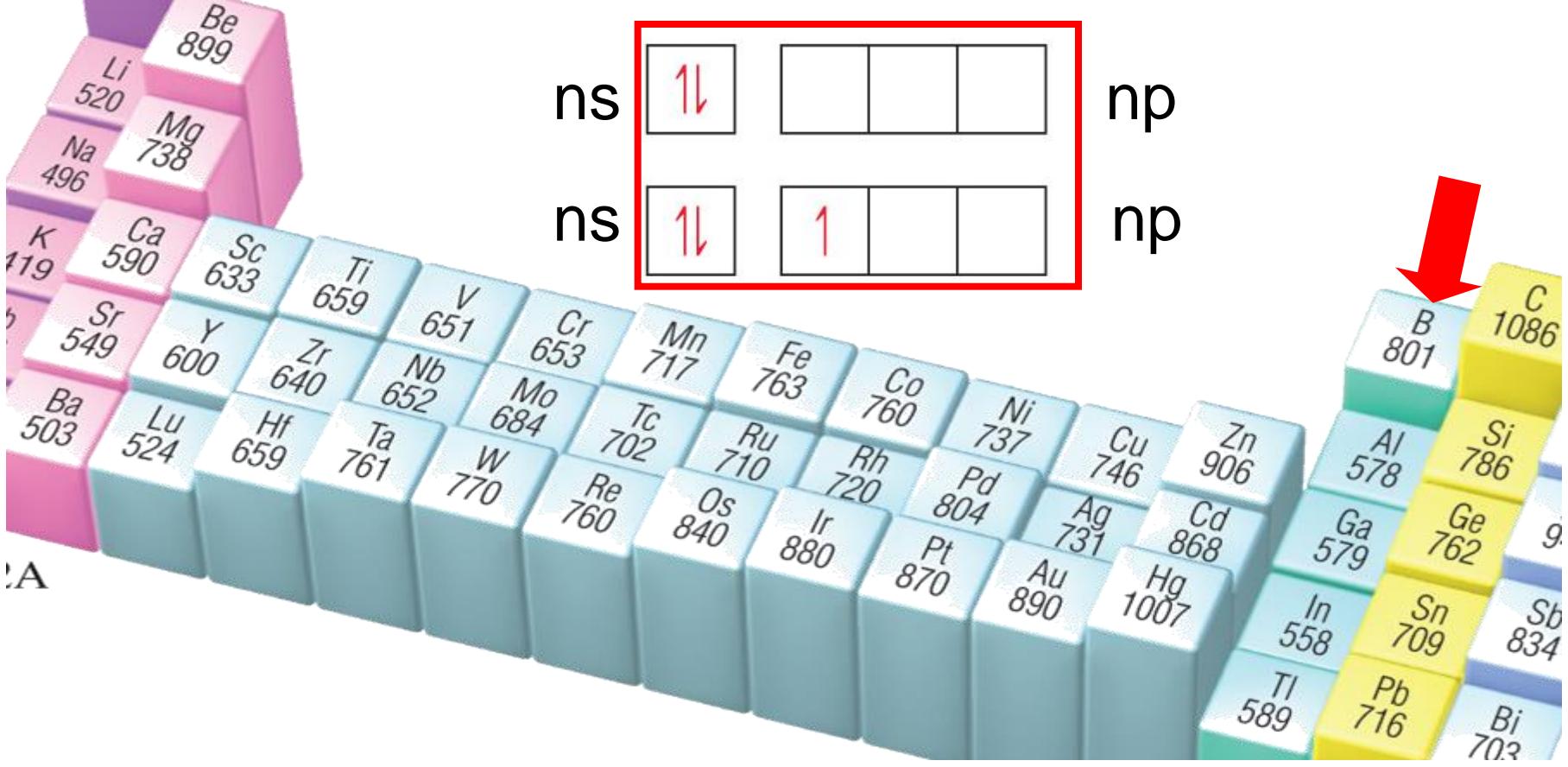


- Generally, when **across a row, more energy** is required to remove an electron (**larger Z_{eff} , more attraction**).
- The s- and p-block elements: a larger range of values for I_1 . (The d-block generally increases slowly; the f-block elements show only small variations.)

Please **write electronic configurations or orbital diagram** to explain I.E. & E.A. to rationalize these special situation.



However, there are two apparent **discontinuities** (不连续) in this trend.



- The first discontinuity between Groups **IIA & IIIA**.
- The electron is removed from a ***p* orbital (farther from the nucleus)** rather than an *s* orbital: **less attraction between the nucleus & the *p* electron** for Group III A.

$$ns^2np^1 \rightarrow ns^2$$

$2p$	<table border="1"> <tr> <td>1</td><td>1</td><td>1</td></tr> </table>	1	1	1
1	1	1		

Oxygen

$2p$	1	1	1
------	---	---	---

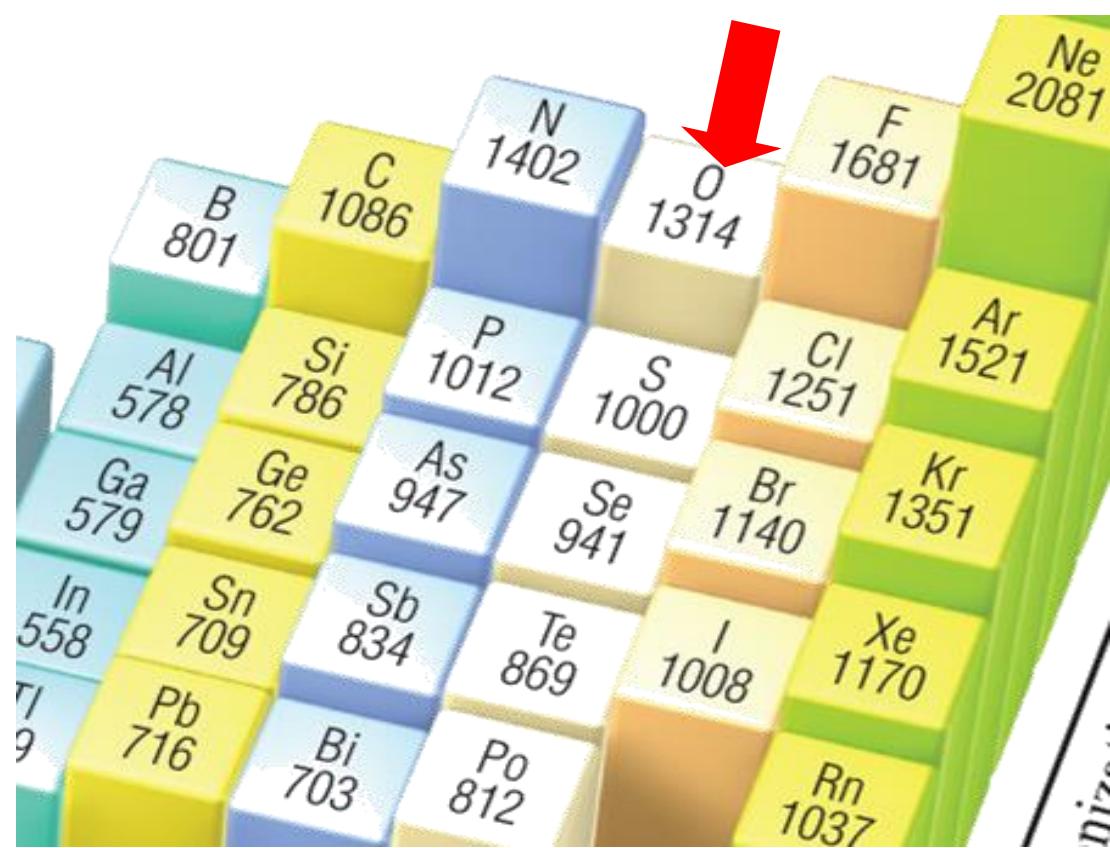
Nitrogen

Group **VIA**:

$$ns^2np^4 \rightarrow ns^2np^3$$

Group **VA**:

$$ns^2np^3 \rightarrow ns^2np^2$$

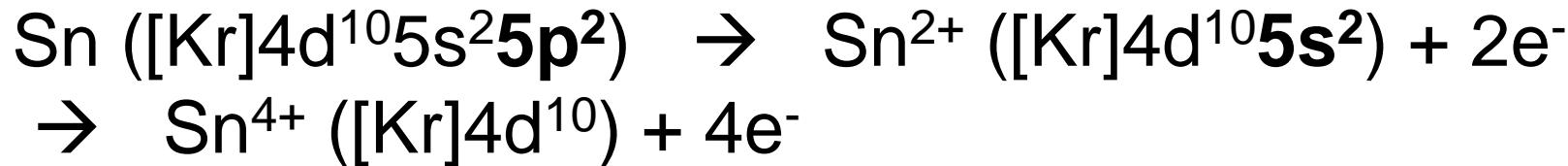


- The second discontinuity between Groups **VA** & **VIA**.
 - The electron removed comes from a **singly occupied orbital** for Group **VA** and from a **doubly occupied orbital** for Group **VIA** e.g. N ($1s^22s^2p^3$) vs. O($1s^22s^2p^4$);
- Repulsion from the other electron in the same orbital promotes the electron removal for O.**

Electrons are **removed** from the occupied orbitals with the **highest principal quantum number (*n*)** first:

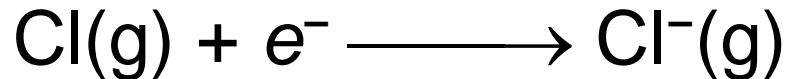


For orbitals with the **same *n*** value (same shell), electrons are **removed** from those with the **highest angular momentum quantum number (*l*)** first:



Electron Affinity (EA, 电子亲合能)

Electron affinity: the **energy change** for the **addition** of an electron to a **gaseous** atom:



Trends in Electron Affinity

1A							8A
H -73	2A	3A	4A	5A	6A	7A	He > 0
Li -60	Be > 0	B -27	C -122	N > 0	O -141	F -328	Ne > 0
Na -53	Mg > 0	Al -43	Si -134	P -72	S -200	Cl -349	Ar > 0
K -48	Ca -2	Ga -30	Ge -119	As -78	Se -195	Br -325	Kr > 0
Rb -47	Sr -5	In -30	Sn -107	Sb -103	Te -190	I -295	Xe > 0

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In general, electron affinity becomes **more exothermic** (more stable anions) when going from **left to right** across a row (**larger Z_{eff} , larger attraction**). More **negative EA, easier to accept an electron**.

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1A							8A	
H -73		2A	3A	4A	5A	6A	7A	He > 0
Li -60	Be > 0	B -27	C -122	N > 0	O -141	F -328	Ne > 0	
Na -53	Mg > 0	Al -43	Si -134	P -72	S -200	Cl -349	Ar > 0	
K -48	Ca -2	Ga -30	Ge -119	As -78	Se -195	Br -325	Kr > 0	
Rb -47	Sr -5	In -30	Sn -107	Sb -103	Te -190	I -295	Xe > 0	

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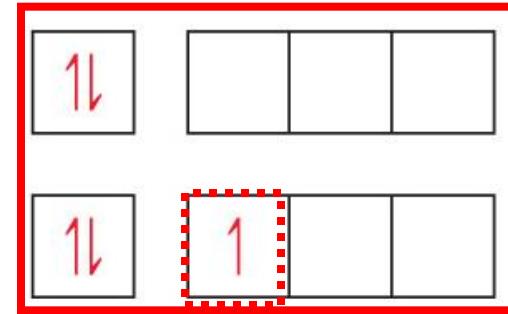
For EA, there are again **two discontinuities**: Groups **IIA & VA**).

(For IE trend, there are two discontinuities:
Group IIIA → Group IIA; **Group VIA → Group VA**)

1A	
H -73	
Li -60	Be > 0
Na -53	Mg > 0
K -48	Ca -2
Rb -47	Sr -5



3A	
B -27	
Al -43	
Ga -30	
In -30	

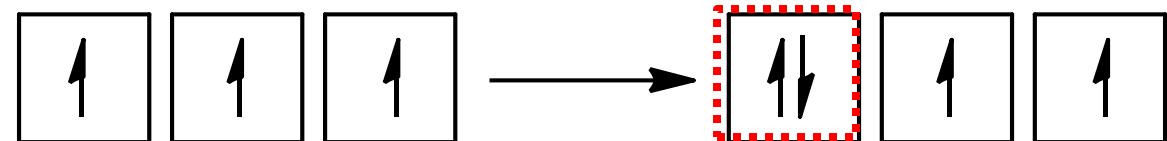
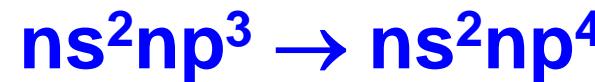


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- The first occurs between Groups IA and IIA.
- The added electron must go in a **p orbital (higher-energy)**, **not a lower-energy s orbital**. The electron in the p orbital is **farther** from the nucleus (weaker interaction) and thus EA is relatively less favorable.

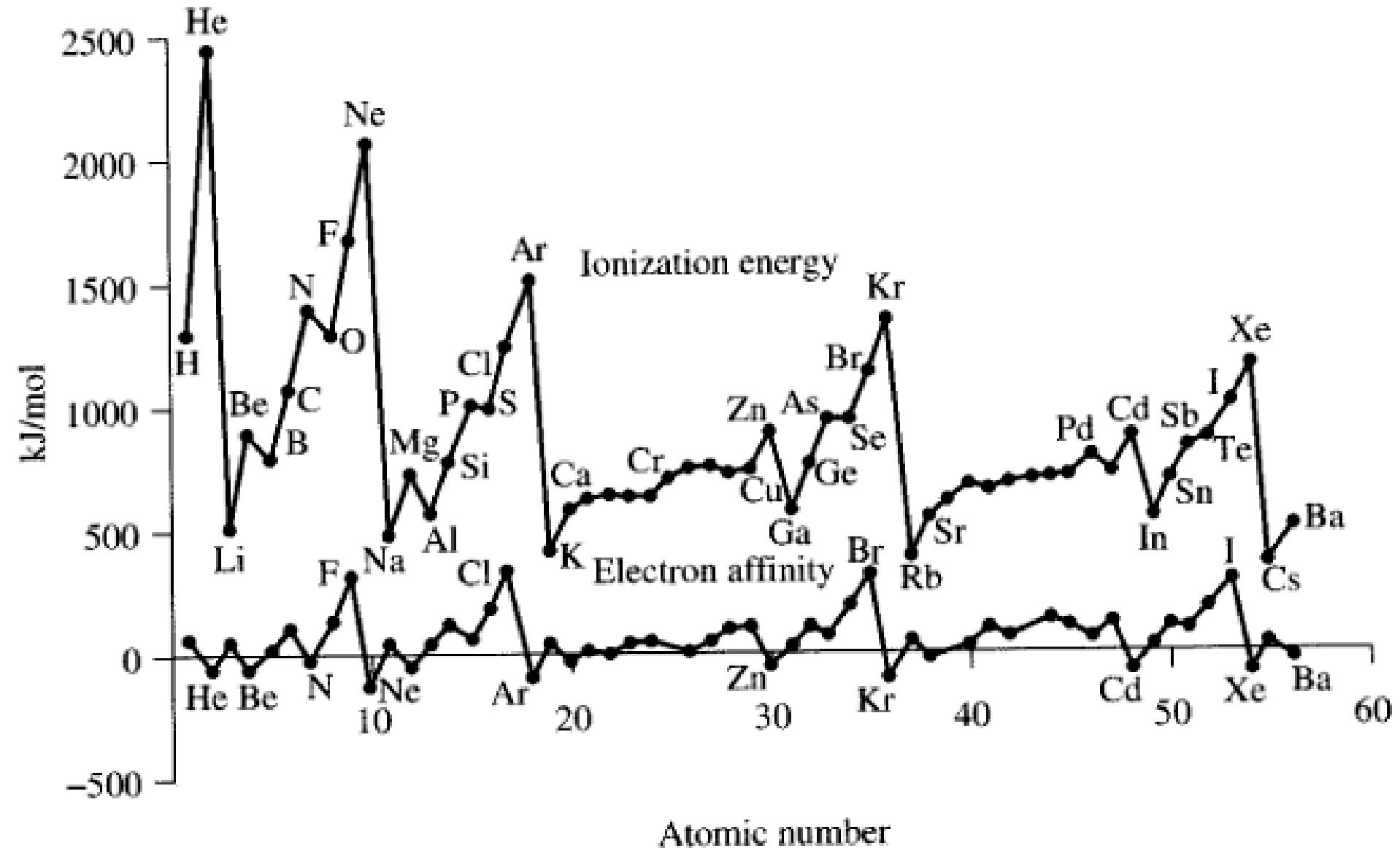
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4A	5A	6A
C	N	O
-122	> 0	-141
Si	P	S
-134	-72	-200
Ge	As	Se
-119	-78	-195
Sn	Sb	Te
-107	-103	-190



- The second discontinuity between Groups **IVA & VA**.
- Group **VA** has **no empty orbitals**. The **extra electron** must go in an **singly occupied orbital**, creating **more repulsion**, and thus EA is relatively less favorable.

Trends in Ionization Energy & (opposite sign) Electron Affinity



The effective nuclear charge felt by an atom's valence electrons (X) going from left to right and (Y) going down a column on the Periodic Table.

- a. X = increases Y = increases
- b. X = increases Y = decreases
- c. X = decreases Y = increases
- d. X = decreases Y = decreases

The correct order of increasing atomic radius (smallest → largest) is

- a. Na < Mg < K < Rb.
- b. Mg < Na < K < Rb.
- c. Rb < K < Na < Mg.
- d. Rb < K < Mg < Na.

The statements below refer to ionic radii. Which statement is FALSE?

- a. Br^{1-} is larger than Cl^{1-} .
- b. Se^{2-} is larger than Br^{1-} .
- c. K^{1+} is larger than Ca^{2+} .
- d. Na^{1+} is larger than K^{1+} .

Two ions are isoelectronic if they have the same

- a. charge.
- b. number of protons.
- c. number of electrons.
- d. number of neutrons.

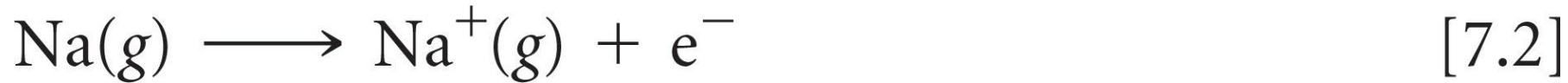
The correct order of increasing first ionization energy (smallest → largest) is

- a. Na < Ca < Al < Sn.
- b. Na < Al < Ca < Sn.
- c. Na < Al < Sn < Ca.
- d. Ca < Na < Sn < Al.

The correct order of increasing electron affinity (most negative → least negative) is

- a. O < Cl < B < C.
- b. O < Cl < C < B.
- c. Cl < O < C < B.
- d. Cl < O < B < C.

Light can be used to ionize atoms and ions. Which of the two processes shown in Equations 7.2 and 7.3 requires shorter-wavelength radiation?



- A. First ionization step, because it takes more energy and hence shorter wavelength.
- B. First ionization step, because it takes less energy and hence shorter wavelength.
- C. Second ionization step, because it takes more energy and hence shorter wavelength.
- D. Second ionization step, because it takes less energy and hence shorter wavelength.

Properties of Metal, Nonmetals, and Metalloids (类金属)

← Increasing metallic character

1A 1 H	2A 2 He											3A 13 B	4A 14 C	5A 15 N	6A 16 O	7A 17 F	8A 18 Ne
3 Li	4 Be	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8 9 10			1B 11	2B 12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
11 Na	12 Mg	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cp	113	114	115	116	117	118
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Metals versus Nonmetals

Metals

Have a shiny luster; various colors, although most are silvery

Solids are malleable and ductile

Good conductors of heat and electricity

Most metal oxides are ionic solids that are basic

Tend to form cations in aqueous solution

**Extensible &
flexible**

Nonmetals

Do not have a luster; various colors

Solids are usually brittle; some are hard, some are soft

Poor conductors of heat and electricity

Most nonmetal oxides are molecular substances that form acidic solutions

Tend to form anions or oxyanions in aqueous solution

Differences between metals and nonmetals tend to revolve around these properties.

- Metals (lower IE) tend to form **cations**.
- Nonmetals (higher IE & more negative EA) tend to form **anions**.

1A														7A		8A							
H^+														H^-									
Li ⁺																							
Na ⁺	Mg ²⁺																						
K ⁺	Ca ²⁺	Sc ³⁺	Ti ⁴⁺	V ⁵⁺ V ⁴⁺	Cr ³⁺	Mn ²⁺ Mn ⁴⁺	Fe ²⁺ Fe ³⁺	Co ²⁺ Co ³⁺	Ni ²⁺	Cu ⁺ Cu ²⁺	Zn ²⁺												
Rb ⁺	Sr ²⁺								Pd ²⁺	Ag ⁺	Cd ²⁺			Sn ²⁺ Sn ⁴⁺	Sb ³⁺ Sb ⁵⁺	Te ²⁻	I ⁻						
Cs ⁺	Ba ²⁺								Pt ²⁺	Au ⁺ Au ³⁺	Hg ₂ ²⁺ Hg ²⁺			Pb ²⁺ Pb ⁴⁺	Bi ³⁺ Bi ⁵⁺								

Transition metals

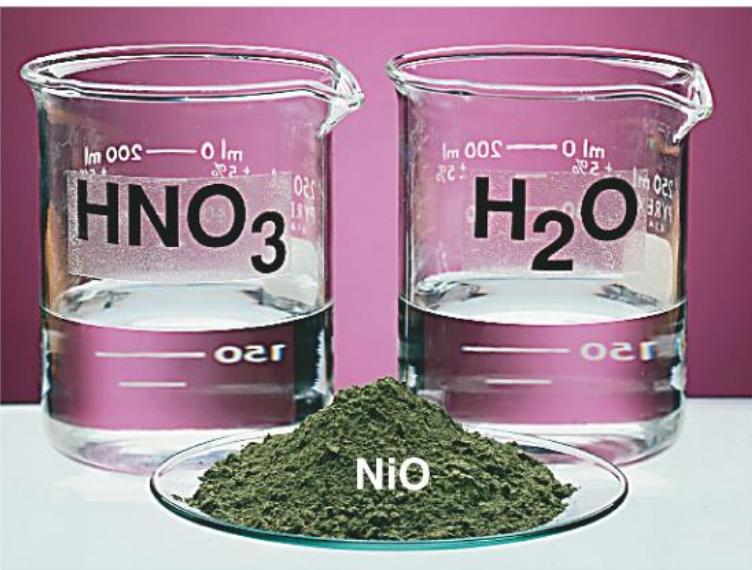
N O B L E G A S E S

Metals

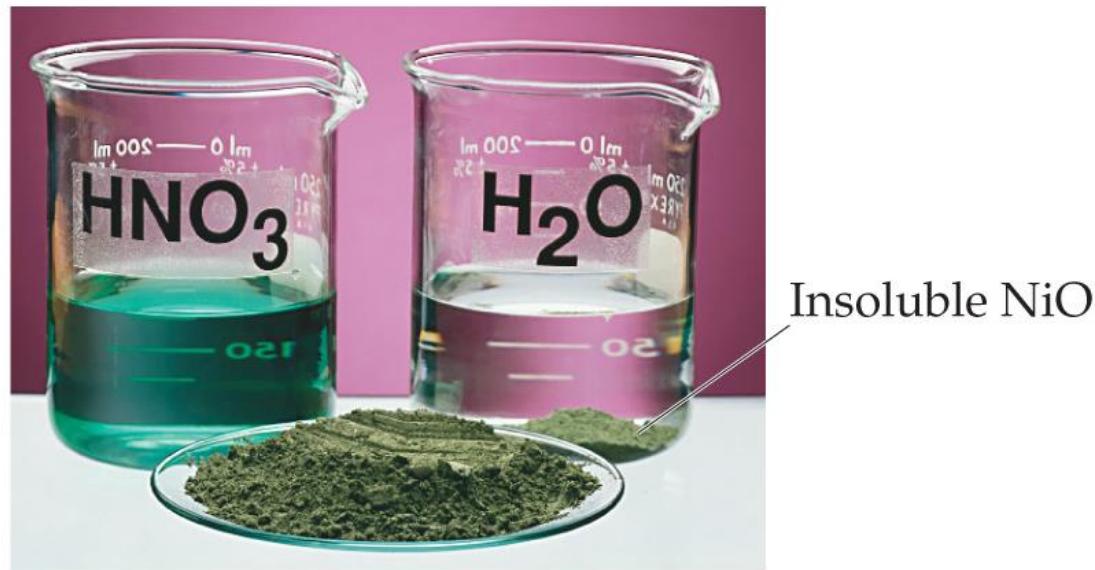


Metals tend to be lustrous(有光泽的), malleable(可锻的), ductile(有延展性的), and good conductors of heat and electricity.

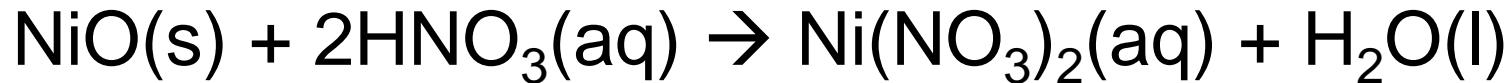
- Compounds formed between metals and nonmetals tend to be **ionic**.
- Metal oxides tend to be **basic**.



Nickel oxide (NiO), nitric acid (HNO_3), and water



NiO is insoluble in water but reacts with HNO_3 to give a green solution of the salt $\text{Ni}(\text{NO}_3)_2$

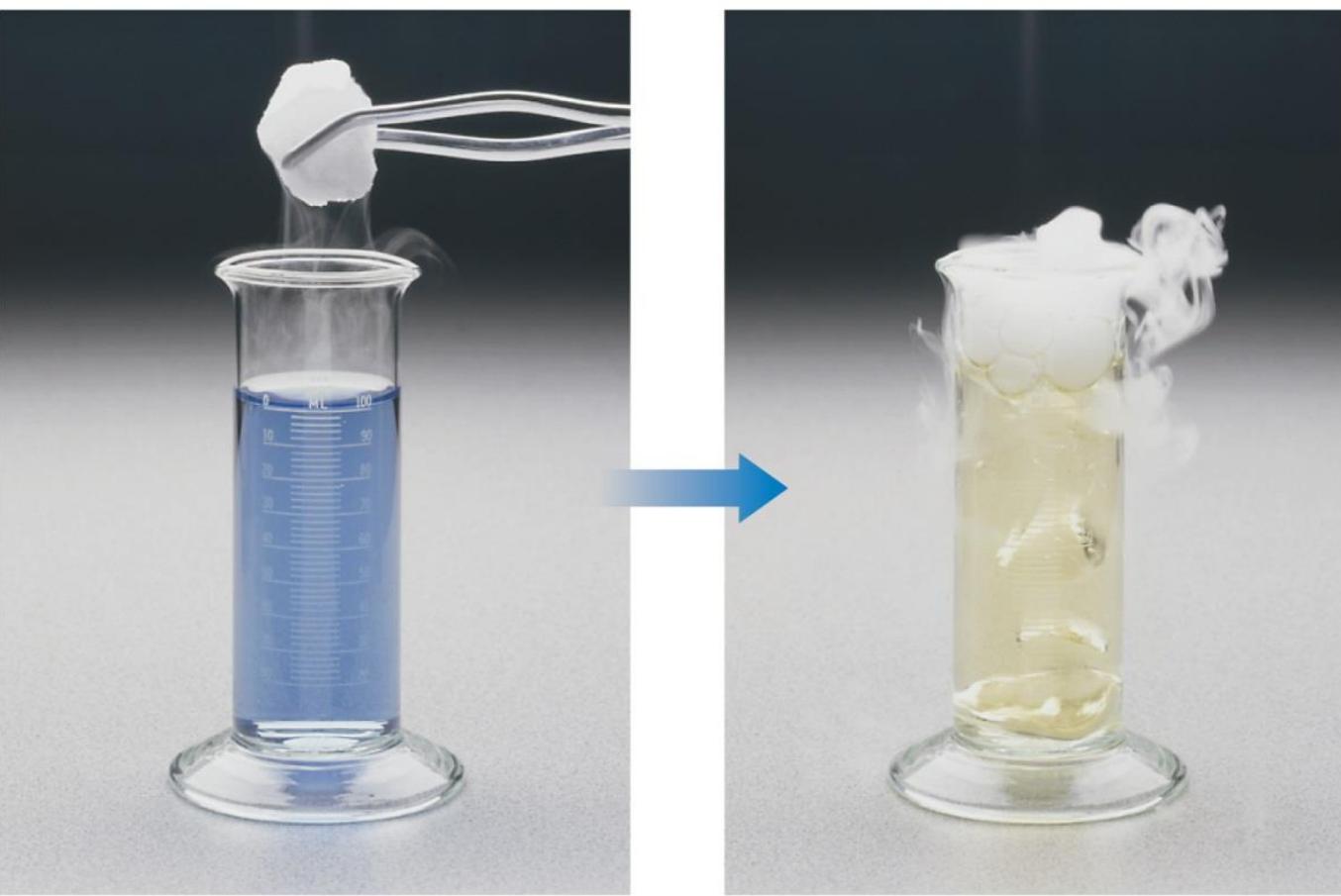


Nonmetals

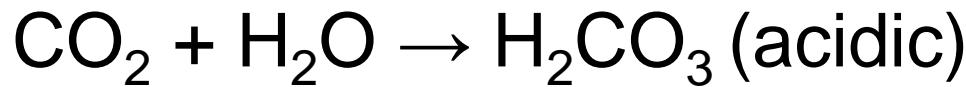


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- Nonmetals are dull (钝的), brittle (易碎的) substances that are poor conductors of heat and electricity.
- They tend to **gain electrons** in reactions with metals to **acquire a noble-gas configuration**.



pH indicator
in the solution



- Substances containing only nonmetals are **molecular compounds**.
- Most **nonmetal oxides** are **acidic**.

Metalloids

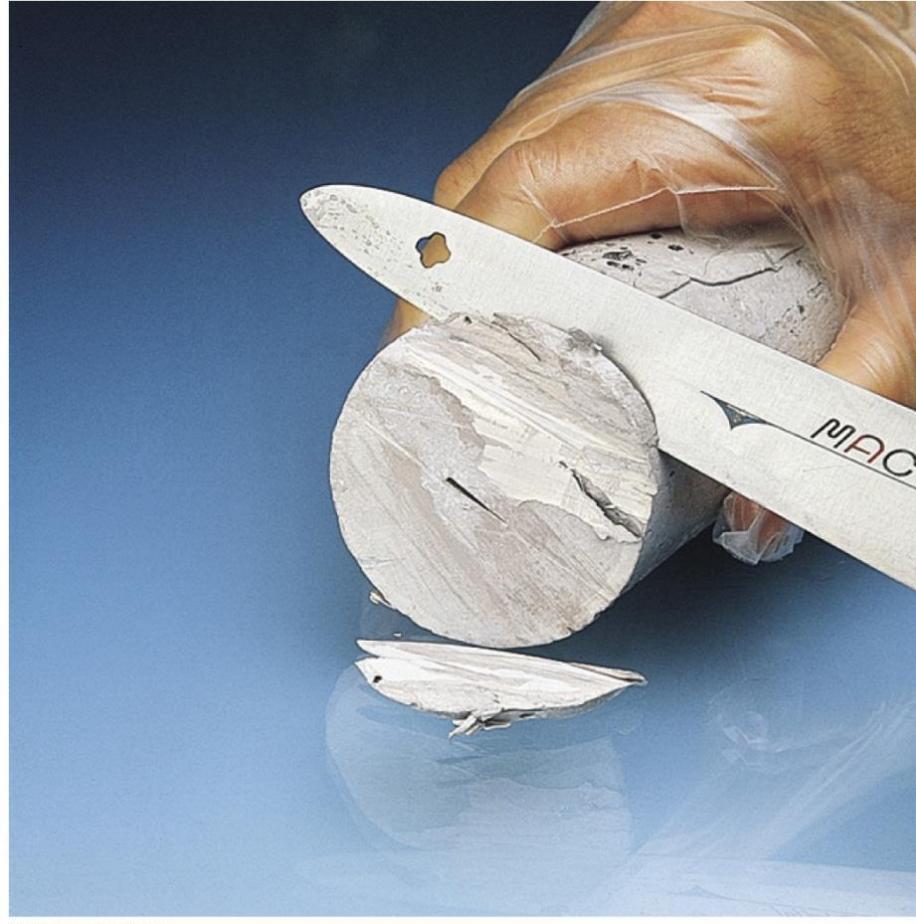


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- Metalloids have **some** characteristics of **metals** and some of **nonmetals**.
- For instance, silicon looks shiny, but is brittle and a fairly poor conductor.

Group Trends

Alkali Metals (Group IA)



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- Alkali metals are **soft**, metallic solids.
- The name comes from the Arabic word for ashes.

- They are usually found only in compounds in nature, not in their elemental forms.
- They have low densities and melting points.
- They also have low ionization energies.

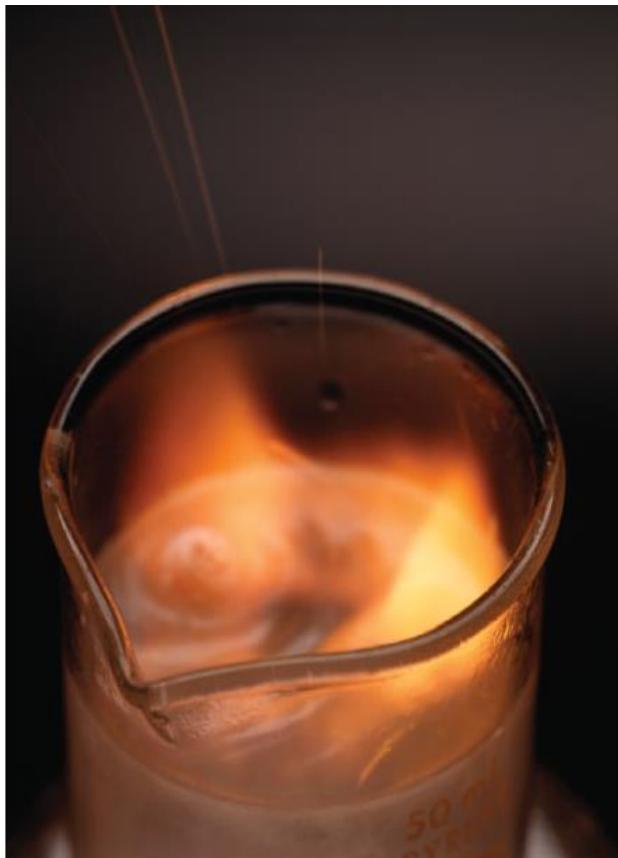
TABLE 7.4 • Some Properties of the Alkali Metals

Element	Electron Configuration	Melting Point (°C)	Density (g/cm ³)	Atomic Radius (Å)	I_1 (kJ/mol)
Lithium	[He]2s ¹	181	0.53	1.34	520
Sodium	[Ne]3s ¹	98	0.97	1.54	496
Potassium	[Ar]4s ¹	63	0.86	1.96	419
Rubidium	[Kr]5s ¹	39	1.53	2.11	403
Cesium	[Xe]6s ¹	28	1.88	2.25	376

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Li

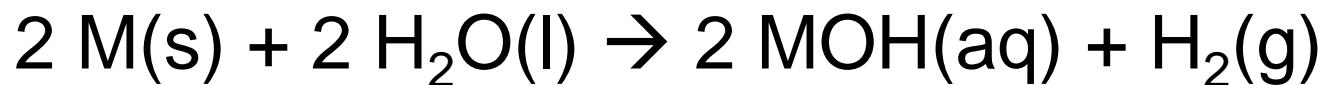


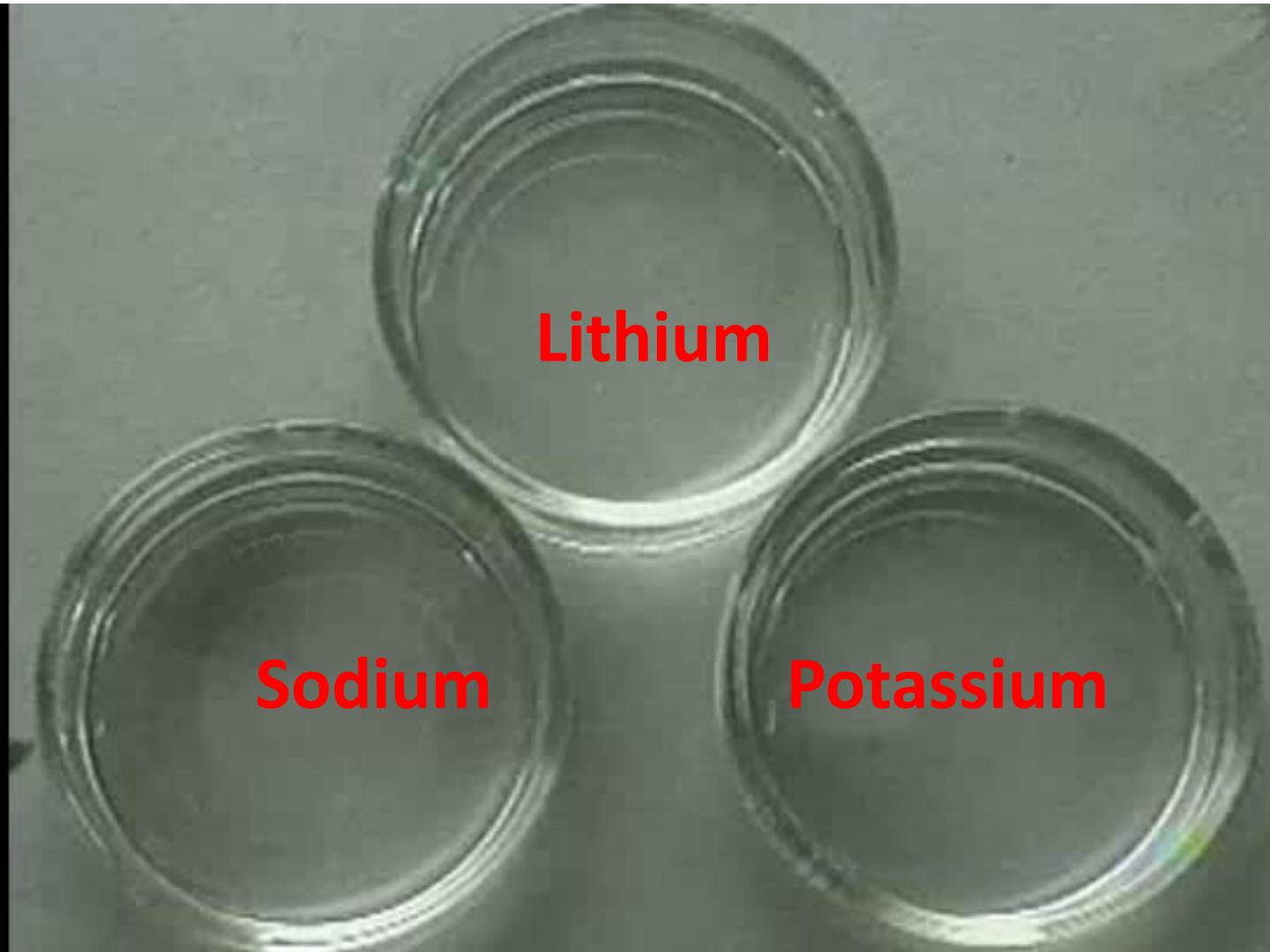
Na



K

Their reactions with water are famously exothermic.





Their reactions with water are famously exothermic.

- Most commonly, alkali metals react with oxygen to form oxides:



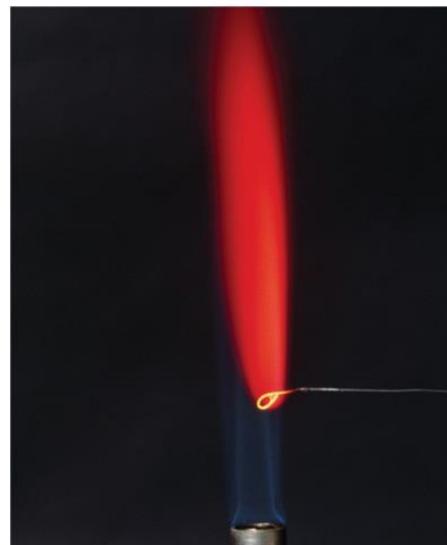
Alkali metals (except Li) can react with oxygen to form **peroxides**:



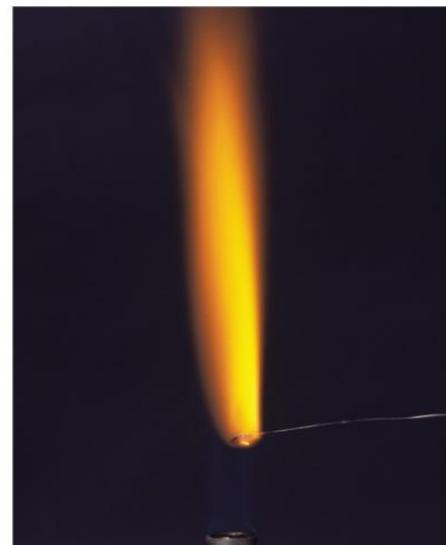
- K, Rb, and Cs also form superoxides:



- They produce bright colors when placed in a flame.



Li



Na



K

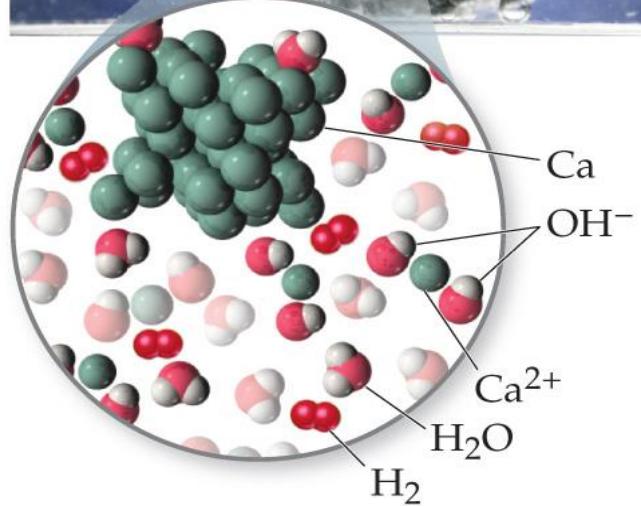
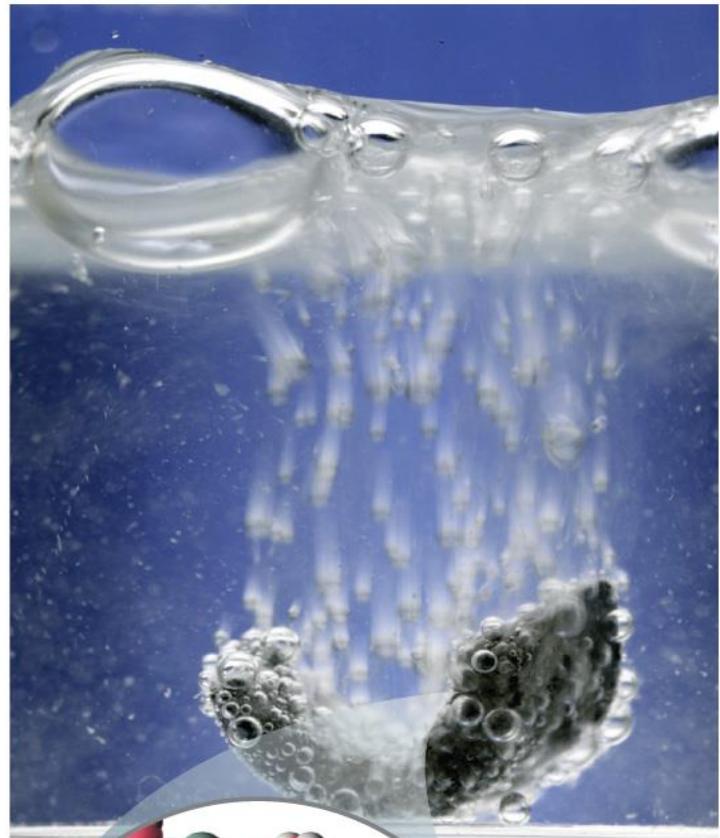
Alkaline Earth Metals (Group 2A)

Table 7.5 Some Properties of the Alkaline Earth Metals

Element	Electron Configuration	Melting Point (°C)	Density (g/cm ³)	Atomic Radius (Å)	I ₁ (kJ/mol)
Beryllium	[He]2s ²	1287	1.85	0.96	899
Magnesium	[Ne]3s ²	650	1.74	1.41	738
Calcium	[Ar]4s ²	842	1.55	1.76	590
Strontium	[Kr]5s ²	777	2.63	1.95	549
Barium	[Xe]6s ²	727	3.51	2.15	503

- Alkaline earth metals have **higher densities & melting points** than alkali metals.
- Their **ionization energies** are low, but not as low as those of alkali metals.

- Beryllium does **NOT** react with water.
- Magnesium reacts **ONLY** with steam.
- The other alkaline earth metals react **readily** with water.
- Reactivity tends to increase as you go down the group.
Why?



Chalcogens (Group 6A)

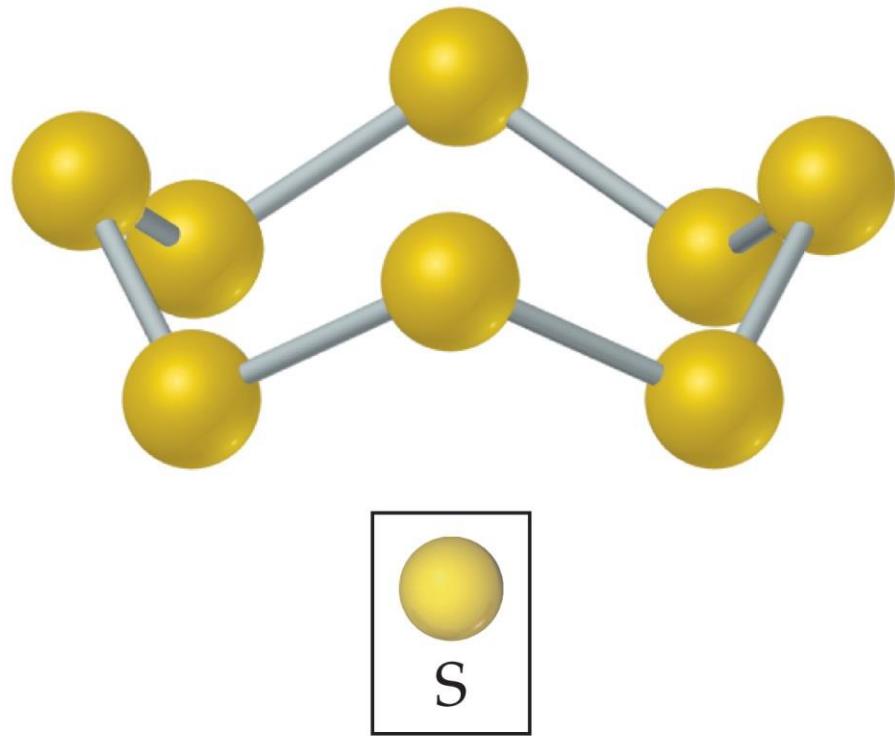
Table 7.6 Some Properties of the Group 6A Elements

Element	Electron Configuration	Melting Point (°C)	Density	Atomic Radius (Å)	I_1 (kJ/mol)
Oxygen	[He] $2s^22p^4$	-218	1.43 g/L	0.66	1314
Sulfur	[Ne] $3s^23p^4$	115	1.96 g/cm ³	1.05	1000
Selenium	[Ar] $3d^{10}4s^24p^4$	221	4.82 g/cm ³	1.20	941
Tellurium	[Kr] $4d^{10}5s^25p^4$	450	6.24 g/cm ³	1.38	869
Polonium	[Xe] $4f^{14}5d^{10}6s^26p^4$	254	9.20 g/cm ³	1.40	812

- Oxygen, sulfur & selenium are **nonmetals**.
- Tellurium is a **metalloid**.
- The radioactive polonium is a **metal**.

Sulfur

- A weaker oxidizer than oxygen.
- The most stable allotrope is S_8 , a ringed molecule.



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Plastic Sulfur





113 °C Melting Point



160 °C

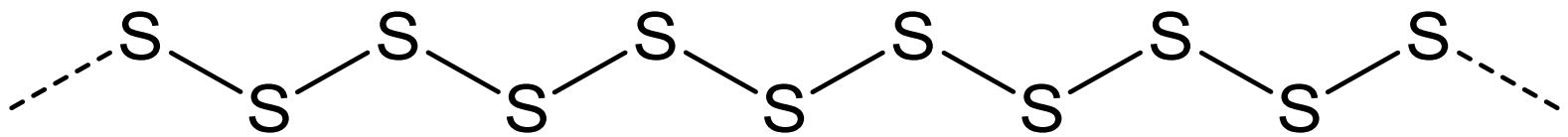
180 °C

S_8 breaks up, forms chains
Brown and Viscous



200 °C
445 °C

Chains Shorten
Boiling Point



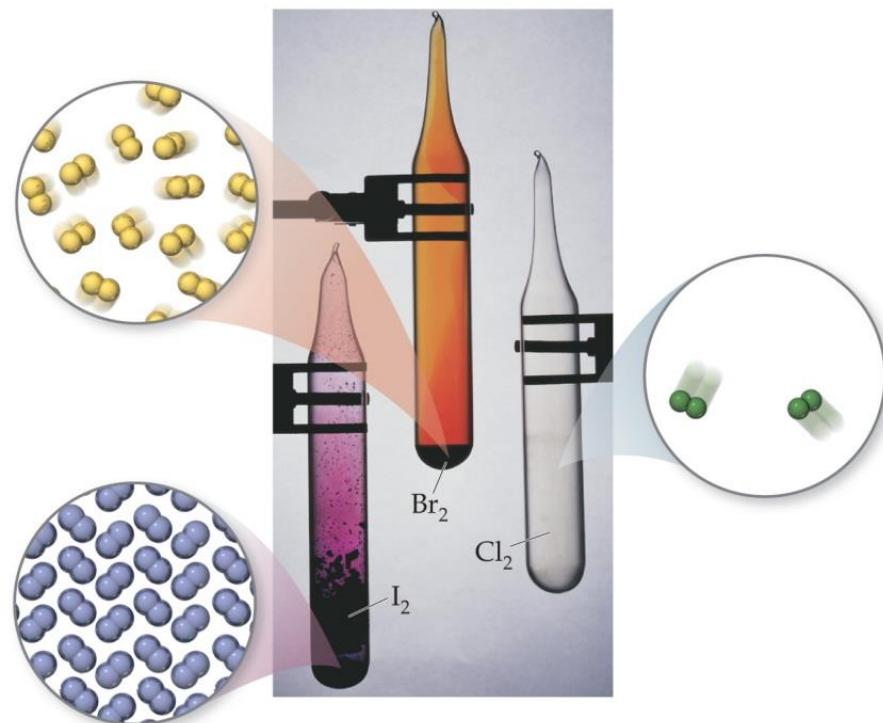
Halogens (Group VIIA)

Table 7.7 Some Properties of the Halogens

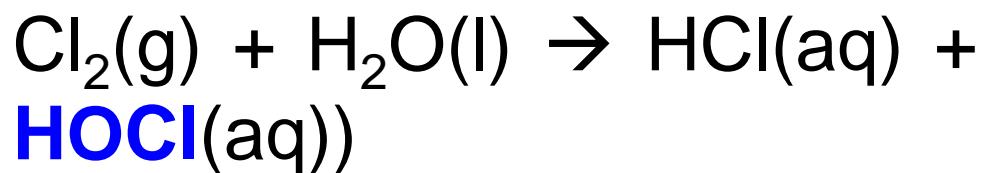
Element	Electron Configuration	Melting Point (°C)	Density	Atomic Radius (Å)	I_1 (kJ/mol)
Fluorine	[He] $2s^22p^5$	-220	1.69 g/L	0.57	1681
Chlorine	[Ne] $3s^23p^5$	-102	3.12 g/L	1.02	1251
Bromine	[Ar] $4s^23d^{10}4p^5$	-7.3	3.12 g/cm ³	1.20	1140
Iodine	[Kr] $5s^24d^{10}5p^5$	114	4.94 g/cm ³	1.39	1008

- The **halogens** are prototypical **nonmetals**.
- The name comes from the Greek words *halos* and *gennao*: “**salt formers**”.

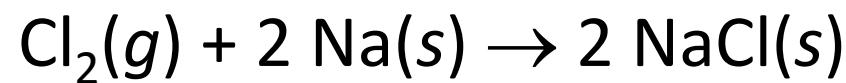
- They have **large, negative electron affinities**. Thus, they tend to **oxidize other elements easily**.



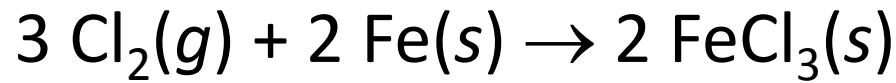
- They react directly with **metals** to **form metal halides**.
- **Chlorine** is added to water supplies to serve as a **disinfectant** (消毒剂)
 $\text{HOCl}(\text{aq})$:



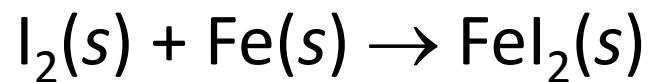
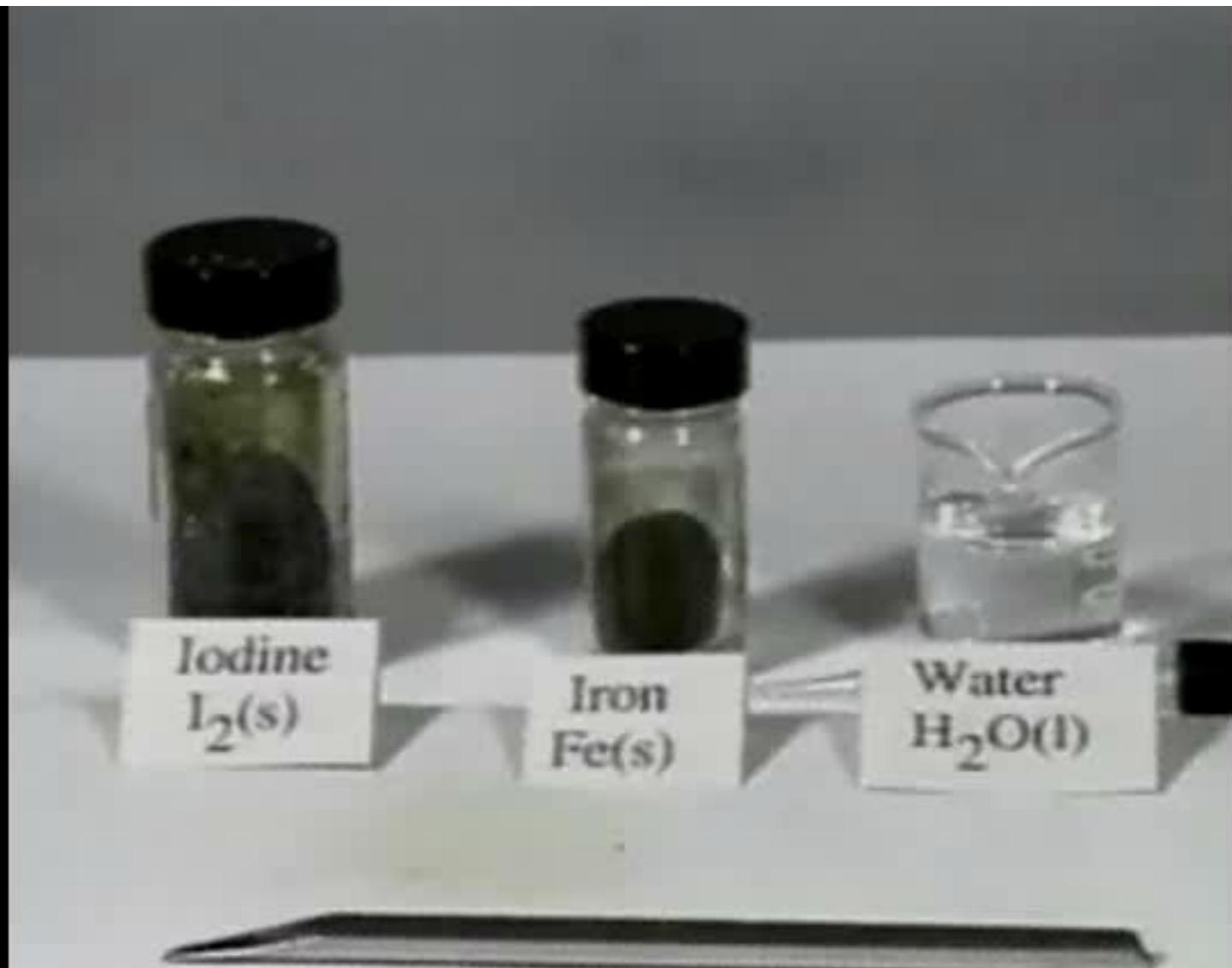
Chlorine Gas Reacts with Sodium Metal



Chlorine Gas Reacts with Iron Metal



Iodine Solid Reacts with Iron Metal



Noble Gases (Group VIII A)

Element	Electron Configuration	Boiling Point (K)	Density (g/L)	Atomic Radius* (Å)	I_1 (kJ/mol)
Helium	$1s^2$	4.2	0.18	0.28	2372
Neon	[He] $2s^22p^6$	27.1	0.90	0.58	2081
Argon	[Ne] $3s^23p^6$	87.3	1.78	1.06	1521
Krypton	[Ar] $4s^23d^{10}4p^6$	120	3.75	1.16	1351
Xenon	[Kr] $5s^24d^{10}5p^6$	165	5.90	1.40	1170
Radon	[Xe] $6s^24f^{14}5d^{10}6p^6$	211	9.73	1.50	1037

*Only the heaviest of the noble-gas elements form chemical compounds. Thus, the atomic radii for the lighter noble gas elements are estimated values.

- The **noble gases** (inert (惰性) gases) have **very large ionization energies**.
- Their **electron affinities** are positive.
- Therefore, they are **relatively unreactive**.
- They are found as **monatomic gases**.
- Synthesized XeF_2 , XeF_4 , XeF_6 , KrF_2 & HArF since 1962

Describe a general relationship between trends in metallic character and trends in ionization energy.

- A. There is no correlation between ionization energy and metallic character.
- B. Increasing ionization energy correlates with decreasing metallic character.
- C. Increasing ionization energy correlates with increasing metallic character.
- D. Decreasing ionization energy correlates with decreasing metallic character.

Most metal oxides form _____ solutions when dissolved in water.

- a. acidic
- b. basic
- c. neutral
- d. amphoteric

Most nonmetal oxides form _____ solutions when dissolved in water.

- a. acidic
- b. basic
- c. neutral
- d. amphoteric

Electron Affinity (-ve)

Ionization Energy

Increasing metallic character

Z_{eff}

Atomic Radius

Increasing metallic character

1A 1 H	2A 2 Li	3B 3 Na	4B 4 Mg	5B 5 Sc	6B 6 Ti	7B 7 V	8B 8 Cr	1B 9 Mn	13 10 Fe	14 11 Ni	15 12 Cu	16 13 Ga	17 14 Ge	18 15 As	2 He
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Ni	28 Cu	29 Ga	30 Ge	31 As	32 Se	33 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Ru	44 Rh	45 Ag	46 Cd	47 In	48 Sn	49 Sb	50 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	85 Po
87 Fr	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Nonmetallic

Metallic

Electron Affinity (-ve)

Ionization Energy

- Metals
- Metalloids
- Nonmetals

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

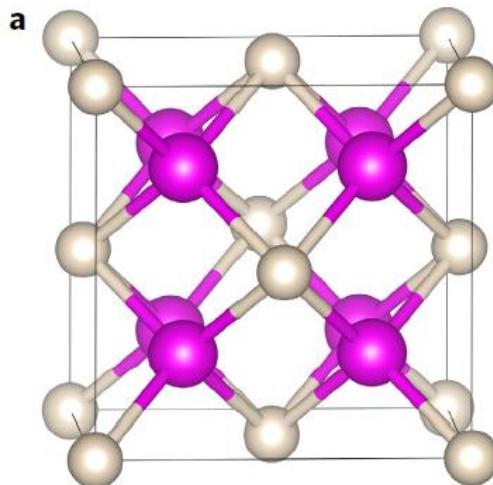
Atomic Radius

A stable compound of helium and sodium at high pressure

Extra Info:

Xiao Dong^{1,2,3}, Artem R. Oganov^{3,4,5,6*}, Alexander F. Goncharov^{7,8}, Elissaios Stavrou^{7,9}, Sergey Lobanov^{7,10}, Gabriele Saleh⁵, Guang-Rui Qian³, Qiang Zhu³, Carlo Gatti¹¹, Volker L. Deringer¹², Richard Dronskowski¹², Xiang-Feng Zhou^{1,3*}, Vitali B. Prakapenka¹³, Zuzana Konôpková¹⁴, Ivan A. Popov^{15,16}, Alexander I. Boldyrev¹⁵ and Hui-Tian Wang^{1,17*}

Helium is generally understood to be chemically inert and this is due to its extremely stable closed-shell electronic configuration, zero electron affinity and an unsurpassed ionization potential. It is not known to form thermodynamically stable compounds, except a few inclusion compounds. Here, using the *ab initio* evolutionary algorithm USPEX and subsequent high-pressure synthesis in a diamond anvil cell, we report the discovery of a thermodynamically stable compound of helium and sodium, Na₂He, which has a fluorite-type structure and is stable at pressures >113 GPa. We show that the presence of He atoms causes strong electron localization and makes this material insulating. This phase is an electride, with electron pairs localized in interstices, forming eight-centre two-electron bonds within empty Na₈ cubes. We also predict the existence of Na₂HeO with a similar structure at pressures above 15 GPa.



X-ray crystal structure of Na₂He at 300 GPa



How to cite:

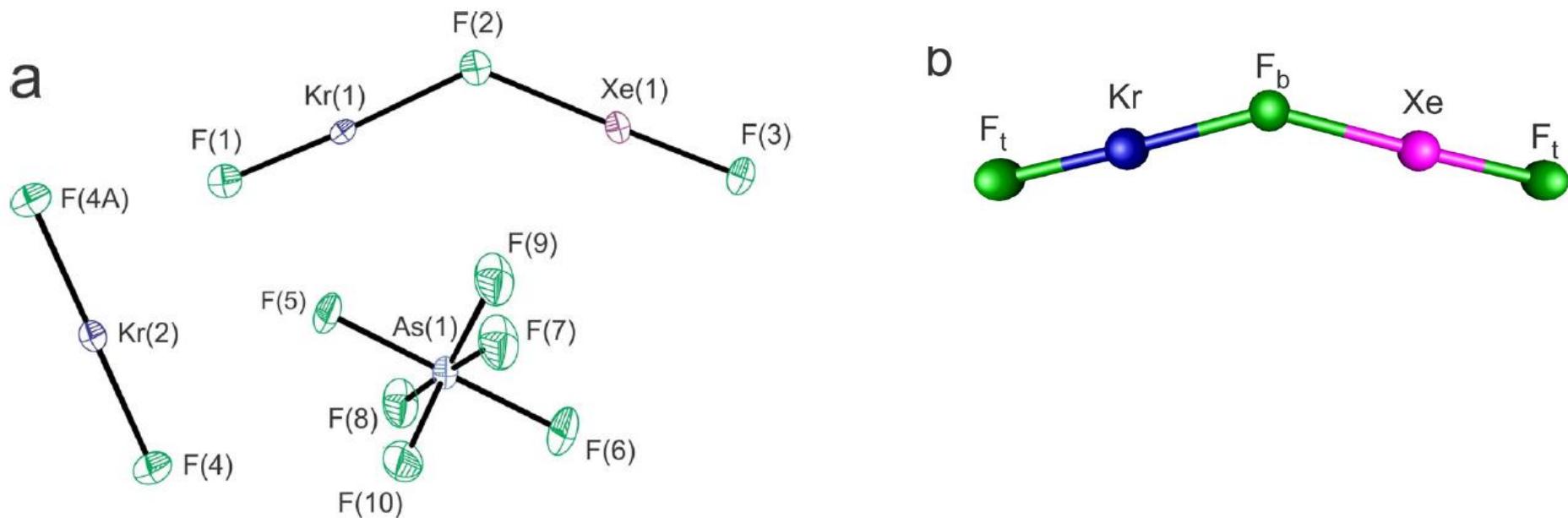
International Edition: doi.org/10.1002/anie.202102205

German Edition: doi.org/10.1002/ange.202102205

Syntheses and Characterizations of the Mixed Noble-Gas Compounds, $[FKr^{II}FXe^{II}F][AsF_6] \cdot 0.5 Kr^{II}F_2 \cdot 2 HF$, $([Kr^{II}_2F_3][AsF_6])_2 \cdot Xe^{IV}F_4$, and $Xe^{IV}F_4 \cdot Kr^{II}F_2$

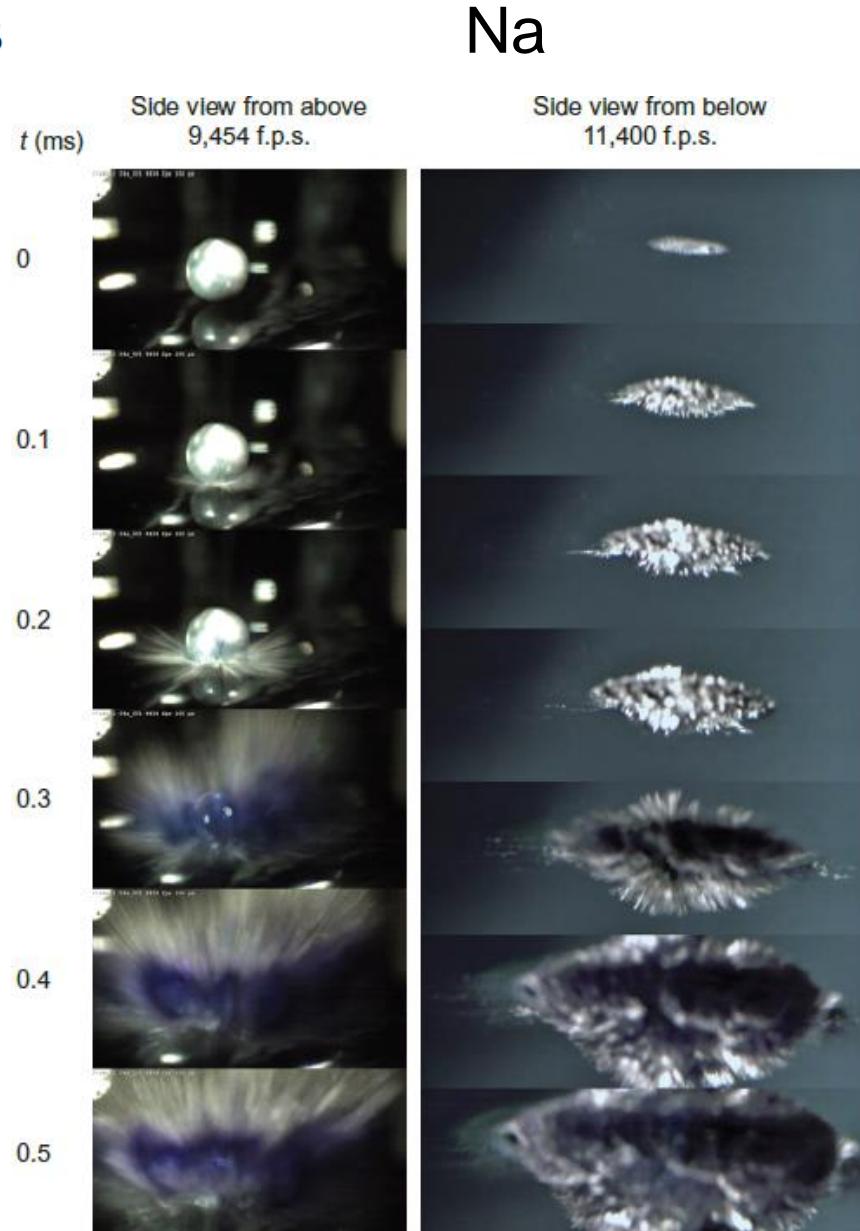
Extra Info:

Mark R. Bortolus, Hélène P. A. Mercier, Brianna Nguyen, and Gary J. Schrobilgen*



Coulomb explosion during the early stages of the reaction of alkali metals with water

High-speed camera



Mason Nature Chem, 2015, 250.

Key Summary

Development of Periodic Table

Periodic Trends:

Effective Nuclear Charge: Shielding

Sizes of Atoms & Ions: (non)bonding atomic radius;
Ionization Energy
Electron Affinity

Properties of Metal, Nonmetals, and Metalloids

**Thank You for Your
Attention!
Any Questions?**