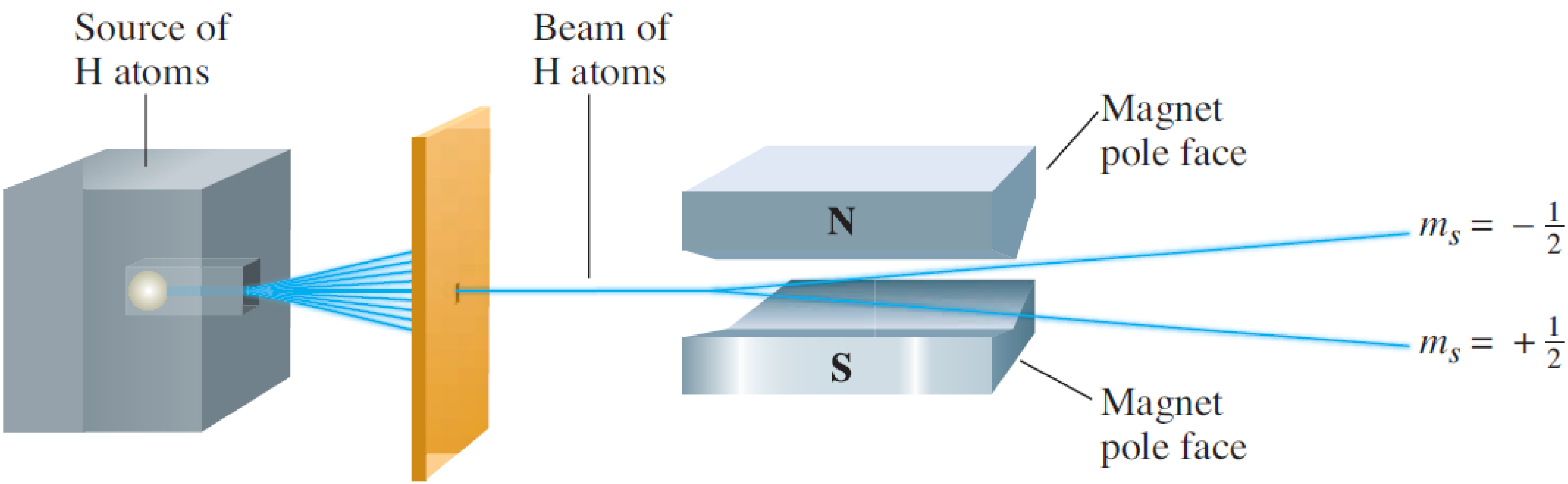
CHAPTER 8 ELECTRON CONFIGURATION AND PERIODICITY

Dr. Yuan Dan

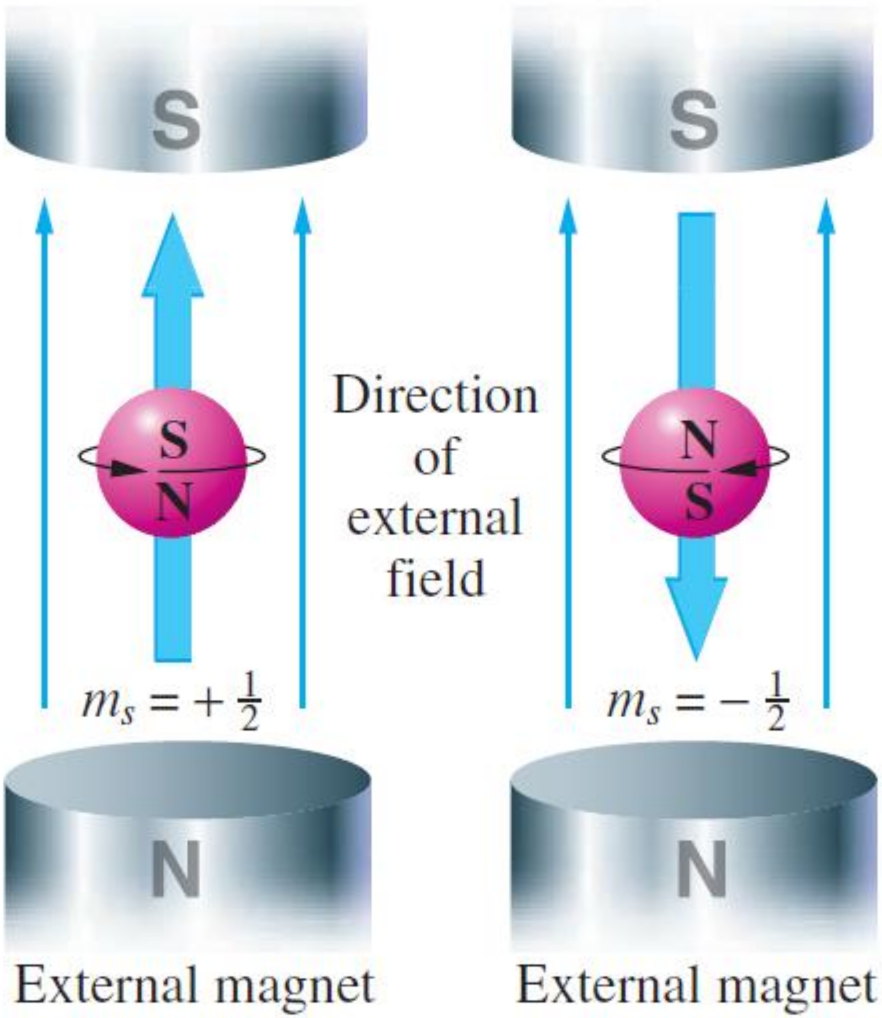
8.1 Electron Spin and the Pauli Exclusion Principle

- The Stern–Gerlach experiment



8.1 Electron Spin and the Pauli Exclusion Principle

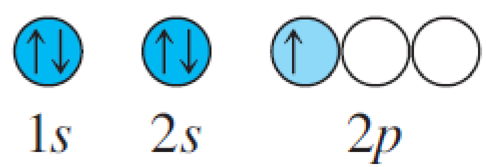
- A representation of electron spin



8.1 Electron Spin and the Pauli Exclusion Principle

- Electron Configurations and Orbital Diagrams
- An electron configuration of an atom is a particular distribution of electrons among available subshells.
- Li: $1s^2 2s^1$
- Orbital diagram: a diagram to show how the orbitals of a subshell are occupied by electrons.

m_s $\uparrow\downarrow$ $\pm\frac{1}{2}$



8.1 Electron Spin and the Pauli Exclusion Principle

- Pauli Exclusion Principle: no two electrons in an atom can have the same four quantum numbers.

1*s*

8.1 Electron Spin and the Pauli Exclusion Principle

- Pauli Exclusion Principle: An orbital can hold at most two electrons, and then only if the electrons have opposite spins.
- Each subshell holds a maximum of twice as many electrons as the number of orbitals in the subshell.

Subshell	Number of Orbitals	Maximum Number of Electrons
$s\ (l = 0)$	1 ↑↓	2
$p\ (l = 1)$	3 ↑↓	6
$d\ (l = 2)$	5	10
$f\ (l = 3)$	7	14

8.2 Building-Up Principle and the Periodic Table

Ground state: lowest energy

基态

Excited state

激发态

$1s^2 2s^2 2p^6 3s^1$ vs. $1s^2 2s^2 2p^6 3p^1$

The chemical properties of an atom are related primarily to the electron configuration of its ground state.

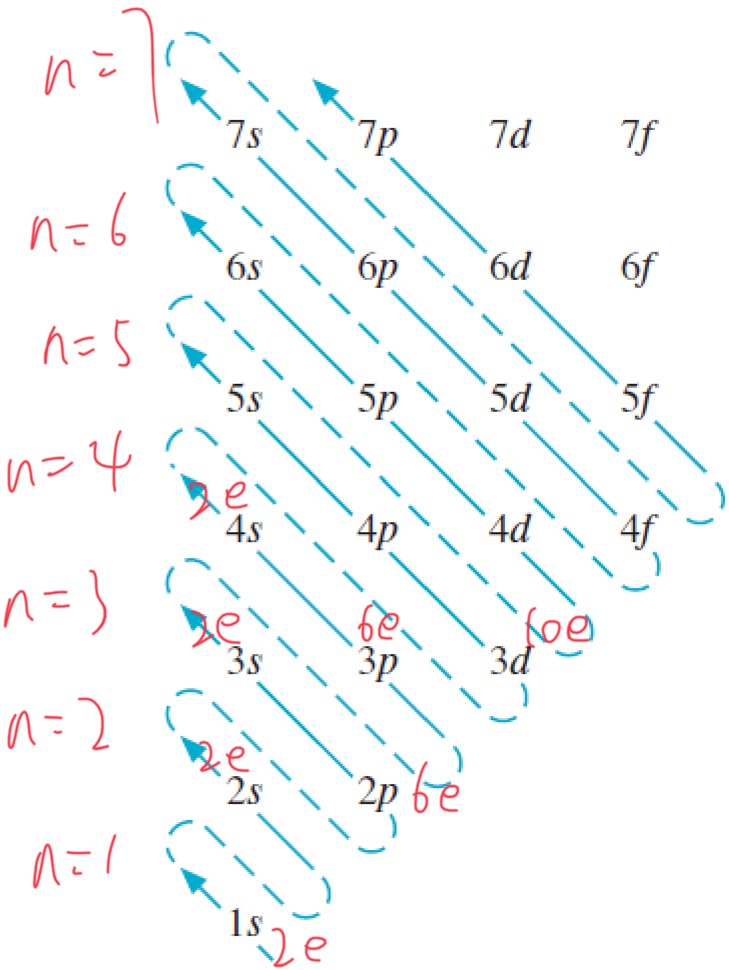
8.2 Building-Up Principle and the Periodic Table

- Building-Up Principle

n越大，能量越大

s < p < d < f < s

$1s^2$



$Z = 3$	lithium	$1s^22s^1$	or	$[He]2s^1$
$Z = 4$	beryllium	$1s^22s^2$	or	$[He]2s^2$
$Z = 5$	boron	$1s^22s^22p^1$	or	$[He]2s^22p^1$
$Z = 6$	carbon	$1s^22s^22p^2$	or	$[He]2s^22p^2$
⋮				
$Z = 10$	neon Ne	$1s^22s^22p^6$	or	$[He]2s^22p^6$
$Z = 11$	sodium	$1s^22s^22p^63s^1$	or	$\boxed{[Ne]}3s^1$
$Z = 12$	magnesium	$1s^22s^22p^63s^2$	or	$[Ne]3s^2$
$Z = 13$	aluminum	$1s^22s^22p^63s^23p^1$	or	$[Ne]3s^23p^1$
⋮				
$Z = 18$	argon	$1s^22s^22p^63s^23p^6$	or	$[Ne]3s^23p^6$

8.2 Building-Up Principle and the Periodic Table

- noble gases

helium	He	$1s^2$	2
neon	Ne	$1s^2 2s^2 2p^6$	10
argon	Ar	$1s^2 2s^2 2p^6 3s^2 3p^6$	18
krypton	Kr	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$	36

- alkaline earth metals

noble-gas core

beryllium	$1s^2 2s^2$	or	$[He]2s^2$
magnesium	$1s^2 2s^2 2p^6 3s^2$	or	$[Ne]3s^2$
calcium	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$	or	$[Ar]4s^2$

8.2 Building-Up Principle and the Periodic Table

- Group IIIA

boron	$1s^22s^22p^1$	or	$[He]2s^22p^1$
aluminum	$1s^22s^22p^63s^23p^1$	or	$[Ne]3s^23p^1$
gallium	$1s^22s^22p^63s^23p^63d^{10}4s^24p^1$	or	$\underbrace{[Ar]3d^{10}}_{}4s^24p^1$

pseudo-noble-gas core

- valence electron: An electron in an atom outside the noble-gas or pseudo-noble-gas core

8.2 Building-Up Principle and the Periodic Table

- the Periodic Table

Main-Group Elements *s* subshell fills

Main-Group Elements *p* subshell fills

Transition Metals *d* subshell fills

Inner Transition Metals *f* subshell fills

Key: 1 H $1s^1$ — Atomic number, Symbol, Valence-shell configuration

Period	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H $1s^1$																	2 He $1s^2$
2	3 Li $2s^1$	4 Be $2s^2$											5 B $2s^22p^1$	6 C $2s^22p^2$	7 N $2s^22p^3$	8 O $2s^22p^4$	9 F $2s^22p^5$	10 Ne $2s^22p^6$
3	11 Na $3s^1$	12 Mg $3s^2$											13 Al $3s^23p^1$	14 Si $3s^23p^2$	15 P $3s^23p^3$	16 S $3s^23p^4$	17 Cl $3s^23p^5$	18 Ar $3s^23p^6$
4	19 K $4s^1$	20 Ca $4s^2$	21 Sc $3d^14s^2$	22 Ti $3d^24s^2$	23 V $3d^34s^2$	24 Cr $3d^54s^1$	25 Mn $3d^54s^2$	26 Fe $3d^64s^2$	27 Co $3d^74s^2$	28 Ni $3d^84s^2$	29 Cu $3d^{10}4s^1$	30 Zn $3d^{10}4s^2$	31 Ga $4s^24p^1$	32 Ge $4s^24p^2$	33 As $4s^24p^3$	34 Se $4s^24p^4$	35 Br $4s^24p^5$	36 Kr $4s^24p^6$
5	37 Rb $5s^1$	38 Sr $5s^2$	39 Y $4d^15s^2$	40 Zr $4d^25s^2$	41 Nb $4d^45s^1$	42 Mo $4d^55s^1$	43 Tc $4d^55s^2$	44 Ru $4d^75s^1$	45 Rh $4d^85s^1$	46 Pd $4d^{10}$	47 Ag $4d^{10}5s^1$	48 Cd $4d^{10}5s^2$	49 In $5s^25p^1$	50 Sn $5s^25p^2$	51 Sb $5s^25p^3$	52 Te $5s^25p^4$	53 I $5s^25p^5$	54 Xe $5s^25p^6$
6	55 Cs $6s^1$	56 Ba $6s^2$	71 Lu $4f^{14}5d^16s^2$	72 Hf $5d^26s^2$	73 Ta $5d^36s^2$	74 W $5d^46s^2$	75 Re $5d^56s^2$	76 Os $5d^66s^2$	77 Ir $5d^76s^2$	78 Pt $5d^96s^1$	79 Au $5d^{10}6s^1$	80 Hg $5d^{10}6s^2$	81 Tl $6s^26p^1$	82 Pb $6s^26p^2$	83 Bi $6s^26p^3$	84 Po $6s^26p^4$	85 At $6s^26p^5$	86 Rn $6s^26p^6$
7	87 Fr $7s^1$	88 Ra $7s^2$	103 Lr $5f^{14}6d^17s^2$	104 Rf $6d^27s^2$	105 Db $6d^37s^2$	106 Sg $6d^47s^2$	107 Bh $6d^57s^2$	108 Hs $6d^67s^2$	109 Mt $6d^77s^2$	110 Uun $6d^87s^2$	111 Rg $6d^97s^2$	112 Uub $6d^{10}7s^2$	113 Uut $7s^27p^1$	114 Uuq $7s^27p^2$	115 Uup $7s^27p^3$	116 Uuh $7s^27p^4$		118 Uuo $7s^27p^6$

Lanthanides	57 La $5d^16s^2$	58 Ce $4f^15d^16s^2$	59 Pr $4f^36s^2$	60 Nd $4f^46s^2$	61 Pm $4f^56s^2$	62 Sm $4f^66s^2$	63 Eu $4f^76s^2$	64 Gd $4f^75d^16s^2$	65 Tb $4f^96s^2$	66 Dy $4f^{10}6s^2$	67 Ho $4f^{11}6s^2$	68 Er $4f^{12}6s^2$	69 Tm $4f^{13}6s^2$	70 Yb $4f^{14}6s^2$
Actinides	89 Ac $6d^17s^2$	90 Th $6d^27s^2$	91 Pa $5f^26d^17s^2$	92 U $5f^36d^17s^2$	93 Np $5f^46d^17s^2$	94 Pu $5f^67s^2$	95 Am $5f^77s^2$	96 Cm $5f^76d^17s^2$	97 Bk $5f^97s^2$	98 Cf $5f^{10}7s^2$	99 Es $5f^{11}7s^2$	100 Fm $5f^{12}7s^2$	101 Md $5f^{13}7s^2$	102 No $5f^{14}7s^2$

Main-group elements | Transition metals | Inner transition metals

8.2 Building-Up Principle and the Periodic Table

- Exceptions to the Building-Up Principle

Cr **Z = 24**

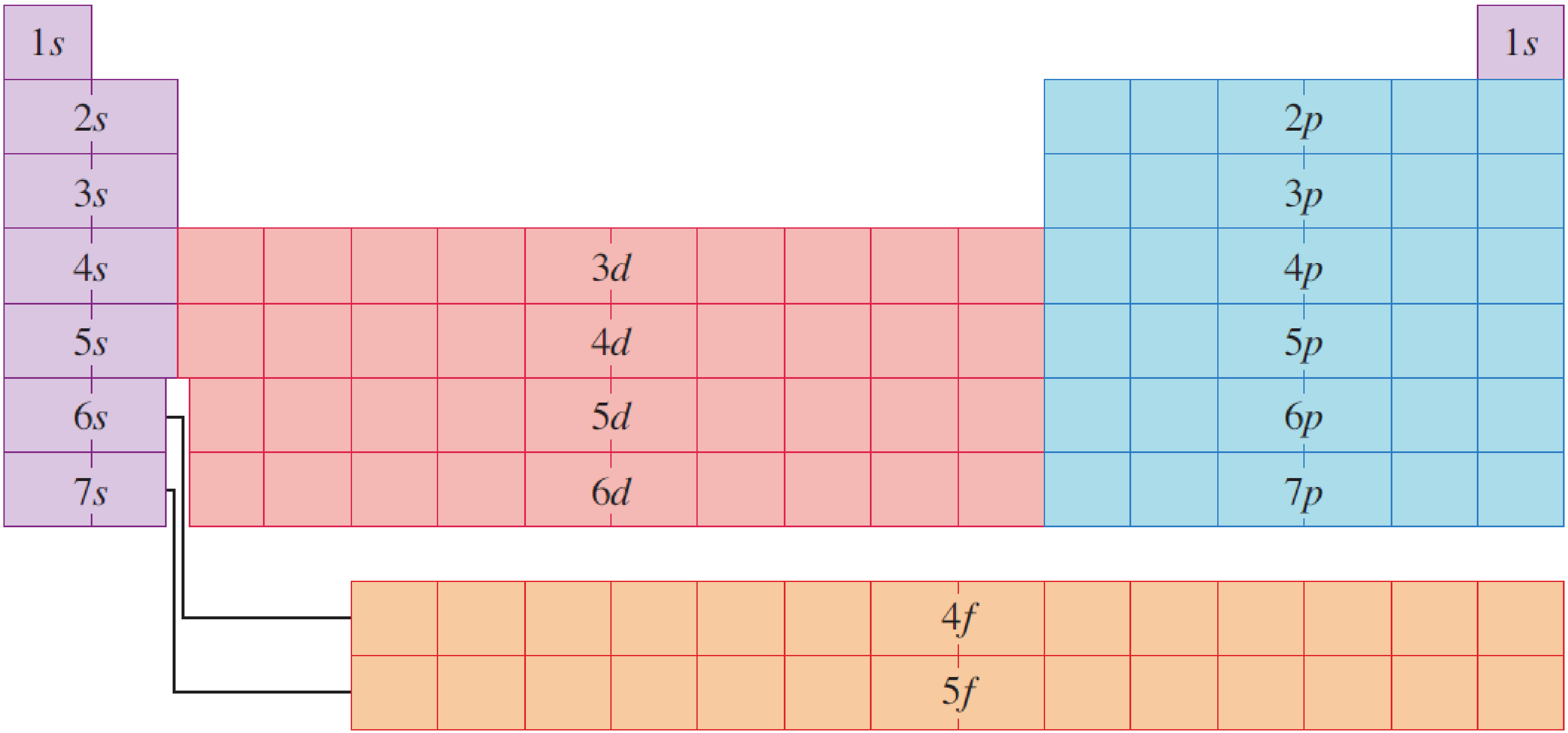
$[Ar]3d^5 4s^1$ instead of $[Ar]3d^4 4s^2$

Cu **Z = 29**

$[Ar]3d^{10} 4s^1$ instead of $[Ar]3d^9 4s^2$

8.3 Writing Electron Configurations Using the Periodic Table

- A periodic table illustrating the building-up order



P306 Example 8.2

Use the building-up principle to obtain the configuration for the ground state of the gallium atom (Z = 31). Give the configuration in complete form (do not abbreviate for the core). What is the valence-shell configuration? $\mathbf{4s^2 4p^1}$

8.3 Writing Electron Configurations Using the Periodic Table

- Determine the configuration of the outer electrons from the position of the element in the periodic table
- Example: valence-shell configuration $ns^a np^b$
- n = the principal quantum number of the outer shell
- = the period number for the element
- The total number of valence electrons, which equals a + b, can be obtained from the group number.

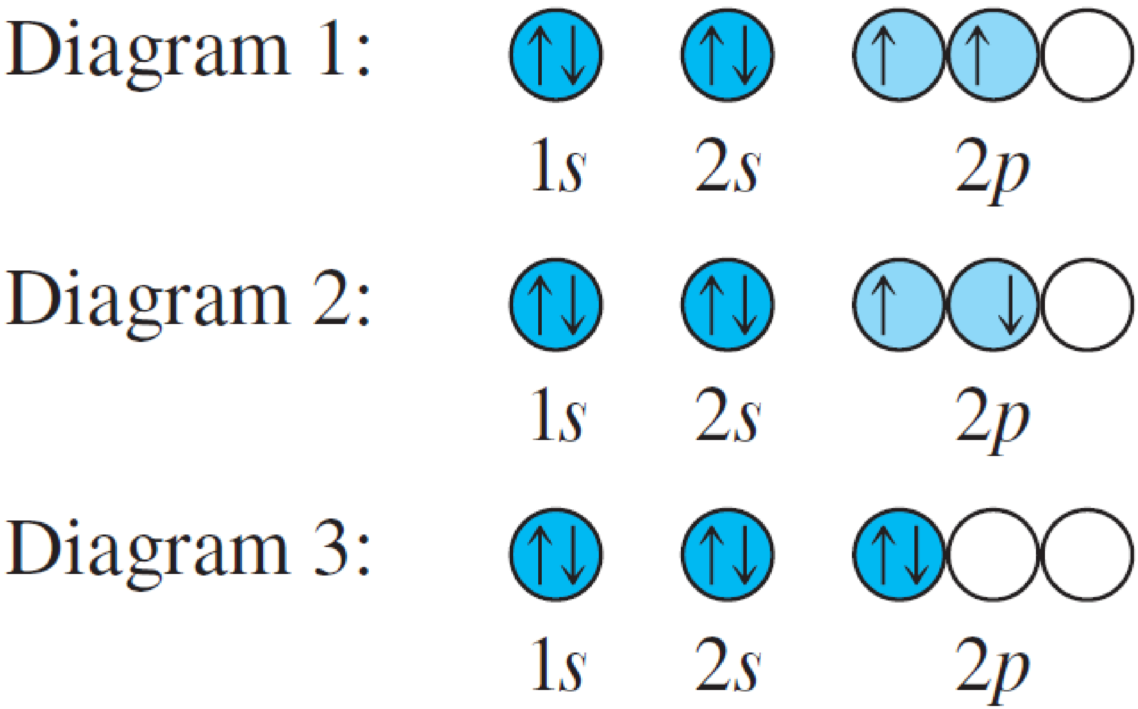
P307 Example 8.3

What are the configurations for the outer electrons of a. tellurium, $Z = 52$, and b. nickel, $Z = 28$?

$\mathbf{5}\boldsymbol{s}^{\mathbf{2}}\mathbf{5}\boldsymbol{p}^{\mathbf{4}}$ $\mathbf{3}\boldsymbol{d}^{\mathbf{8}}\mathbf{4}\boldsymbol{s}^{\mathbf{2}}$

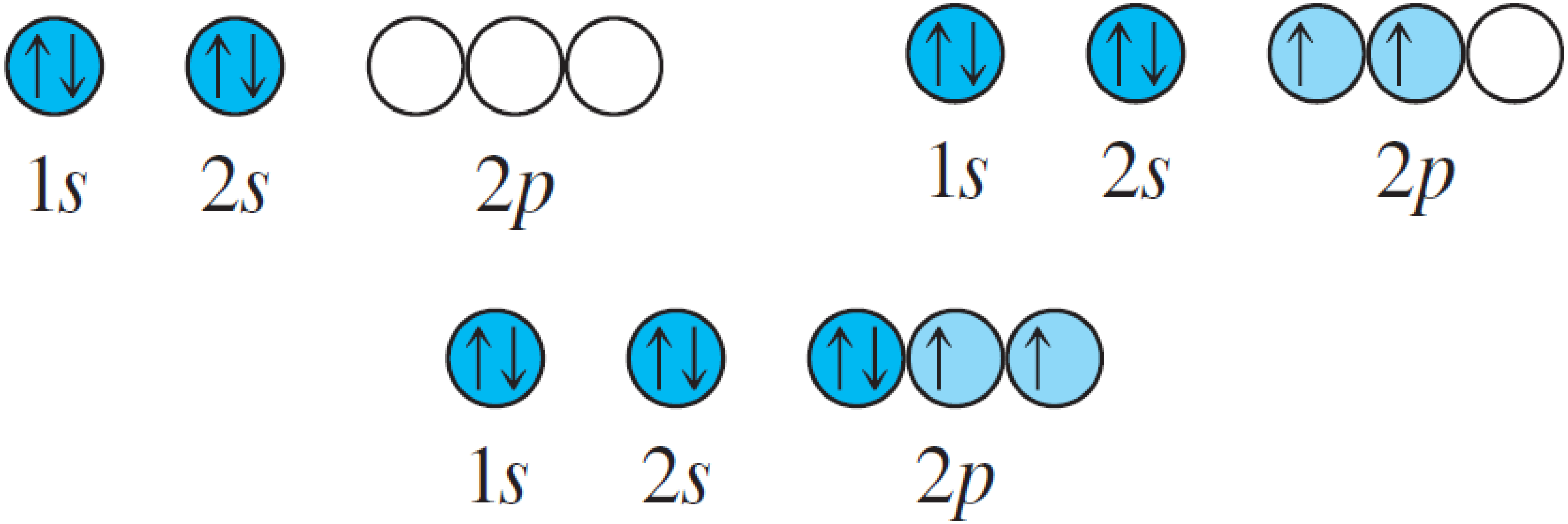
8.4 Orbital Diagrams of Atoms; Hund's Rule

- Electron configuration



8.4 Orbital Diagrams of Atoms; Hund's Rule

- Hund's Rule: the lowest-energy arrangement of electrons in a subshell is obtained by putting electrons in separate orbitals of the shell with the same spin before paring electrons.



8.4 Orbital Diagrams of Atoms; Hund's Rule

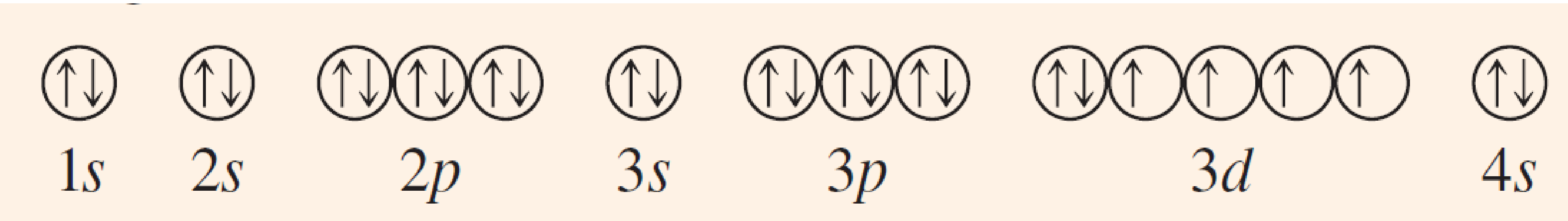
- Hund's Rule

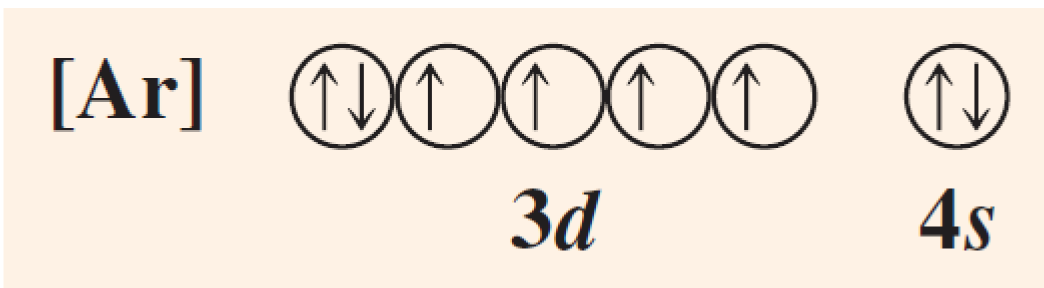
Table 8.2 Orbital Diagrams for the Ground States of Atoms from $Z = 1$ to $Z = 10$

			Orbital Diagram		
Atom	Z	Configuration	$1s$	$2s$	$2p$
Hydrogen	1	$1s^1$	(↑)	( )	( )( )( )
Helium	2	$1s^2$	(↑↓)	( )	( )( )( )
Lithium	3	$1s^2 2s^1$	(↑↓)	(↑)	( )( )( )
Beryllium	4	$1s^2 2s^2$	(↑↓)	(↑↓)	( )( )( )
Boron	5	$1s^2 2s^2 2p^1$	(↑↓)	(↑↓)	(↑)( )( )
Carbon	6	$1s^2 2s^2 2p^2$	(↑↓)	(↑↓)	(↑)(↑)( )
Nitrogen	7	$1s^2 2s^2 2p^3$	(↑↓)	(↑↓)	(↑)(↑)(↑)
Oxygen	8	$1s^2 2s^2 2p^4$	(↑↓)	(↑↓)	(↑↓)(↑)(↑)
Fluorine	9	$1s^2 2s^2 2p^5$	(↑↓)	(↑↓)	(↑↓)(↑↓)(↑)
Neon	10	$1s^2 2s^2 2p^6$	(↑↓)	(↑↓)	(↑↓)(↑↓)(↑↓)

P309 Example 8.4

Write an orbital diagram for the ground state of the iron atom.





8.4 Orbital Diagrams of Atoms; Hund's Rule

- Magnetic Properties of Atoms
- an atom with unpaired electrons does exhibit a net magnetism.
- paramagnetic substance: a substance that is weakly attracted by a magnetic field, and this attraction is generally the result of unpaired electrons.

8.4 Orbital Diagrams of Atoms; Hund's Rule

- Magnetic Properties of Atoms
- diamagnetic substance: a substance that is not attracted by a magnetic field or is very slightly repelled by such a field. This property generally means that the substance has only paired electrons.

8.5 Mendeleev’s Predictions from the Periodic Table

- Mendeleev’s periodic table

Tabelle II.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^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=85	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	—	— — — —

8.5 Mendeleev's Predictions from the Periodic Table

- Mendeleev's periodic table

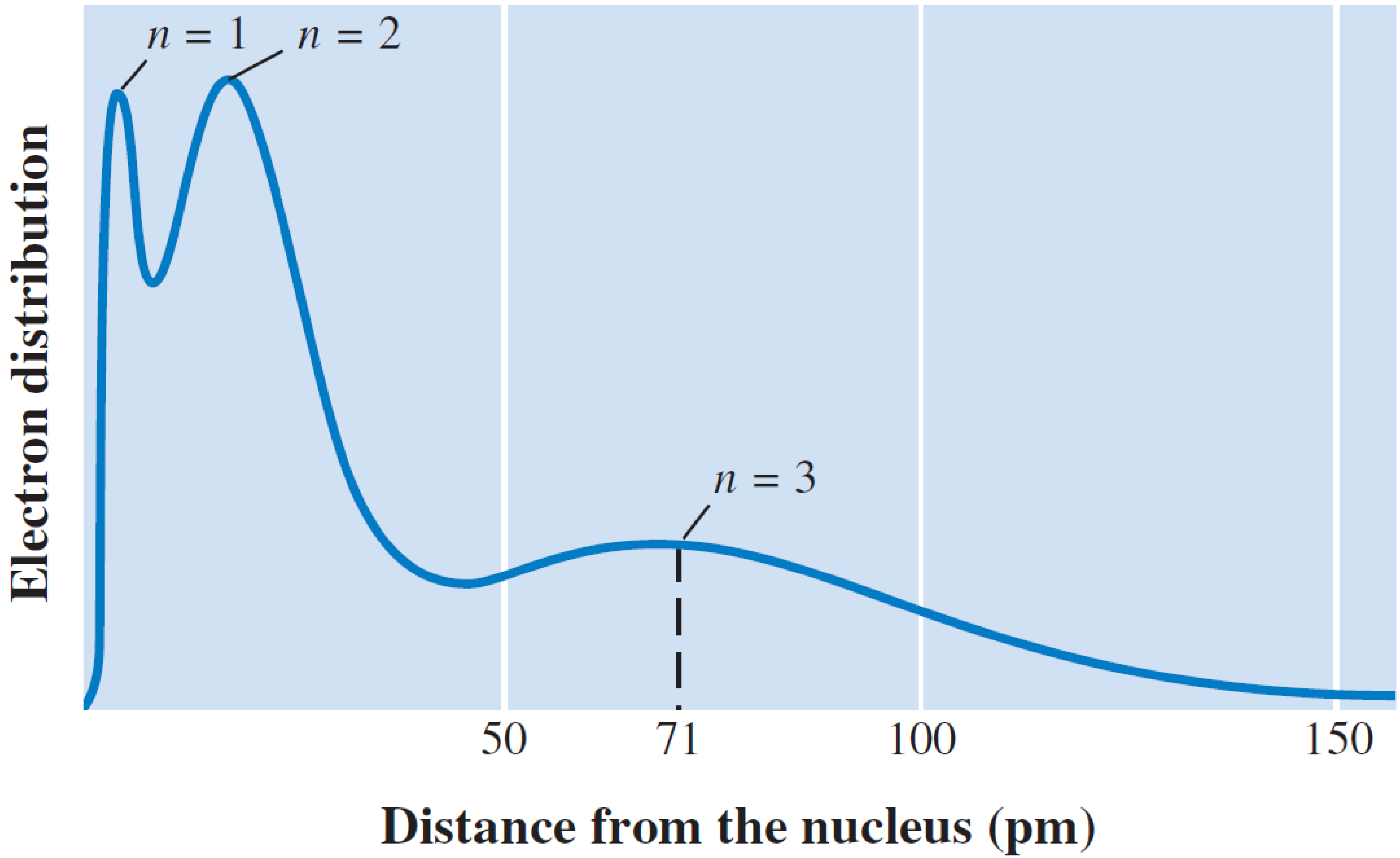
Property	***Predicted for Eka-Aluminum***	***Found for Gallium***
Atomic weight	68 amu	69.7 amu
Formula of oxide	Ea_2O_3	Ga_2O_3
Density of the element	5.9 g/cm^3	5.91 g/cm^3
Melting point of the element	Low	30.1°C
Boiling point of the element	High	1983°C

8.6 Some Periodic Properties

- Periodic law: when the elements are arranged by atomic number, their physical and chemical properties vary periodically.
- Some Periodic Properties
  - Atom Radius
  - Ionization Energy
  - Electron Affinity

8.6 Some Periodic Properties

- Atom Radius



8.6 Some Periodic Properties

- Atom Radius
- Covalent radii: obtained from measurements of distances between the nuclei of atoms in the chemical bonds of molecular substances.

8.6 Some Periodic Properties

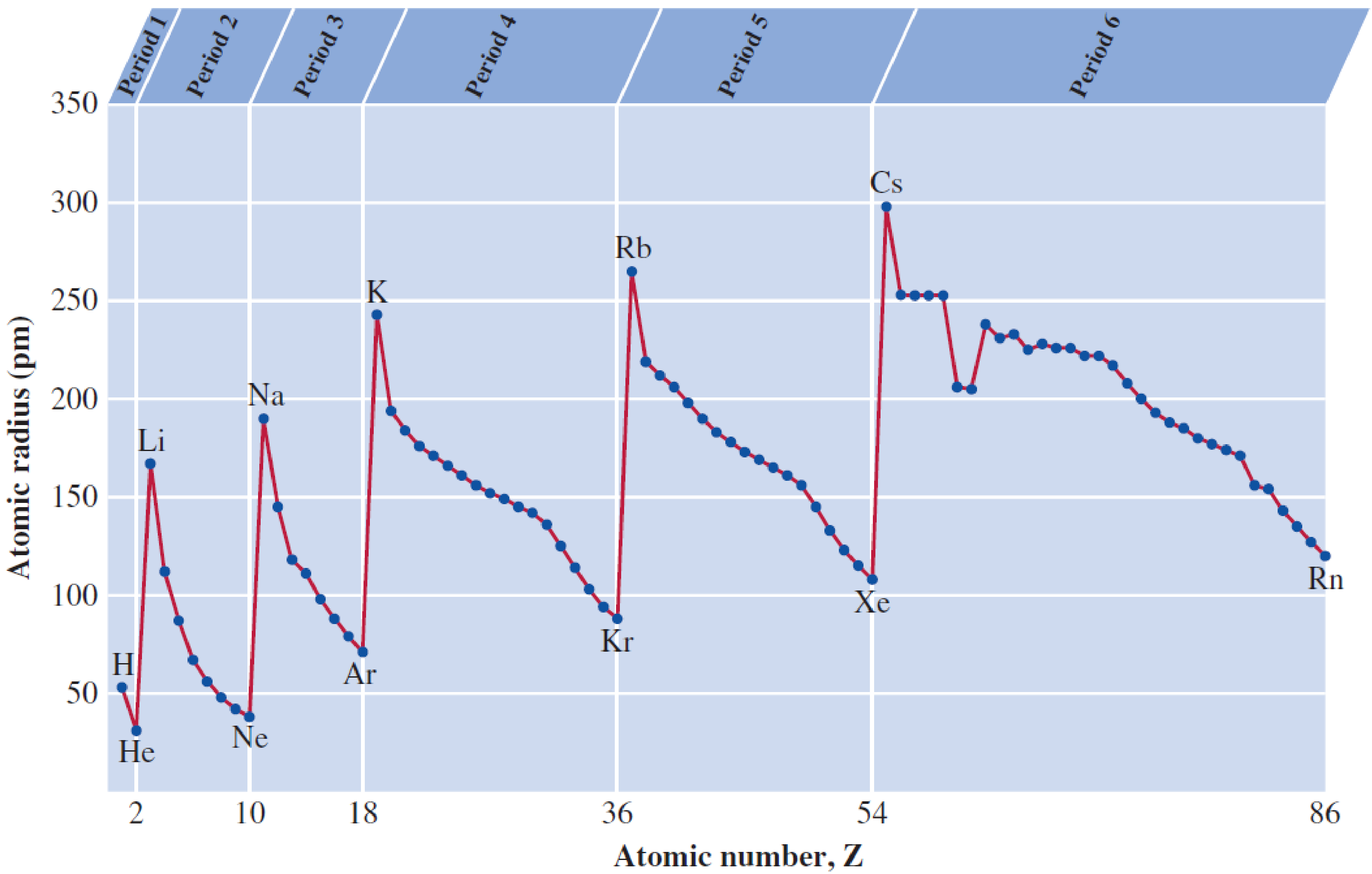
- Atom Radius-General trends:
- 1) Within each period (horizontal row), the atomic radius tends to decrease with increasing atomic number (nuclear charge). The largest atom in a period is a Group IA atom and the smallest is a noble-gas atom. Because effective nuclear charge increases.

8.6 Some Periodic Properties

- Atom Radius-General trends:
- Effective nuclear charge: the positive charge that an electron experiences from the nucleus, equal to the nuclear charge but reduced by any shielding or screening from any intervening electron distribution.

8.6 Some Periodic Properties

- General trends:



P314 Example 8.5

Refer to a periodic table and use the trends noted for size of atomic radii to arrange the following in order of increasing atomic radius: Al, C, Si.

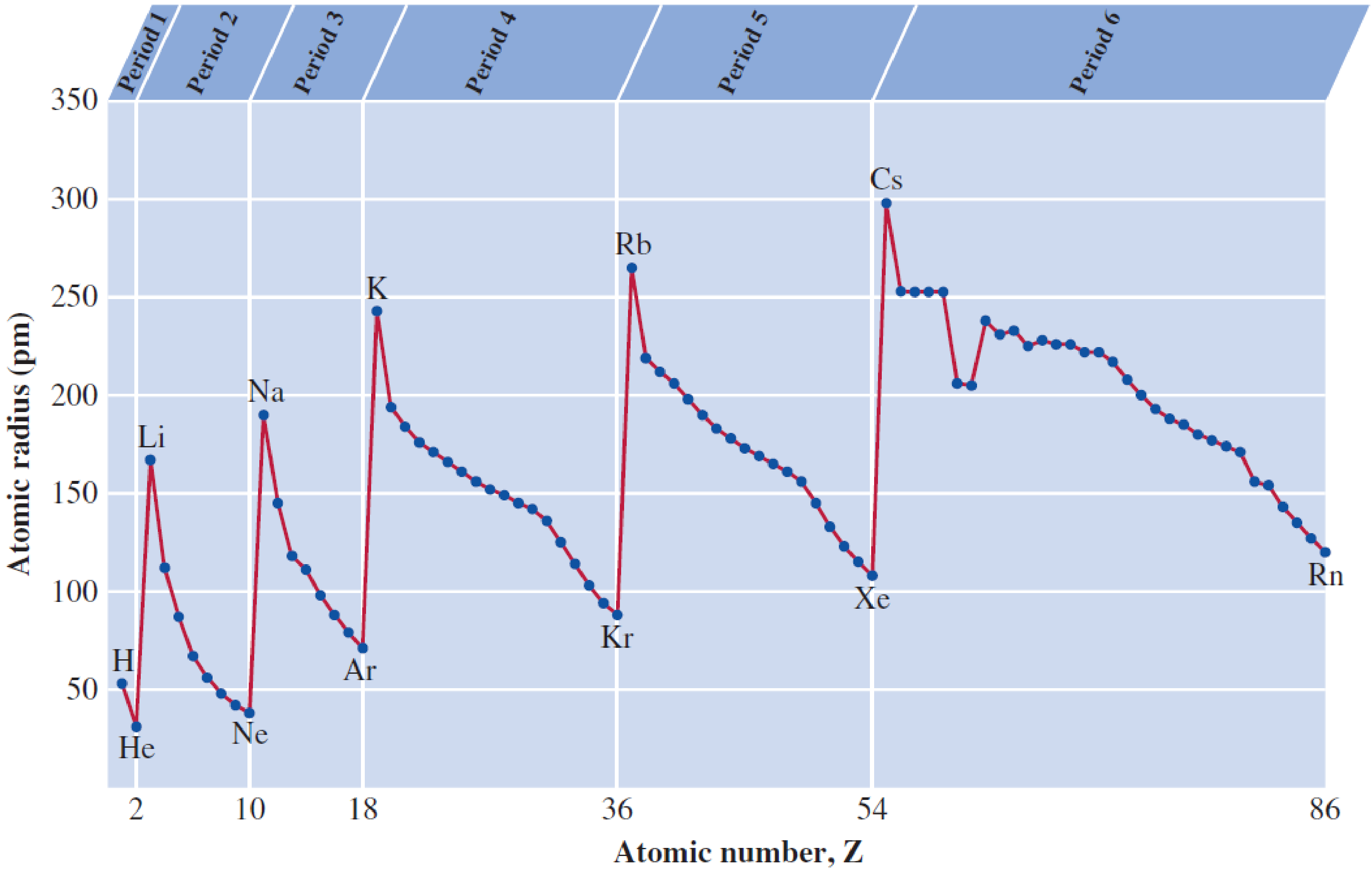
C < Si < Al

8.6 Some Periodic Properties

- Atom Radius-General trends:
- 1) Within each period (horizontal row)…
- 2) Within each group (vertical column), the atomic radius tends to increase with the period number. Because the principal quantum number *n* increases.

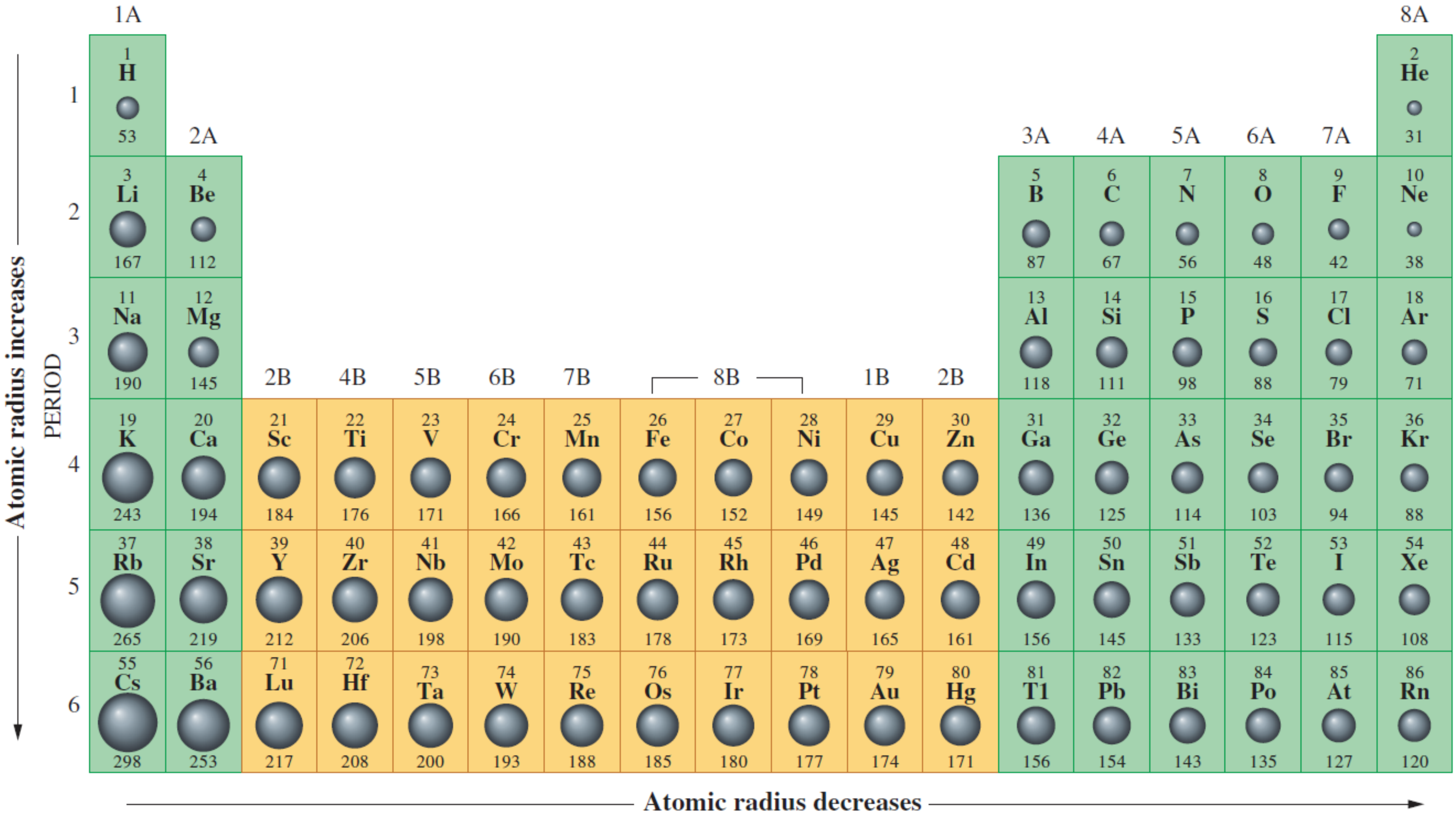
8.6 Some Periodic Properties

- General trends:



8.6 Some Periodic Properties

- General trends:



8.6 Some Periodic Properties

- Ionization Energy 电离能
- First ionization energy: the minimum energy needed to remove the highest-energy (that is, the outermost) electron from the neutral atom in the gaseous state.

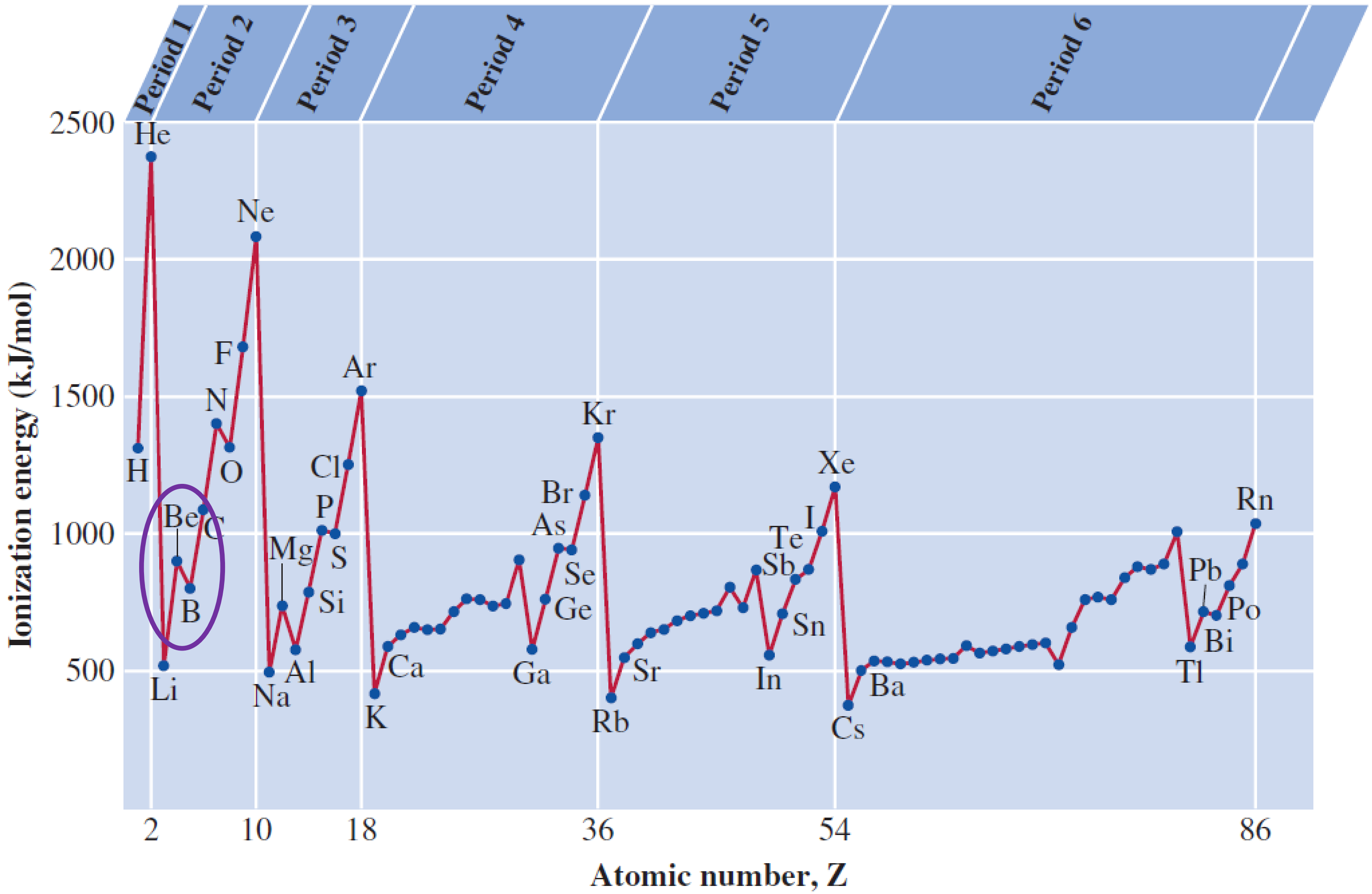
吸热过程。

$$\mathrm{Li}(1s^2 2s^1) \longrightarrow \mathrm{Li}^+(1s^2) + e^-$$

- The ionization energy of the lithium atom is 520 kJ/mol.

8.6 Some Periodic Properties

- Ionization Energy 电离能越大，过程越难



P316 Example 8.6

Using a periodic table only, arrange the following elements in order of increasing ionization energy: Ar, Se, S.

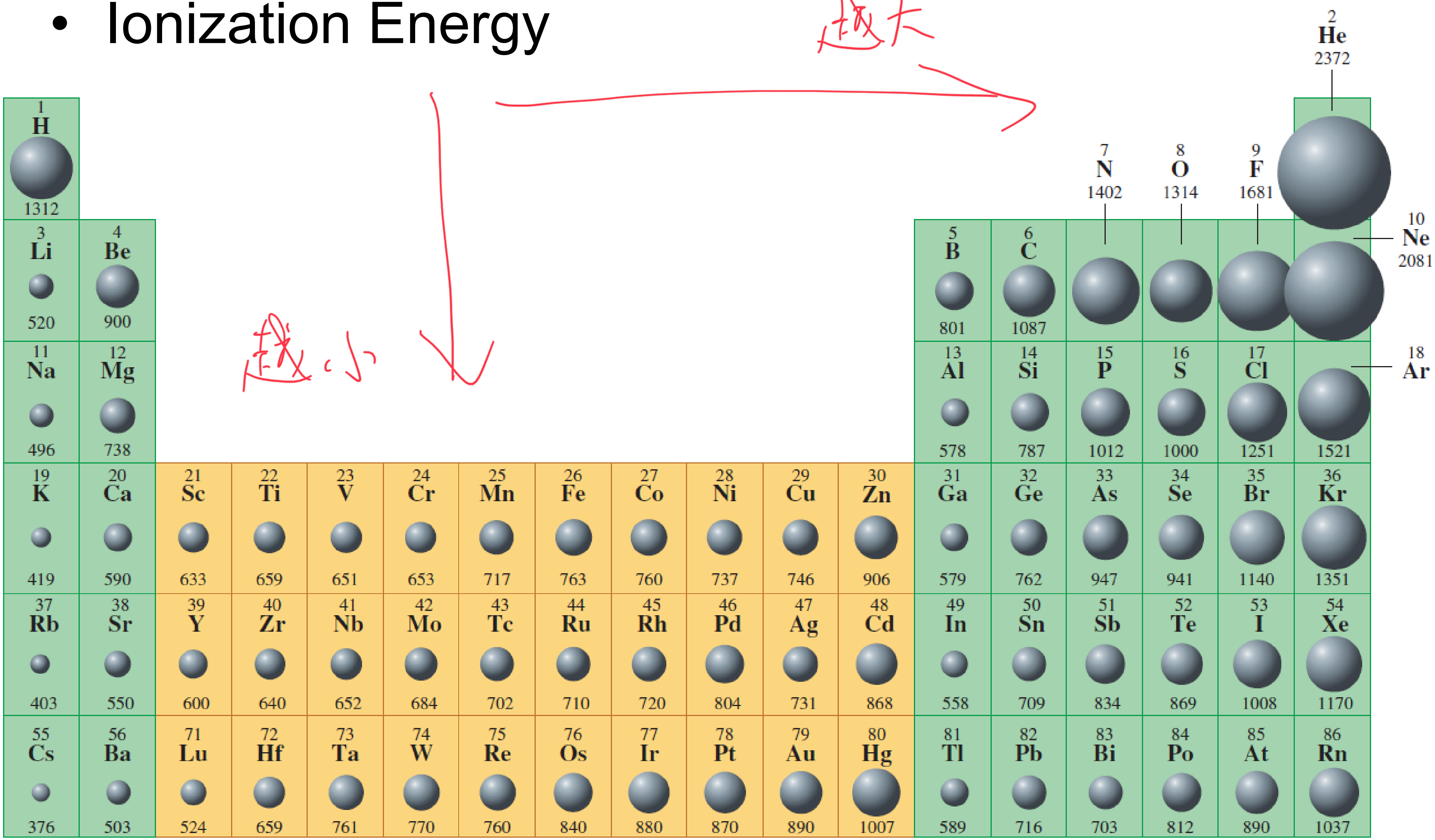
Se < S < Ar

8.6 Some Periodic Properties

- Ionization Energy

越大

越小



8.6 Some Periodic Properties

- Ionization Energy

M^+ M^{2+} M^{3+} M^{4+}

Table 8.3 Successive Ionization Energies of the First Ten Elements (kJ/mol)*

Element	First	Second	Third	Fourth	Fifth	Sixth	Seventh
H	1312						
He	2372	5250					
Li	520	7298	11,815				
Be	900	1757	14,848	21,006			
B	801	2427	3660	25,026	32,827		
C	1086	2353	4620	6223	37,831	47,277	
N	1402	2856	4578	7475	9445	53,267	64,360
O	1314	3388	5300	7469	10,990	13,326	71,330
F	1681	3374	6050	8408	11,023	15,164	17,868
Ne	2081	3952	6122	9371	12,177	15,238	19,999

*Ionization energies to the right of a vertical line correspond to removal of electrons from the core of the atom.

8.6 Some Periodic Properties

亲电能

- Electron Affinity: the energy change for the process of adding an electron to a neutral atom in the gaseous state to form a negative ion.

kJ/mol

$$Cl([Ne]3s^23p^5) + e^- \longrightarrow Cl^-([Ne]3s^23p^6);$$

Electron affinity = -349 kJ/mol

放热

越大，加电能力越大

8.6 Some Periodic Properties

- Electron Affinity

电负性 electron negativity

- the general trend is toward more negative electron affinities from left to right in any period.

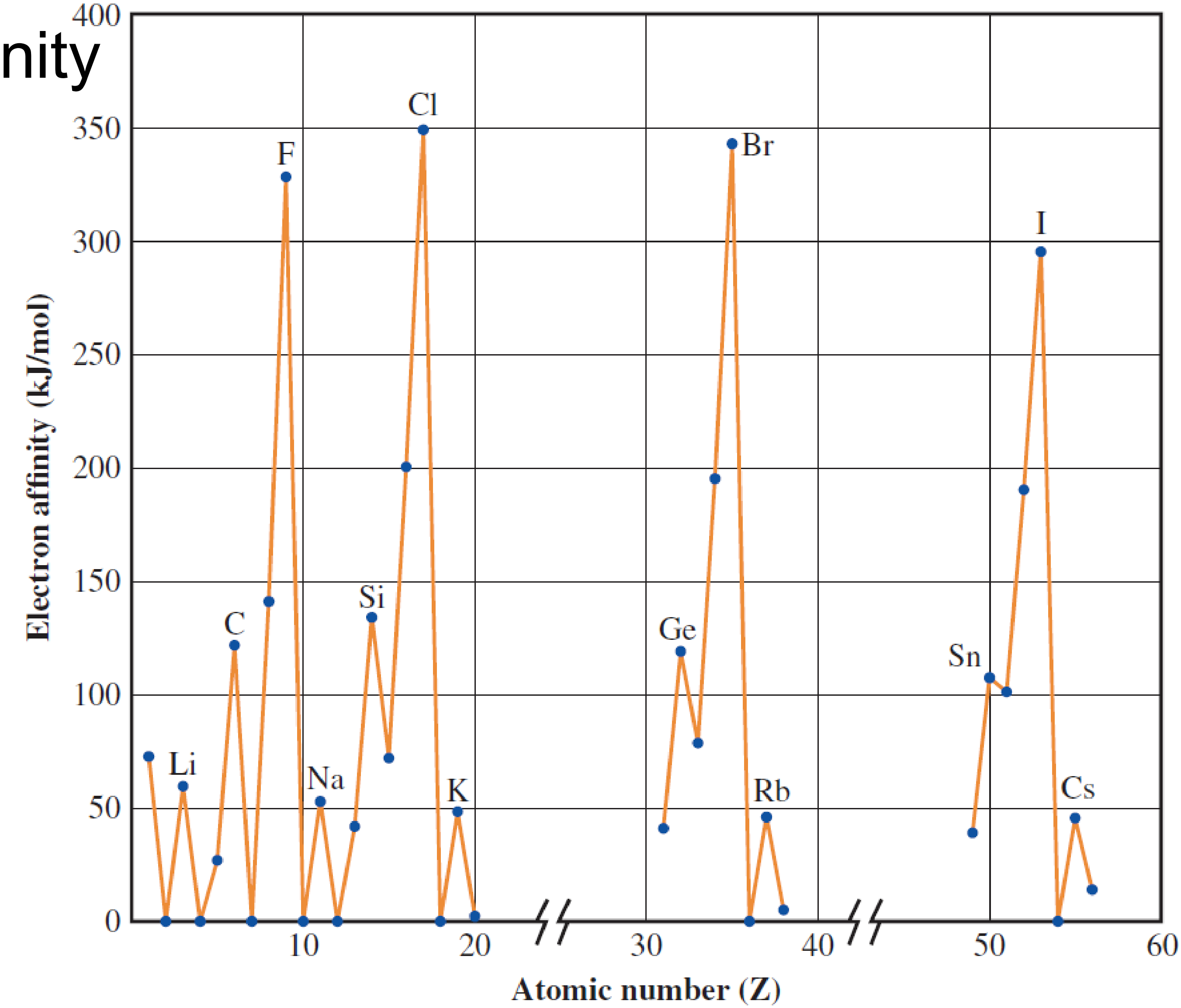
最大，吸引电子能力强

Table 8.4 Electron Affinities of the Main-Group Elements (kJ/mol)

Period	1A	2A	3A	4A	5A	6A	7A	8A
1	H 73							He ≤0
2	Li 60	Be ≤0	B 27	C 122	N ≤0	O 141	F 328	Ne ≤0
3	Na 53	Mg ≤0	Al 44	Si 134	P 72	S 200	Cl 349	Ar ≤0
4	K 48	Ca 2	Ga 41	Ge 119	As 78	Se 195	Br 325	Kr ≤0
5	Rb 47	Sr 5	In 37	Sn 107	Sb 101	Te 190	I 295	Xe ≤0
6	Cs 46	Ba 14	Tl 36	Pb 35	Bi 91	Po 180	At 270	Rn ≤0

8.6 Some Periodic Properties

Electron Affinity



8.6 Some Periodic Properties

- Electron Affinity

$$K([Ar]4s^1) + e^- \longrightarrow K^-([Ar]4s^2);\ \Delta E = -48\ \text{kJ/mol}$$

$$Ca([Ar]4s^2) + e^- \longrightarrow Ca^-([Ar]4s^24p^1);\ \Delta E = -2\ \text{kJ/mol}$$

$$Ga([Ar]4s^24p^1) + e^- \longrightarrow Ga^-([Ar]4s^24p^2);\ \Delta E = -41\ \text{kJ/mol}\ ($$

$$Ge([Ar]4s^24p^2) + e^- \longrightarrow Ge^-([Ar]4s^24p^3);\ \Delta E = -119\ \text{kJ/mol}$$

$$As([Ar]4s^24p^3) + e^- \longrightarrow As^-([Ar]4s^24p^4);\ \Delta E = -78\ \text{kJ/mol}\ ($$

$$Se([Ar]4s^24p^4) + e^- \longrightarrow Se^-([Ar]4s^24p^5);\ \Delta E = -195\ \text{kJ/mol}$$

$$Br([Ar]4s^24p^5) + e^- \longrightarrow Br^-([Ar]4s^24p^6);\ \Delta E = -325\ \text{kJ/mol}$$

8.7 Periodicity in the Main-Group Elements

- Move left to right in any row of the periodic table, the metallic character of the elements decreases
- Progress down a column, the elements tend to increase in metallic character
- Elements with low ionization energy tend to be metallic, whereas those with high ionization energy tend to be nonmetallic.

8.7 Periodicity in the Main-Group Elements

- basic oxide – most metal oxides
- acidic oxide – most nonmetal oxides
- amphoteric oxide

Hydrogen ($1s^1$)

Considered as belonging in a group by itself

a colorless gas composed of H_2 molecules

8.7 Periodicity in the Main-Group Elements

- **Group IA Elements, the Alkali Metals (*ns*^{1})** Na在水中反应
- The alkali metals are soft and reactive, with the reactivities increasing as you move down the column of elements.
  碱金属
- All of the metals react with water to produce hydrogen.

$$2\text{Li}(s) + 2\text{H}_2\text{O}(l) \longrightarrow 2\text{LiOH}(aq) + \text{H}_2(g)$$

8.7 Periodicity in the Main-Group Elements

- **Group IA Elements, the Alkali Metals (*ns*^{1})**
- The vigor of the reaction increases from lithium (moderate) to rubidium (violent).
- All of the alkali metals form basic oxides with the general formula R_2O.

8.7 Periodicity in the Main-Group Elements

- **Group IIA Elements, the Alkaline Earth Metals (*ns*^{2})**
- The alkaline earth metals are also chemically reactive but much less so than the alkali metals.
- Reactivities increase going down the group.
- The alkaline earth metals form basic oxides with the general formula RO.

8.7 Periodicity in the Main-Group Elements

- **Group IIIA Elements (*ns^2np^1*)**
- The first Group IIIA element, boron, is a metalloid.
- Other elements in this group—aluminum, gallium, indium, and thallium are metals.
- Boron oxide, B_2O_3, is an acidic oxide.
- aluminum oxide, Al_2O_3, and gallium oxide, Ga_2O_3, are amphoteric oxides.

8.7 Periodicity in the Main-Group Elements

- **Group IVA Elements (*ns^2np^2*)**
- C nonmetal
- Si & Ge metalloid
- Sn & Pd metal
- CO_2 acidic, gas
- SiO_2 acidic, particles of quartz
- GeO_2 acidic
- SnO_2 & PdO_2 amphoteric

8.7 Periodicity in the Main-Group Elements

- **Group VA Elements (*ns^2np^3*)**
- N & P nonmetal
- As & Sb metalloid
- Bi metal
- N_2O_3, N_2O_5, P_4O_6, P_4O_{10}, As_2O_3, As_2O_5 acidic
- Sb_2O_3, Sb_2O_5 amphoteric
- Bi_2O_3 basic

8.7 Periodicity in the Main-Group Elements

- **Group VIA Elements, the Chalcogens (ns^2np^4)**
- O, S, Se nonmetal
- Te metalloid
- Po metal
- Exist as O_2, O_3, S_8
- Sulfur, selenium, and tellurium form oxides with the formulas RO_2 and RO_3

8.7 Periodicity in the Main-Group Elements

- **Group VIIA Elements, the Halogens (*ns^2np^5*)**
- F_2, Cl_2, Br_2, I_2

8.7 Periodicity in the Main-Group Elements

- **Group VIIIA Elements, the Noble Gases (*ns^2np^6*)**
- Exist as gases consisting of uncombined atoms
- Known as the noble gases because of their relative unreactivity