

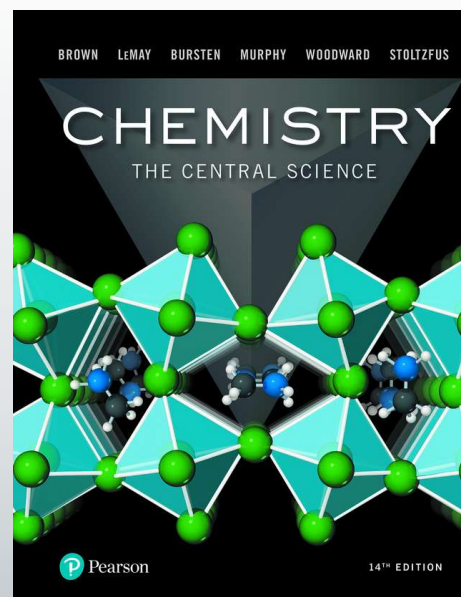
# Chapter 7

## Periodic Properties of the Elements

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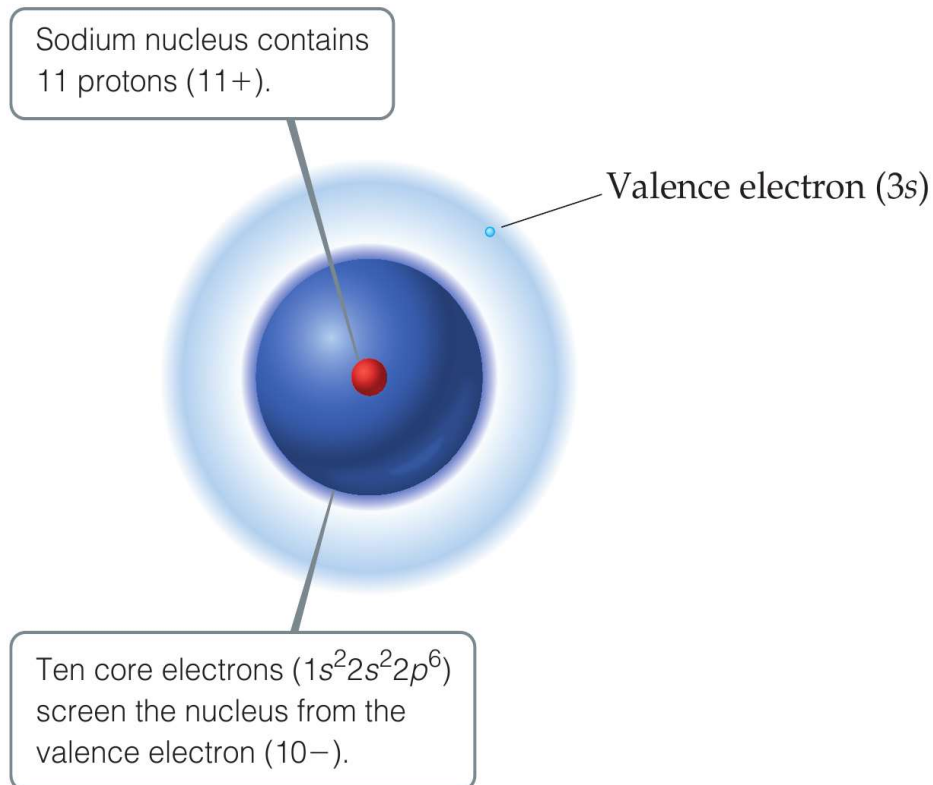
## 7.2 Effective Nuclear Charge

- ❖ The attractive force between an electron and the nucleus increases as the nuclear charge increases and decreases as the electron moves farther from the nucleus.
- ❖ In a many-electron atom, in addition to the attraction of each electron to the nucleus, each electron experiences the repulsion due to other electrons.
- ❖ Each electron in a many-electron atom is **screened** from the nucleus by the other electrons.
- ❖ The partially screened nuclear charge is called the **effective nuclear charge**,  $Z_{\text{eff}}$ .

## 7.2 Effective Nuclear Charge

- ❖ The amount of screening of the actual nuclear charge ( $Z$ ) is defined by using a **screening constant** ( $S$ ), a positive number, such that

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



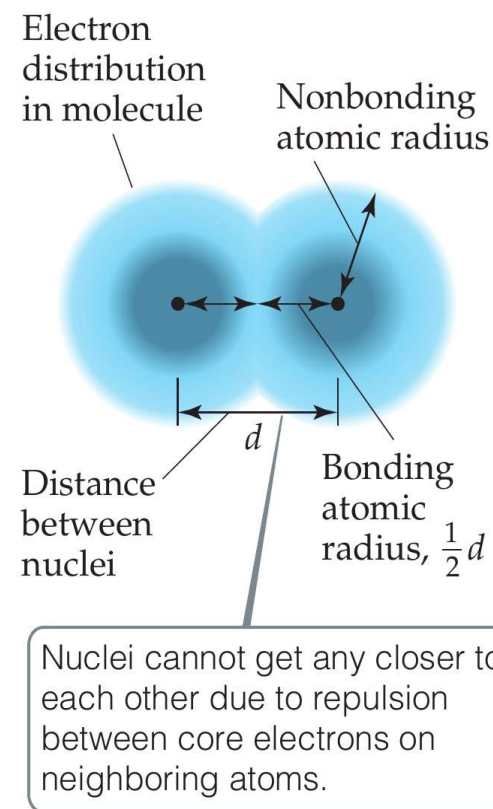
$$Z_{\text{eff}} = 11 - 10 = 1$$

## 7.2 Effective Nuclear Charge

- ❖ The notion of effective nuclear charge also explains an important effect: For a many-electron atom, the energies of orbitals with the same  $n$  value increase with increasing  $l$  value (i. e.,  $ns < np < nd$ ).
- ❖ The effective nuclear charge **increases** from **left to right** across any period of the periodic table.
- ❖ The effective nuclear charge **increases slightly** as we go down a column because the more diffuse core electron cloud is less able to screen the valence electrons from the nuclear charge.

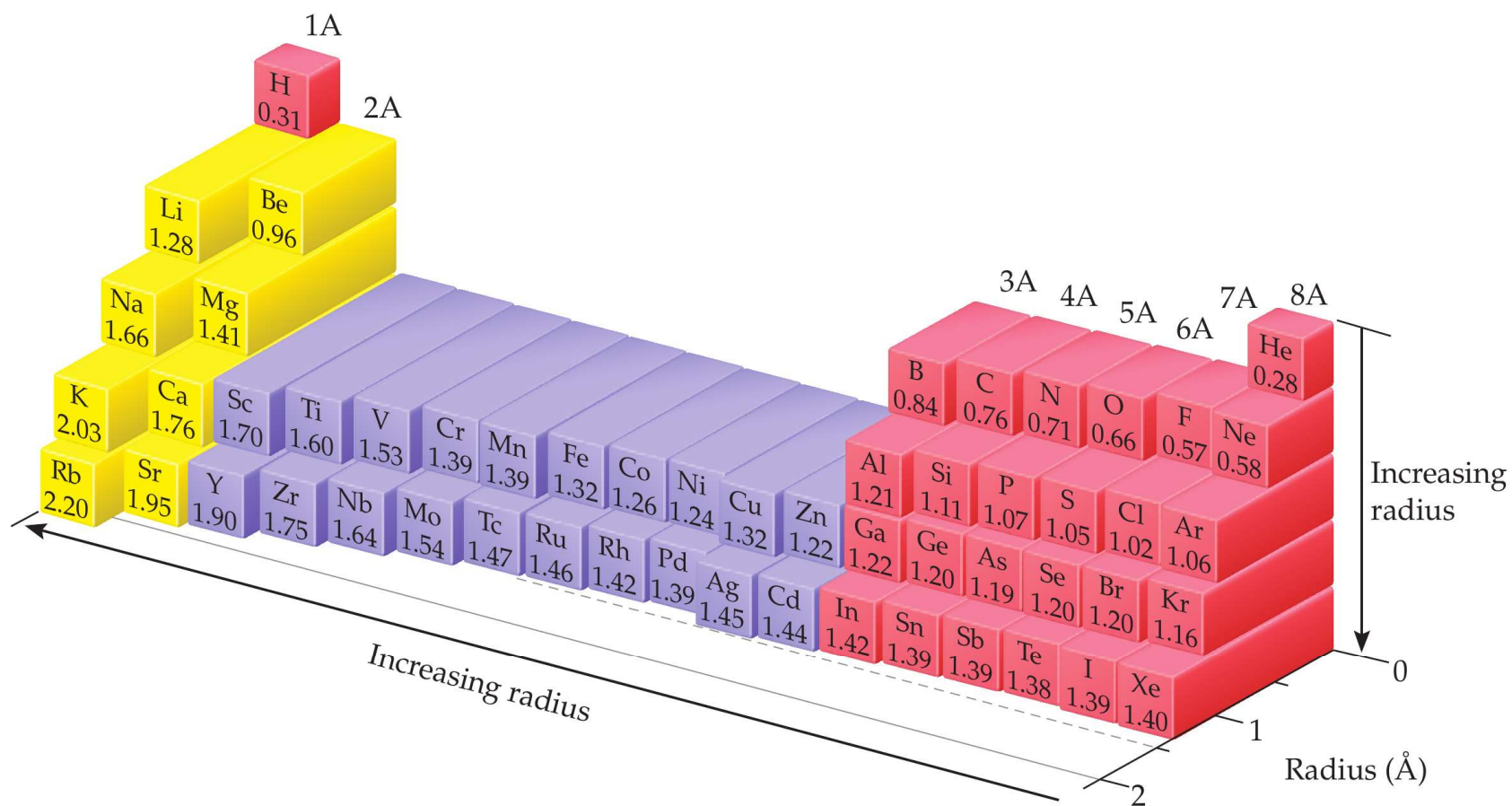
## 7.3 Sizes of Atoms and Ions

- ❖ According to the quantum-mechanical model, atoms do not have sharply defined boundaries at which the electron distribution becomes zero.
- ❖ The radius of an atom is called the **nonbonding atomic radius** or the **van der Waals radius**.
- ❖ The **bonding atomic radius** (also known as the **covalent radius**) for any atom in a molecule is equal to half of the bond distance  $d$ .



▲ **Figure 7.6** Distinction between nonbonding and bonding atomic radii within a molecule.

## 7.3 Sizes of Atoms and Ions



▲ **Figure 7.7** Trends in bonding atomic radii for periods 1 through 5.

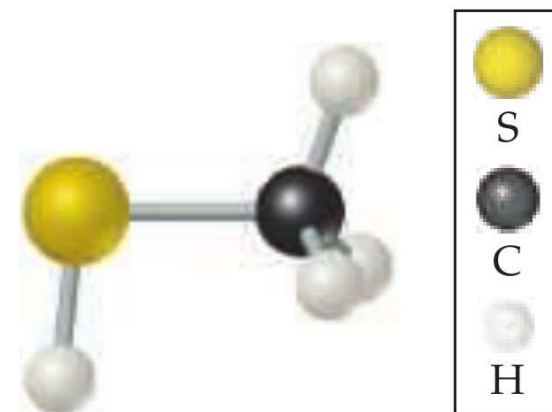
## Sample Exercise 7.1

Natural gas used in home heating and cooking is odorless. Because natural gas leaks pose the danger of explosion or suffocation, various smelly substances are added to the gas to allow detection of a leak. One such substance is methyl mercaptan,  $\text{CH}_3\text{SH}$ . Use Figure 7.7 to predict the lengths of the C–S, C–H, and S–H bonds in this molecule.

$$\text{Bond length C} - \text{S} = 0.76 + 1.05 = 1.81 \text{ \AA}$$

$$\text{Bond length C} - \text{H} = 0.76 + 0.31 = 1.07 \text{ \AA}$$

$$\text{Bond length S} - \text{H} = 1.05 + 0.31 = 1.36 \text{ \AA}$$



Methyl mercaptan

## 7.3 Sizes of Atoms and Ions

### Periodic Trends in Atomic Radii

- ❖ Within each group, bonding atomic radius tends to **increase** from top to bottom: This trend results primarily from the increase in the principal quantum number ( $n$ ) of the outer electrons.
- ❖ Within each period, bonding atomic radius tends to **decrease** from left to right: The major factor influencing this trend is the increase in effective nuclear charge  $Z_{\text{eff}}$  across a period. The increasing effective nuclear charge steadily draws the valence electrons closer to the nucleus, causing the bonding atomic radius to decrease.



## Sample Exercise 7.2

Referring to the periodic table, arrange (as much as possible) the atoms B, C, Al, and Si in order of increasing size.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602																
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182																
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305																
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293
55 <b>Cs</b> Cesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71 <b>Lanthanides</b>	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103 <b>Actinides</b>	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.5	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

➤  $C < B \sim Si < Al$

## Sample Exercise 7.2: Practice Exercise 1

By referring to the periodic table, place the following atoms in order of increasing bonding atomic radius: N, O, P, Ge.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602	<div><div>Atomic Name Weight</div><div><div>C Solid</div><div>Hg Liquid</div><div>H Gas</div><div>Rf Unknown</div></div></div>																273	<b>He</b> Helium 4.002602
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182	<div><div>Metalloids</div><div>Other nonmetals</div><div>Halogens</div><div>Noble gases</div></div>																	
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305	<div><div>Metals</div><div>Alkali metals</div><div>Alkaline earth metals</div><div>Lanthanoids</div><div>Actinoids</div><div>Transition metals</div><div>Post-transition metals</div></div>																	
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798		
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293		
55 <b>Cs</b> Cesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)		
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)		
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																			
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89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)					

➤  $O < N < P < Ge$

## 7.3 Sizes of Atoms and Ions

### Periodic Trends in Ionic Radii

- ❖ When a cation is formed the number of electron–electron repulsions is reduced; therefore, cations are **smaller** than their parent atoms.
- ❖ When electrons are added to an atom to form an anion, the increased electron–electron repulsions cause the electrons to spread out more in space; thus, anions are **larger** than their parent atoms.
- ❖ For ions carrying the same charge, ionic radius increases as we move down a column in the periodic table.

## Sample Exercise 7.3

Arrange  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ , and  $\text{Ca}$  in order of decreasing radius.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602																
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182																
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305																
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37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293
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87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103 <b>Actinoids</b>	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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➤  $\text{Ca} > \text{Ca}^{2+} > \text{Mg}^{2+}$



## Sample Exercise 7.3: Practice Exercise 1

Arrange the following atoms and ions in order of increasing ionic radius: F, S<sup>2-</sup>, Cl, and Se<sup>2-</sup>.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602	<div><div>Atomic Sym</div><div><div>C Solid</div><div>Hg Liquid</div><div>H Gas</div><div>Rf Unknown</div></div></div>																273	<b>He</b> Helium 4.002602
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182	<div><div>Metalloids</div><div>Other nonmetals</div><div>Halogens</div><div>Noble gases</div></div>																	
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305	<div><div>Metals</div><div>Alkali metals</div><div>Alkaline earth metals</div><div>Lanthanoids</div><div>Actinoids</div><div>Transition metals</div><div>Post-transition metals</div></div>																	
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798		
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293		
55 <b>Cs</b> Cesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)		
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)		
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																			
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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.5	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668					
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)					

➤ F < Cl < S<sup>2-</sup> < Se<sup>2-</sup>

## 7.3 Sizes of Atoms and Ions

- ❖ An **isoelectronic series** is a group of ions all containing the same number of electrons.
- ❖ In any isoelectronic series, because the number of electrons remains constant, ionic radius decreases with increasing nuclear charge as the electrons are more strongly attracted to the nucleus:

Increasing nuclear charge →				
8 protons	9 protons	11 protons	12 protons	13 protons
10 electrons	10 electrons	10 electrons	10 electrons	10 electrons
$\text{O}^{2-}$	$\text{F}^{-}$	$\text{Na}^{+}$	$\text{Mg}^{2+}$	$\text{Al}^{3+}$
1.26 Å	1.19 Å	1.16 Å	0.86 Å	0.68 Å
Decreasing ionic radius →				

## Sample Exercise 7.4

Arrange the ions  $K^+$ ,  $Cl^-$ ,  $Ca^{2+}$ , and  $S^{2-}$  in order of decreasing size.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602	<div><div>Atomic Name Weight</div><div><div>C Solid</div><div>Hg Liquid</div><div>H Gas</div><div>Rf Unknown</div></div></div> <div><div>Metalloids</div><div>Other nonmetals</div><div>Halogens</div><div>Noble gases</div></div> <div><div>Metals</div><div>Alkali metals</div><div>Alkaline earth metals</div><div>Lanthanoids</div><div>Actinoids</div><div>Transition metals</div><div>Post-transition metals</div></div>																2 <b>He</b> Helium 4.002602
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182	5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.0107	7 <b>N</b> Nitrogen 14.0067	8 <b>O</b> Oxygen 15.9994	9 <b>F</b> Fluorine 18.9984032	10 <b>Ne</b> Neon 20.1797	11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305	13 <b>Al</b> Aluminum 26.9815386	14 <b>Si</b> Silicon 28.0855	15 <b>P</b> Phosphorus 30.973762	16 <b>S</b> Sulfur 32.065	17 <b>Cl</b> Chlorine 35.453	18 <b>Ar</b> Argon 39.948			
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798	
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293	
55 <b>Cs</b> Cesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)	
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)	

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.5	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

➤  $S^{2-} > Cl^- > K^+ > Ca^{2+}$



## Sample Exercise 7.4: Practice Exercise 1

Arrange the following ions in order of increasing ionic radius:  $\text{Br}^-$ ,  $\text{Rb}^+$ ,  $\text{Se}^{2-}$ ,  $\text{Sr}^{2+}$ ,  $\text{Te}^{2-}$ .

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602																
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182																
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305																
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293
55 <b>Cs</b> Cesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.5	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

➤  $\text{Sr}^{2+} < \text{Rb}^+ < \text{Br}^- < \text{Se}^{2-} < \text{Te}^{2-}$

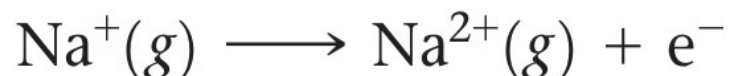


## 7.4 Ionization Energy

- ❖ The **ionization energy** of an atom or ion is the minimum energy required to remove an electron from the ground state of the isolated gaseous atom or ion.
- ❖ The **first ionization energy**,  $I_1$ , is the energy needed to remove the first electron from a neutral atom.



- ❖ The **second ionization energy**,  $I_2$ , is the energy needed to remove the second electron.



## 7.4 Ionization Energy

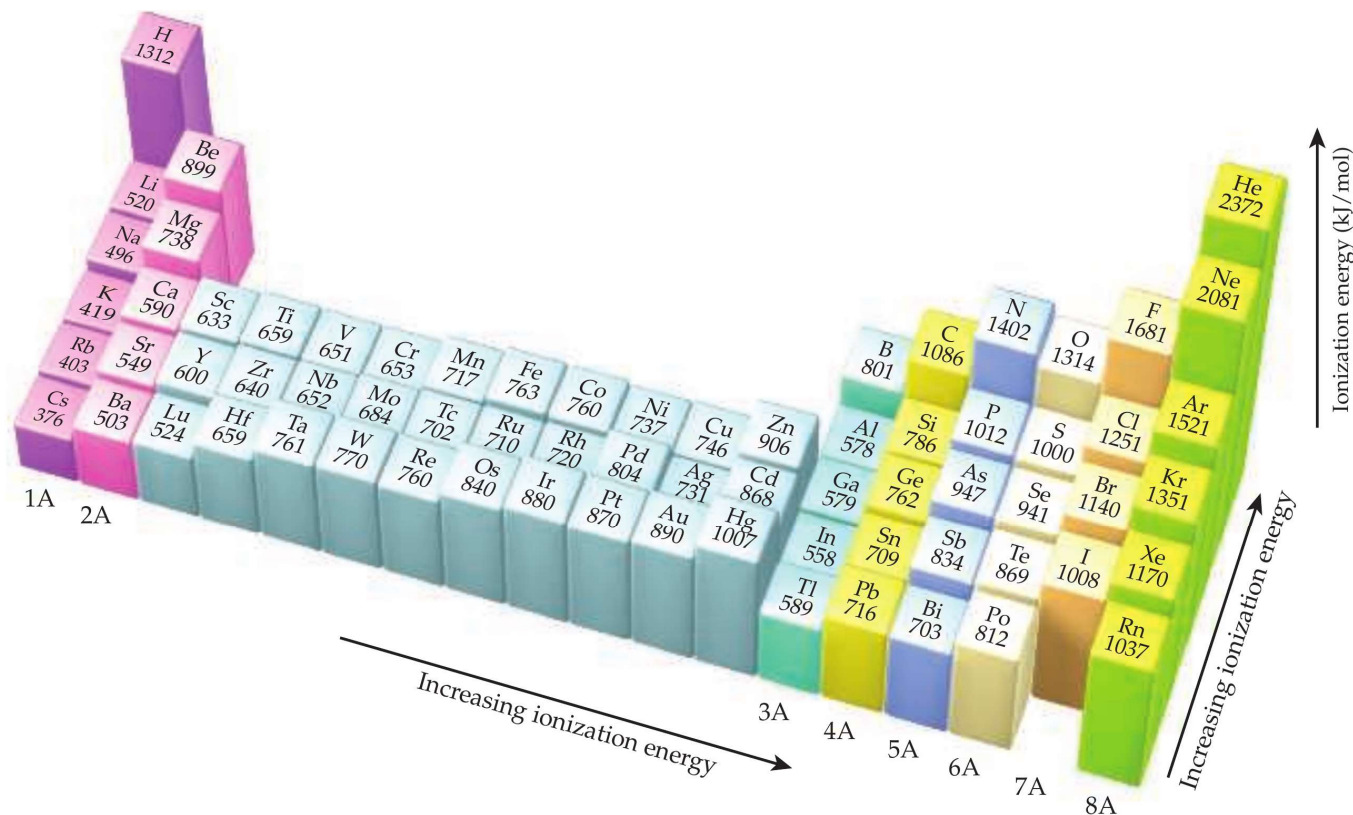
### Variations in Successive Ionization Energies

- ❖ The greater the ionization energy, the more difficult it is to remove an electron.
- ❖ Thus, the ionization energies for a given element increase as successive electrons are removed:  $I_1 < I_2 < I_3$ , and so forth.

## 7.4 Ionization Energy

### Periodic Trends in First Ionization Energies

- ❖  $I_1$  generally increases as we move left to right across a period.
- ❖  $I_1$  generally decreases as we move down any column in the periodic table.



▲ Figure 7.10 The first ionization energies of the elements in kJ/mol.

## 7.4 Ionization Energy

- ❖ The *s*- and *p*-block elements show a larger range of  $I_1$  values than do the transition-metal elements.
- ❖ Generally, the ionization energies of the transition metals increase slowly from left to right in a period.
- ❖ As we move across a period, there is both an increase in effective nuclear charge and a decrease in atomic radius, causing the ionization energy to increase.
- ❖ As we move down a column, the atomic radius increases, while the effective nuclear charge increases only gradually; the increase in radius dominates, so the attraction between the nucleus and the electron decreases, causing the ionization energy to decrease.

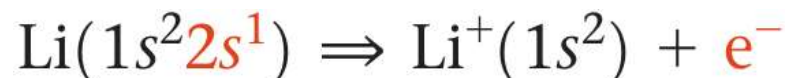
## 7.4 Ionization Energy

- ❖ The irregularities in a given period are subtle but still readily explained.
- ❖ The decrease in ionization energy from beryllium ( $[\text{He}]2s^2$ ) to boron ( $[\text{He}]2s^22p^1$ ), occurs because the third valence electron of B must occupy the  $2p$  subshell, which is empty for Be.
- ❖ The slight decrease in ionization energy when moving from nitrogen ( $[\text{He}]2s^22p^3$ ) to oxygen ( $[\text{He}]2s^22p^4$ ) is the result of the repulsion of paired electrons in the  $p^4$  configuration.

## 7.4 Ionization Energy

### Electron Configurations of Ions

- ❖ When electrons are removed from an atom to form a cation, they are always removed first from the occupied orbitals having the largest principal quantum number,  $n$ .



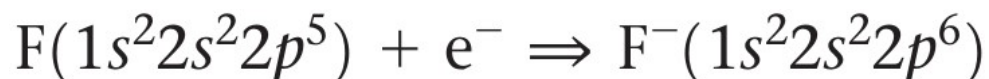
- ❖ Thus, in forming ions, transition metals lose the valence-shells electrons first, then as many  $d$  electrons as required to reach the charge of the ion.

## 7.4 Ionization Energy

- ❖ If there is more than one occupied subshell for a given value of  $n$ , the electrons are first removed from the orbital with the highest value of  $l$ .



- ❖ Electrons added to an atom to form an anion are added to the empty or partially filled orbital having the lowest value of  $n$ .



## Sample Exercise 7.6

Referring to the periodic table, arrange the atoms Ne, Na, P, Ar, K in order of increasing first ionization energy.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 <b>H</b> Hydrogen 1.00794	2 <b>He</b> Helium 4.002602																
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182																
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.305																
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293
55 <b>Cs</b> Cesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71 <b>La</b> Lanthanum 138.90547	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103 <b>Ac</b> Actinium (227)	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.5	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

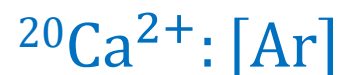
➤  $K < Na < P < Ar < Ne$



## Sample Exercise 7.7

Write the electron configurations for

a.  $\text{Ca}^{2+}$



b.  $\text{Co}^{3+}$



c.  $\text{S}^{2-}$



## 7.5 Electron Affinity

- ❖ All ionization energies for atoms are positive: Energy must be **absorbed** to remove an electron.



- ❖ The energy change that occurs when an electron is added to a gaseous atom is called the **electron affinity** because it measures the attraction, or **affinity**, of the atom for the added electron.
- ❖ For most atoms, energy is **released** when an electron is added.



## 7.5 Electron Affinity

- ❖ The greater the attraction between an atom and an added electron, the more negative the atom's electron affinity.
- ❖ For some elements, such as the noble gases, the electron affinity has a positive value, meaning that the anion is higher in energy than are the separated atom and electron:



- ❖ The fact that the electron affinity is positive means that an electron will not attach itself to an Ar atom; in other words, the  $\text{Ar}^{-}$  ion is unstable and does not form.