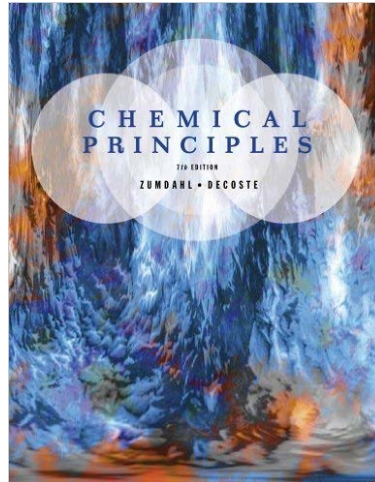


# Chemistry 1B-AL

## Fall 2016

adventures lectures 7-8



Zumdahl

(pp. 571-582 *[atomic properties]*),  
606-609 *[ionic radii]*)

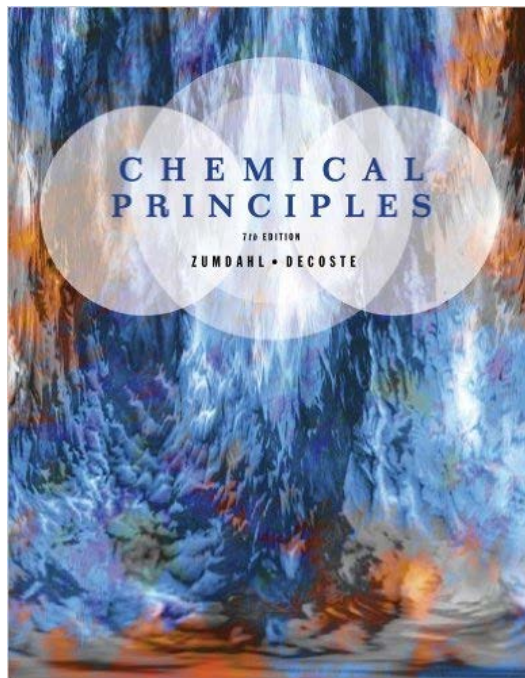
Chemistry IB -AL

Electronic Structure

and

Periodic Properties of

Atoms



Zumdahl

(pp. 571-582 *[atomic properties]*),  
606-609 *[ionic radii]*)

# worksheet IV- sections I.1-I.3 and upcoming clickeroos

## Learning Objectives and Worksheet IV

### Chemistry 1B-AL Fall 2016

#### Lectures (7-8) Periodic Properties of Atoms and ions

Read pp. 571-582 and 606-609 [ionic radii]

Supplementary video: The Electron: Crash Course Chemistry

Link: <http://youtu.be/rcKilE9CdaA>

In 1869 Dmitri Mendeleev published *The Dependence between the Properties of the Atomic Weights of the Elements* which was the basis of the modern Periodic Table. One of the beautiful aspects of the theory of atomic structure is that it enables one to understand, and thus predict, a great number observable chemical properties of the elements based on the concepts of the Aufbau Principle and effective nuclear charge.

#### I. General Periodic Trends

1. Atomic 'energies' and atomic 'size' are two important quantities in understanding the properties of atoms. Two relationships (taken from Bohr's treatment of the H atom) are:

gas phase energy of electron with  $n$ ,  $Z_{\text{eff}}$ :  $E \approx -(2.18 \times 10^{-18} \text{ J}) \frac{Z_{\text{eff}}^2}{n^2}$  and

"Bohr" radius in gas phase  $r \approx (0.529 \times 10^{-10} \text{ m}) \frac{n^2}{Z_{\text{eff}}}$

- As  $n$  get higher the energy \_\_\_\_\_.
  - As  $Z_{\text{eff}}$  becomes larger (more positive) the energy \_\_\_\_\_.
  - An  $n$  gets larger the radius \_\_\_\_\_.
  - As  $Z_{\text{eff}}$  becomes larger (more positive) the radius \_\_\_\_\_.
2. An understanding of how  $n$  and  $Z_{\text{eff}}$  change as one adds protons and electrons is crucial. For the electrons in the 'outermost' shell:
- As one goes across a given row of the periodic table adding protons and electrons (i.e. as atomic number increases in neutral atoms) how does:  
 $n$  change \_\_\_\_\_  
 $Z_{\text{eff}}$  change \_\_\_\_\_
  - As one goes down a given column of the periodic table adding protons and electrons (i.e. as atomic number increases in neutral atoms) how does:  
 $n$  change \_\_\_\_\_  
 $Z_{\text{eff}}$  change \_\_\_\_\_

- iii. From part i above. Why does  $Z_{\text{eff}}$  \_\_\_\_\_ for successive elements going across a given row of the periodic table?

- iv. From part ii above: Why is  $Z_{\text{eff}}$  \_\_\_\_\_ for successive elements going down a column of the periodic table?

Additional resource on trends in properties and periodicity:

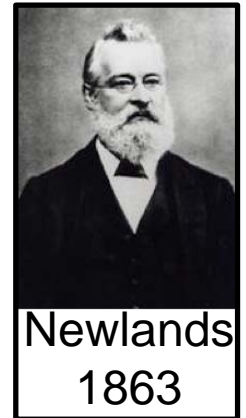
<http://chemistry.about.com/od/periodictableelements/a/periodictrends.htm>

3. How do  $n$  and  $Z_{\text{eff}}$  for an ion compare to those for the neutral atom:
- Consider an anion where electrons have been added to attain a complete shell octet, e.g.  $\text{O}^{2-}$  from O.  
How will  $n$  for the outer shell electrons in  $\text{O}^{2-}$  compare to that of the outer shells electrons in O?  $n$  for  $\text{O}^{2-}$  \_\_\_\_\_  $n$  for O  
How will  $Z_{\text{eff}}$  for the outer shell electrons in  $\text{O}^{2-}$  compare to  $Z_{\text{eff}}$  for the outer shell electrons in O?  $Z_{\text{eff}}$  for  $\text{O}^{2-}$  \_\_\_\_\_  $Z_{\text{eff}}$  for O
  - Consider a cation where electrons have been removed to attain a complete shell octet, e.g.  $\text{Na}^+$  from Na.  
How will  $n$  for the outer shell electrons in  $\text{Na}^+$  compare to that of the outer shells electrons in Na?  $n$  for  $\text{Na}^+$  \_\_\_\_\_  $n$  for Na  
How will  $Z_{\text{eff}}$  for the outer shell electrons in  $\text{Na}^+$  compare to  $Z_{\text{eff}}$  for the outer shell electrons in Na?  $Z_{\text{eff}}$  for  $\text{Na}^+$  \_\_\_\_\_  $Z_{\text{eff}}$  for Na

# periodicity (figure 12.29)



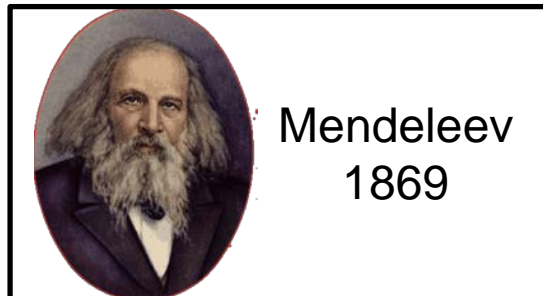
Period number, highest occupied electron level	Representative Elements		<i>d</i> -Transition Elements										Representative Elements					Noble Gases
	1A <i>ns</i> <sup>1</sup>	2A <i>ns</i> <sup>2</sup>	3A <i>ns</i> <sup>2</sup> <i>np</i> <sup>1</sup>	4A <i>ns</i> <sup>2</sup> <i>np</i> <sup>2</sup>	5A <i>ns</i> <sup>2</sup> <i>np</i> <sup>3</sup>	6A <i>ns</i> <sup>2</sup> <i>np</i> <sup>4</sup>	7A <i>ns</i> <sup>2</sup> <i>np</i> <sup>5</sup>	8A <i>ns</i> <sup>2</sup> <i>np</i> <sup>6</sup>										
1	1 H <i>1s</i> <sup>1</sup>	2 He <i>1s</i> <sup>2</sup>																
2	3 Li <i>2s</i> <sup>1</sup>	4 Be <i>2s</i> <sup>2</sup>	5 B <i>2s</i> <sup>2</sup> <i>2p</i> <sup>1</sup>	6 C <i>2s</i> <sup>2</sup> <i>2p</i> <sup>2</sup>	7 N <i>2s</i> <sup>2</sup> <i>2p</i> <sup>3</sup>	8 O <i>2s</i> <sup>2</sup> <i>2p</i> <sup>4</sup>	9 F <i>2s</i> <sup>2</sup> <i>2p</i> <sup>5</sup>	10 Ne <i>2s</i> <sup>2</sup> <i>2p</i> <sup>6</sup>										
3	11 Na <i>3s</i> <sup>1</sup>	12 Mg <i>3s</i> <sup>2</sup>	13 Al <i>3s</i> <sup>2</sup> <i>3p</i> <sup>1</sup>	14 Si <i>3s</i> <sup>2</sup> <i>3p</i> <sup>2</sup>	15 P <i>3s</i> <sup>2</sup> <i>3p</i> <sup>3</sup>	16 S <i>3s</i> <sup>2</sup> <i>3p</i> <sup>4</sup>	17 Cl <i>3s</i> <sup>2</sup> <i>3p</i> <sup>5</sup>	18 Ar <i>3s</i> <sup>2</sup> <i>3p</i> <sup>6</sup>										
4	19 K <i>4s</i> <sup>1</sup>	20 Ca <i>4s</i> <sup>2</sup>	21 Sc <i>4s</i> <sup>2</sup> <i>3d</i> <sup>1</sup>	22 Ti <i>4s</i> <sup>2</sup> <i>3d</i> <sup>2</sup>	23 V <i>4s</i> <sup>1</sup> <i>3d</i> <sup>3</sup>	24 Cr <i>4s</i> <sup>1</sup> <i>3d</i> <sup>5</sup>	25 Mn <i>4s</i> <sup>2</sup> <i>3d</i> <sup>5</sup>	26 Fe <i>4s</i> <sup>2</sup> <i>3d</i> <sup>6</sup>	27 Co <i>4s</i> <sup>1</sup> <i>3d</i> <sup>7</sup>	28 Ni <i>4s</i> <sup>2</sup> <i>3d</i> <sup>8</sup>	29 Cu <i>4s</i> <sup>1</sup> <i>3d</i> <sup>10</sup>	30 Zn <i>4s</i> <sup>2</sup> <i>3d</i> <sup>10</sup>	31 Ga <i>4s</i> <sup>2</sup> <i>4p</i> <sup>1</sup>	32 Ge <i>4s</i> <sup>2</sup> <i>4p</i> <sup>2</sup>	33 As <i>4s</i> <sup>2</sup> <i>4p</i> <sup>3</sup>	34 Se <i>4s</i> <sup>2</sup> <i>4p</i> <sup>4</sup>	35 Br <i>4s</i> <sup>2</sup> <i>4p</i> <sup>5</sup>	36 Kr <i>4s</i> <sup>2</sup> <i>4p</i> <sup>6</sup>
5	37 Rb <i>5s</i> <sup>1</sup>	38 Sr <i>5s</i> <sup>2</sup>	39 Y <i>5s</i> <sup>2</sup> <i>4d</i> <sup>1</sup>	40 Zr <i>5s</i> <sup>2</sup> <i>4d</i> <sup>2</sup>	41 Nb <i>5s</i> <sup>1</sup> <i>4d</i> <sup>3</sup>	42 Mo <i>5s</i> <sup>1</sup> <i>4d</i> <sup>5</sup>	43 Tc <i>5s</i> <sup>2</sup> <i>4d</i> <sup>5</sup>	44 Ru <i>5s</i> <sup>1</sup> <i>4d</i> <sup>7</sup>	45 Rh <i>5s</i> <sup>1</sup> <i>4d</i> <sup>8</sup>	46 Pd <i>4d</i> <sup>10</sup>	47 Ag <i>5s</i> <sup>1</sup> <i>4d</i> <sup>10</sup>	48 Cd <i>5s</i> <sup>2</sup> <i>4d</i> <sup>10</sup>	49 In <i>5s</i> <sup>2</sup> <i>5p</i> <sup>1</sup>	50 Sn <i>5s</i> <sup>2</sup> <i>5p</i> <sup>2</sup>	51 Sb <i>5s</i> <sup>2</sup> <i>5p</i> <sup>3</sup>	52 Te <i>5s</i> <sup>2</sup> <i>5p</i> <sup>4</sup>	53 I <i>5s</i> <sup>2</sup> <i>5p</i> <sup>5</sup>	54 Xe <i>5s</i> <sup>2</sup> <i>5p</i> <sup>6</sup>
6	55 Cs <i>6s</i> <sup>1</sup>	56 Ba <i>6s</i> <sup>2</sup>	57 La* <i>6s</i> <sup>2</sup> <i>5d</i> <sup>1</sup>	72 Hf <i>6s</i> <sup>2</sup> <i>5d</i> <sup>2</sup>	73 Ta <i>6s</i> <sup>2</sup> <i>5d</i> <sup>3</sup>	74 W <i>6s</i> <sup>2</sup> <i>5d</i> <sup>4</sup>	75 Re <i>6s</i> <sup>2</sup> <i>5d</i> <sup>5</sup>	76 Os <i>6s</i> <sup>2</sup> <i>5d</i> <sup>6</sup>	77 Ir <i>6s</i> <sup>1</sup> <i>5d</i> <sup>7</sup>	78 Pt <i>6s</i> <sup>1</sup> <i>5d</i> <sup>9</sup>	79 Au <i>6s</i> <sup>1</sup> <i>5d</i> <sup>10</sup>	80 Hg <i>6s</i> <sup>2</sup> <i>5d</i> <sup>10</sup>	81 Tl <i>6s</i> <sup>2</sup> <i>6p</i> <sup>1</sup>	82 Pb <i>6s</i> <sup>2</sup> <i>6p</i> <sup>2</sup>	83 Bi <i>6s</i> <sup>2</sup> <i>6p</i> <sup>3</sup>	84 Po <i>6s</i> <sup>2</sup> <i>6p</i> <sup>4</sup>	85 At <i>6s</i> <sup>2</sup> <i>6p</i> <sup>5</sup>	86 Rn <i>6s</i> <sup>2</sup> <i>6p</i> <sup>6</sup>
7	87 Fr <i>7s</i> <sup>1</sup>	88 Ra <i>7s</i> <sup>2</sup>	89 Ac** <i>7s</i> <sup>2</sup> <i>6d</i> <sup>1</sup>	104 Db <i>7s</i> <sup>2</sup> <i>6d</i> <sup>2</sup>	105 Sg <i>7s</i> <sup>2</sup> <i>6d</i> <sup>3</sup>	106 Bh <i>7s</i> <sup>2</sup> <i>6d</i> <sup>4</sup>	107 Hs <i>7s</i> <sup>2</sup> <i>6d</i> <sup>6</sup>	108 Mt <i>7s</i> <sup>2</sup> <i>6d</i> <sup>7</sup>	109 Ds <i>7s</i> <sup>2</sup> <i>6d</i> <sup>9</sup>	110 Uub <i>7s</i> <sup>2</sup> <i>6d</i> <sup>10</sup>	111 Uuu <i>7s</i> <sup>2</sup> <i>6d</i> <sup>10</sup>	112 Uub <i>7s</i> <sup>2</sup> <i>6d</i> <sup>10</sup>	114 Uuq <i>7s</i> <sup>2</sup> <i>7p</i> <sup>2</sup>					



*f*-Transition Elements

*Lanthanides	58 Ce <i>6s</i> <sup>2</sup> <i>4f</i> <sup>1</sup> <i>5d</i> <sup>1</sup>	59 Pr <i>6s</i> <sup>2</sup> <i>4f</i> <sup>3</sup> <i>5d</i> <sup>0</sup>	60 Nd <i>6s</i> <sup>2</sup> <i>4f</i> <sup>4</sup> <i>5d</i> <sup>0</sup>	61 Pm <i>6s</i> <sup>2</sup> <i>4f</i> <sup>5</sup> <i>5d</i> <sup>0</sup>	62 Sm <i>6s</i> <sup>2</sup> <i>4f</i> <sup>6</sup> <i>5d</i> <sup>0</sup>	63 Eu <i>6s</i> <sup>2</sup> <i>4f</i> <sup>7</sup> <i>5d</i> <sup>0</sup>	64 Gd <i>6s</i> <sup>2</sup> <i>4f</i> <sup>7</sup> <i>5d</i> <sup>1</sup>	65 Tb <i>6s</i> <sup>2</sup> <i>4f</i> <sup>9</sup> <i>5d</i> <sup>0</sup>	66 Dy <i>6s</i> <sup>2</sup> <i>4f</i> <sup>10</sup> <i>5d</i> <sup>0</sup>	67 Ho <i>6s</i> <sup>2</sup> <i>4f</i> <sup>11</sup> <i>5d</i> <sup>0</sup>	68 Er <i>6s</i> <sup>2</sup> <i>4f</i> <sup>12</sup> <i>5d</i> <sup>0</sup>	69 Tm <i>6s</i> <sup>2</sup> <i>4f</i> <sup>13</sup> <i>5d</i> <sup>0</sup>	70 Yb <i>6s</i> <sup>2</sup> <i>4f</i> <sup>14</sup> <i>5d</i> <sup>0</sup>	71 Lu <i>6s</i> <sup>2</sup> <i>4f</i> <sup>14</sup> <i>5d</i> <sup>1</sup>
**Actinides	90 Th <i>7s</i> <sup>2</sup> <i>5f</i> <sup>0</sup> <i>6d</i> <sup>2</sup>	91 Pa <i>7s</i> <sup>2</sup> <i>5f</i> <sup>2</sup> <i>6d</i> <sup>1</sup>	92 U <i>7s</i> <sup>2</sup> <i>5f</i> <sup>3</sup> <i>6d</i> <sup>1</sup>	93 Np <i>7s</i> <sup>2</sup> <i>5f</i> <sup>4</sup> <i>6d</i> <sup>1</sup>	94 Pu <i>7s</i> <sup>2</sup> <i>5f</i> <sup>6</sup> <i>6d</i> <sup>1</sup>	95 Am <i>7s</i> <sup>2</sup> <i>5f</i> <sup>7</sup> <i>6d</i> <sup>1</sup>	96 Cm <i>7s</i> <sup>2</sup> <i>5f</i> <sup>7</sup> <i>6d</i> <sup>2</sup>	97 Bk <i>7s</i> <sup>2</sup> <i>5f</i> <sup>9</sup> <i>6d</i> <sup>1</sup>	98 Cf <i>7s</i> <sup>2</sup> <i>5f</i> <sup>10</sup> <i>6d</i> <sup>1</sup>	99 Es <i>7s</i> <sup>2</sup> <i>5f</i> <sup>11</sup> <i>6d</i> <sup>1</sup>	100 Fm <i>7s</i> <sup>2</sup> <i>5f</i> <sup>11</sup> <i>6d</i> <sup>2</sup>	101 Md <i>7s</i> <sup>2</sup> <i>5f</i> <sup>13</sup> <i>6d</i> <sup>1</sup>	102 No <i>7s</i> <sup>2</sup> <i>5f</i> <sup>14</sup> <i>6d</i> <sup>1</sup>	103 Lr <i>7s</i> <sup>2</sup> <i>5f</i> <sup>14</sup> <i>6d</i> <sup>2</sup>

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*EXPLAIN THIS !!!! (atomic radii, fig. 12.38)*

---

increase atomic number of atom

atomic radii ( $10^{-12}$  m):

Li 152  
Na 186  
K 227  
Rb 247  
Cs 265  
Fr 270



<b>L A R G E R</b>	3 Li	4 Be
	11 Na	12 Mg
	19 K	20 Ca
	37 Rb	38 Sr
	55 Cs	56 Ba
	87 Fr	88 Ra

but

3 Li	4 Be	5 B	6 C	7 N	8 O	9 F	10 Ne
---------	---------	--------	--------	--------	--------	--------	----------

Li 152    Be 113    B 88    C 77    N 70    O 66    F 64    Ne 69\*



**S M A L L E R**

*explain this*

---



**why  $Na^+$  ?**

**why  $Br^-$  ?**

# periodicity (figure 12.29)

Period number, highest occupied electron level	Representative Elements		<i>d</i> -Transition Elements										Representative Elements					Noble Gases
	1A $ns^1$	Group numbers 2A $ns^2$											3A $ns^2np^1$	4A $ns^2np^2$	5A $ns^2np^3$	6A $ns^2np^4$	7A $ns^2np^5$	8A $ns^2np^6$
1	1 H $1s^1$	2 He $1s^2$																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 $4s^23d^1$	22 Ti $4s^23d^2$	23 V $4s^23d^3$	24 Cr $4s^13d^5$	25 Mn $4s^23d^5$	26 Fe $4s^23d^6$	27 Co $4s^23d^7$	28 Ni $4s^23d^8$	29 Cu $4s^13d^{10}$	30 Zn $4s^23d^{10}$	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 $5s^24d^1$	40 Zr $5s^24d^2$	41 Nb $5s^14d^4$	42 Mo $5s^14d^5$	43 Tc $5s^24d^5$	44 Ru $5s^14d^7$	45 Rh $5s^14d^8$	46 Pd $4d^{10}$	47 Ag $4d^{10}$	48 Cd $5s^24d^{10}$	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 $6s^2$	57 La* $6s^25d^1$	72 Hf $6s^25d^2$	73 Ta $6s^25d^3$	74 W $6s^25d^4$	75 Re $6s^25d^5$	76 Os $6s^25d^6$	77 Ir $6s^25d^7$	78 Pt $6s^15d^9$	79 Au $6s^15d^{10}$	80 Hg $6s^25d^{10}$	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 $7s^2$	89 Ac** $7s^26d^1$	104 Rf $7s^26d^2$	105 Db $7s^26d^3$	106 Sg $7s^26d^4$	107 Bh $7s^26d^5$	108 Hs $7s^26d^6$	109 Mt $7s^26d^7$	110 Ds $7s^26d^8$	111 Uuu $7s^16d^{10}$	112 Uub $7s^26d^{10}$						

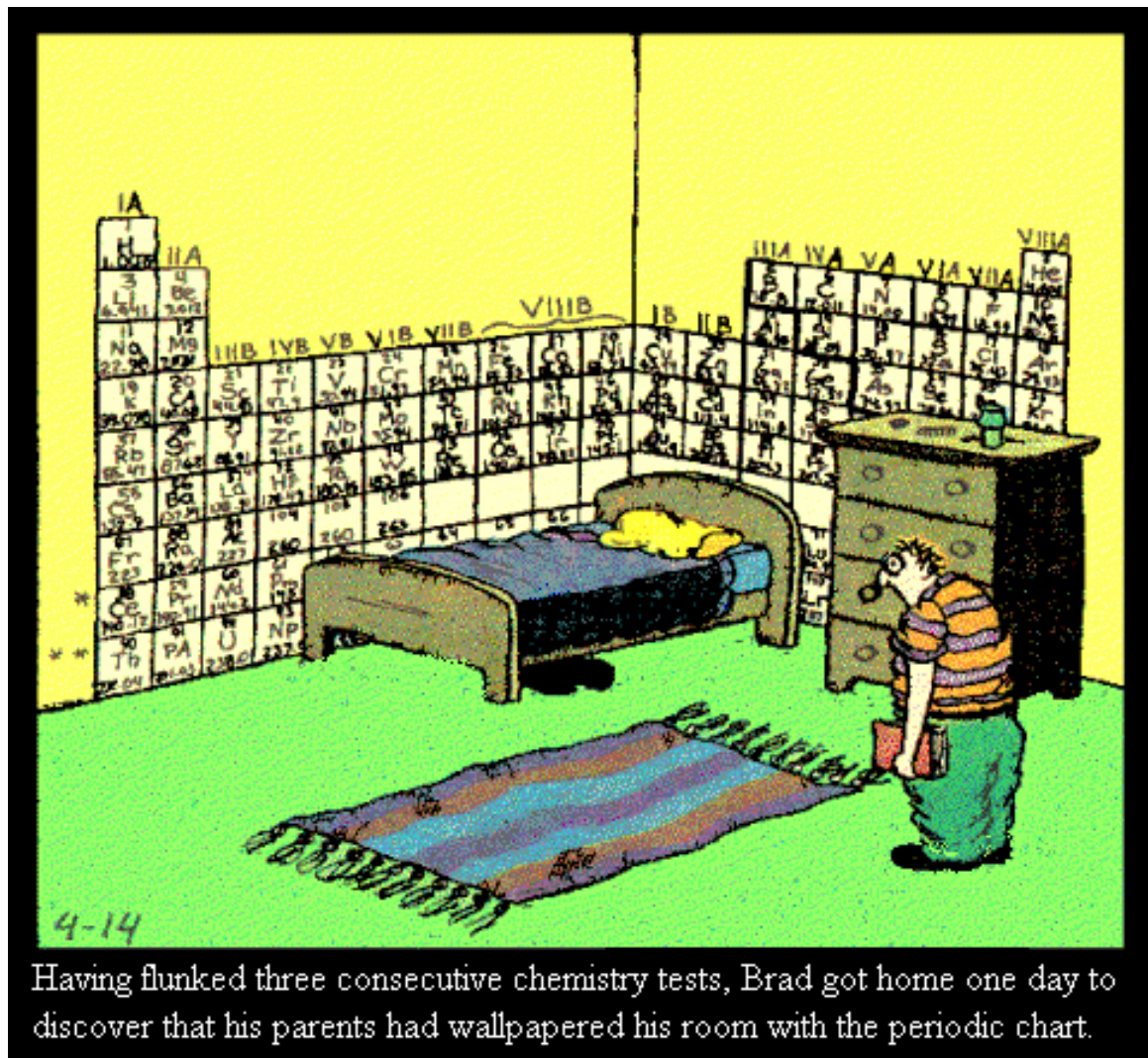
VOILA!!!

## *f*-Transition Elements

*Lanthanides	58 Ce $6s^24f^15d^0$	59 Pr $6s^24f^35d^0$	60 Nd $6s^24f^45d^0$	61 Pm $6s^24f^55d^0$	62 Sm $6s^24f^65d^0$	63 Eu $6s^24f^75d^0$	64 Gd $6s^24f^75d^1$	65 Tb $6s^24f^95d^0$	66 Dy $6s^24f^105d^0$	67 Ho $6s^24f^115d^0$	68 Er $6s^24f^125d^0$	69 Tm $6s^24f^135d^0$	70 Yb $6s^24f^145d^0$	71 Lu $6s^24f^145d^1$
**Actinides	90 Th $7s^25f^66d^2$	91 Pa $7s^25f^76d^1$	92 U $7s^25f^66d^1$	93 Np $7s^25f^66d^1$	94 Pu $7s^25f^66d^0$	95 Am $7s^25f^76d^0$	96 Cm $7s^25f^76d^0$	97 Bk $7s^25f^76d^0$	98 Cf $7s^25f^106d^0$	99 Es $7s^25f^106d^0$	100 Fm $7s^25f^106d^0$	101 Md $7s^25f^106d^0$	102 No $7s^25f^146d^0$	103 Lr $7s^25f^146d^1$

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**gas phase energy of electron with  $n$ ,  $Z_{\text{eff}}$**

$$E \approx - \left( 2.18 \times 10^{-18} \text{ J} \right) \frac{Z_{\text{eff}}^2}{n^2}$$

$$IE = + \left( 2.18 \times 10^{-18} \text{ J} \right) \frac{Z_{\text{eff}}^2}{n^2}$$

**"Bohr" radius in gas phase**

$$r \approx (0.529 \times 10^{-10} \text{ m}) \frac{n^2}{Z_{\text{eff}}}$$

$$r \approx (52.9 \text{ pm}) \frac{n^2}{Z_{\text{eff}}}$$

**pm =  $10^{-12}$  m (picometer)**

basic trends for  $n$  and  $Z_{\text{eff}}$  in periodic table (figure 8.9, Silberberg)

$n$   $Z_{\text{eff}}$

across



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	1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 <b>H</b> $1s^1$							2 <b>He</b> $1s^2$
2	3 <b>Li</b> $[\text{He}] 2s^1$	4 <b>Be</b> $[\text{He}] 2s^2$	5 <b>B</b> $[\text{He}] 2s^2 2p^1$	6 <b>C</b> $[\text{He}] 2s^2 2p^2$	7 <b>N</b> $[\text{He}] 2s^2 2p^3$	8 <b>O</b> $[\text{He}] 2s^2 2p^4$	9 <b>F</b> $[\text{He}] 2s^2 2p^5$	10 <b>Ne</b> $[\text{He}] 2s^2 2p^6$
3	11 <b>Na</b> $[\text{Ne}] 3s^1$	12 <b>Mg</b> $[\text{Ne}] 3s^2$	13 <b>Al</b> $[\text{Ne}] 3s^2 3p^1$	14 <b>Si</b> $[\text{Ne}] 3s^2 3p^2$	15 <b>P</b> $[\text{Ne}] 3s^2 3p^3$	16 <b>S</b> $[\text{Ne}] 3s^2 3p^4$	17 <b>Cl</b> $[\text{Ne}] 3s^2 3p^5$	18 <b>Ar</b> $[\text{Ne}] 3s^2 3p^6$

Period

down



*basic trends for  $n$  and  $Z_{\text{eff}}$  in periodic table (figure 8.9, Silberberg)*

---

$n$   $Z_{\text{eff}}$

across



for each sequential atom a proton and an electron **in same shell** is added:

for an outermost (valence) electron:

$n$ : stays the same as one goes across a row

$Z_{\text{eff}}$ : add +1 to  $Z$  (actual nuclear charge), increases attraction

add electron in same shell; repulsion shields other electron

**but not full -1 repulsion since in same shell**

$Z_{\text{eff}}$  increases across row (period)

$n$  is not changing

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	1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 <b>H</b> $1s^1$							2 <b>He</b> $1s^2$
2	3 <b>Li</b> $[\text{He}] 2s^1$	4 <b>Be</b> $[\text{He}] 2s^2$	5 <b>B</b> $[\text{He}] 2s^2 2p^1$	6 <b>C</b> $[\text{He}] 2s^2 2p^2$	7 <b>N</b> $[\text{He}] 2s^2 2p^3$	8 <b>O</b> $[\text{He}] 2s^2 2p^4$	9 <b>F</b> $[\text{He}] 2s^2 2p^5$	10 <b>Ne</b> $[\text{He}] 2s^2 2p^6$
3	11 <b>Na</b> $[\text{Ne}] 3s^1$	12 <b>Mg</b> $[\text{Ne}] 3s^2$	13 <b>Al</b> $[\text{Ne}] 3s^2 3p^1$	14 <b>Si</b> $[\text{Ne}] 3s^2 3p^2$	15 <b>P</b> $[\text{Ne}] 3s^2 3p^3$	16 <b>S</b> $[\text{Ne}] 3s^2 3p^4$	17 <b>Cl</b> $[\text{Ne}] 3s^2 3p^5$	18 <b>Ar</b> $[\text{Ne}] 3s^2 3p^6$

$n$   $Z_{\text{eff}}$

for each sequential atom, complete **inner shells** are added:  
for an outermost (valence) electron:

$n$ : increases by 1 as one goes down a column

$Z_{\text{eff}}$ : add same number of protons and electrons (e.g. 8 in going period 2→3)

but electrons are inner shell so 'almost' complete shielding  
so nuclear attraction and electron repulsion (shielding)  
cancel

down



$n$   
increases down column (group)

$Z_{\text{eff}}$  increases across row (period)

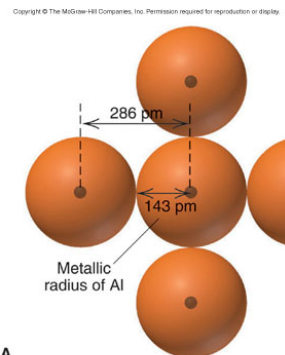
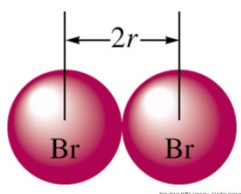
$Z_{\text{eff}}$  is 'relatively' constant

$n$  is not changing

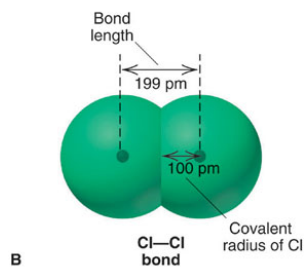
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	1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 <b>H</b> $1s^1$							2 <b>He</b> $1s^2$
2	3 <b>Li</b> $[\text{He}] 2s^1$	4 <b>Be</b> $[\text{He}] 2s^2$	5 <b>B</b> $[\text{He}] 2s^2 2p^1$	6 <b>C</b> $[\text{He}] 2s^2 2p^2$	7 <b>N</b> $[\text{He}] 2s^2 2p^3$	8 <b>O</b> $[\text{He}] 2s^2 2p^4$	9 <b>F</b> $[\text{He}] 2s^2 2p^5$	10 <b>Ne</b> $[\text{He}] 2s^2 2p^6$
3	11 <b>Na</b> $[\text{Ne}] 3s^1$	12 <b>Mg</b> $[\text{Ne}] 3s^2$	13 <b>Al</b> $[\text{Ne}] 3s^2 3p^1$	14 <b>Si</b> $[\text{Ne}] 3s^2 3p^2$	15 <b>P</b> $[\text{Ne}] 3s^2 3p^3$	16 <b>S</b> $[\text{Ne}] 3s^2 3p^4$	17 <b>Cl</b> $[\text{Ne}] 3s^2 3p^5$	18 <b>Ar</b> $[\text{Ne}] 3s^2 3p^6$

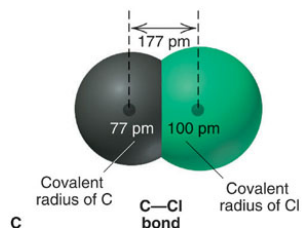
# Estimating atomic radii (metallic and covalent) (figs. Zumdahl 12.37, Silberberg 8.14)



A



B



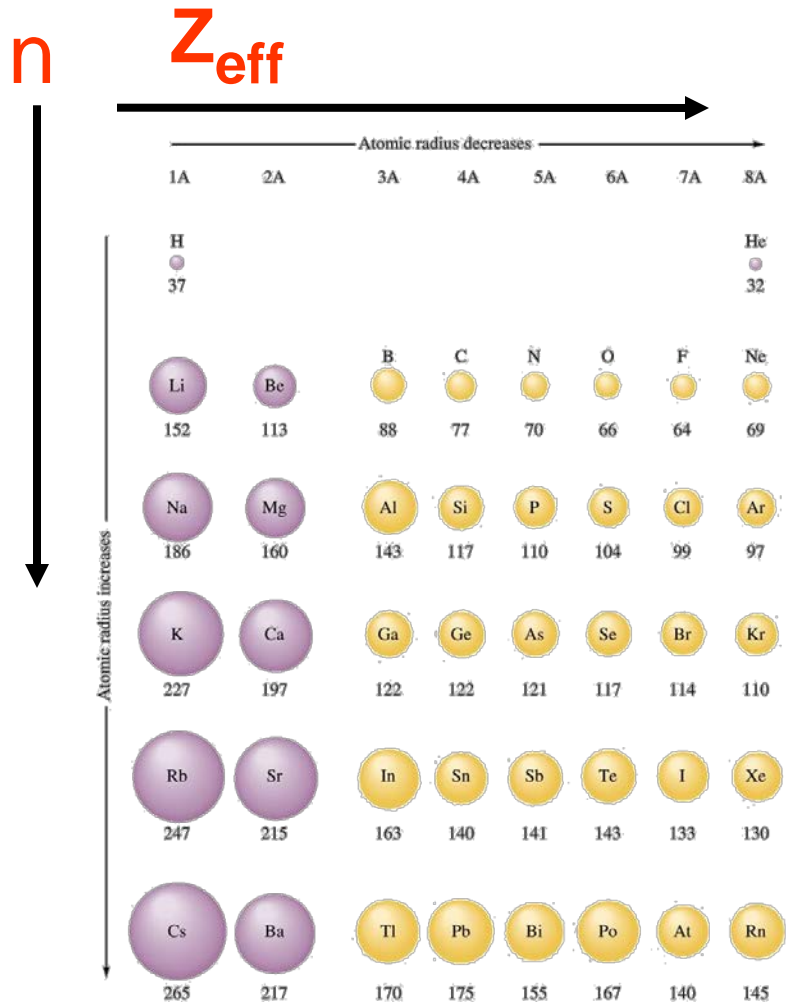
C

for metals

for nonmetals-  
*can vary from  
compound  
to compound*



# covalent and metallic atomic radii periodic trends (fig. 12.38)



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gas phase 'Bohr' radius

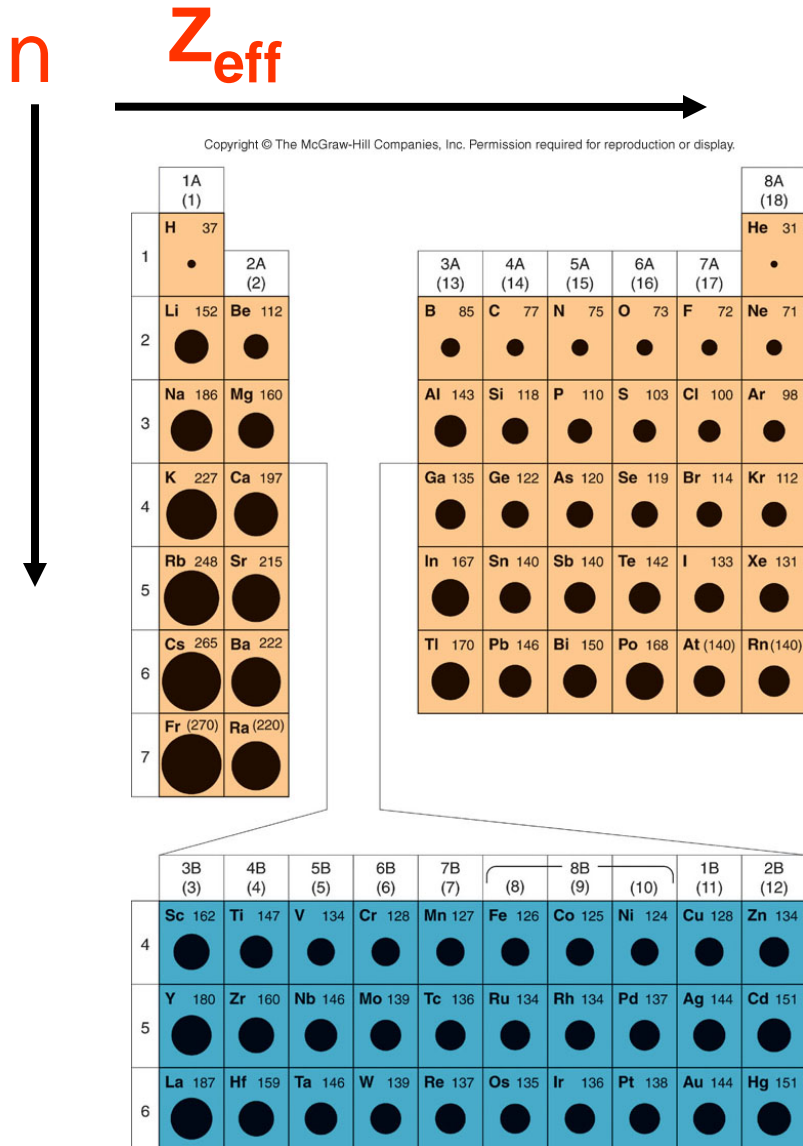
$$r \approx (0.529 \times 10^{-10} \text{ m}) \frac{n^2}{Z_{\text{eff}}}$$

don't take formula too 'literally' for  
metallic/covalent radii

but :

larger  $n \Rightarrow$  larger  $r$

larger  $Z_{\text{eff}} \Rightarrow$  smaller  $r$



gas phase 'Bohr' radius

$$r \approx (0.529 \times 10^{-10} \text{ m}) \frac{n^2}{Z_{\text{eff}}}$$

don't take formula too 'literally' for  
metallic/covalent radii

but :

larger n ⇒ larger r

larger Z<sub>eff</sub> ⇒ smaller r

atomic radii (Silberberg fig. 8.15) numerical values differ slightly from Zumdahl

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gas phase 'Bohr' radius

$r = \frac{n^2 a_0}{Z_{\text{eff}}}$

'literally' for radii

	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	(8)	8B (9)	(10)	1B (11)	2B (12)
4	Sc 162	Ti 147	V 134	Cr 128	Mn 127	Fe 126	Co 125	Ni 124	Cu 128	Zn 134
5	Y 180	Zr 160	Nb 146	Mo 139	Tc 136	Ru 134	Rh 134	Pd 137	Ag 144	Cd 151
6	La 187	Hf 159	Ta 146	W 139	Re 137	Os 135	Ir 136	Pt 138	Au 144	Hg 151

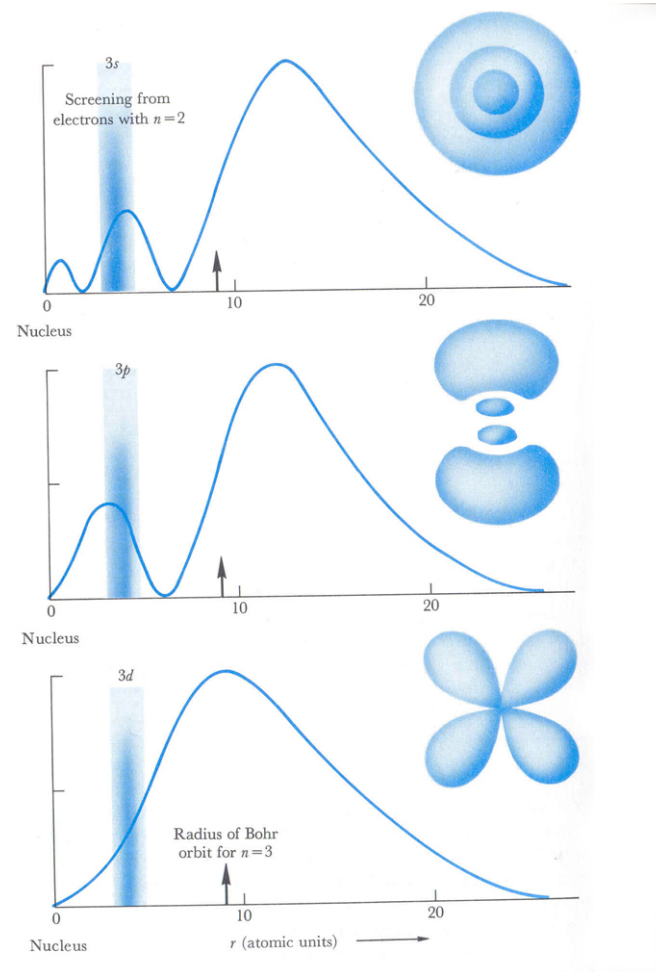
transition metals  
(special considerations)



## *radii for transition metal (neutral) atoms in 4<sup>th</sup> period*

Even though the  $E_{4s} < E_{3d}$  (due to penetration effects), the average position (radius) of the 3d orbitals is somewhat smaller.

Thus, in terms of atomic size, the 4s is the “outermost” orbital for all of the atoms; and as one goes across the period, successive e’s are added to “inner” 3d orbitals and the radii are relatively constant.



**how would the radius of F compare to that of F<sup>-</sup> ?**

- **F**  $1s^2 2s^2 2p^{\textcircled{5}}$       **F<sup>-</sup>**  $1s^2 2s^2 2p^{\textcircled{6}}$
- **outer electron n=2 for both,  $Z_{\text{nuclear}}=+9$  for both**
- **how does  $Z_{\text{eff}}$  for 2p in F compare to  $Z_{\text{eff}}$  for 2p in F<sup>-</sup> ?**
  - **2p e in F is shielded by ? electrons in same subshell**
  - **2p e in F<sup>-</sup> is shielded by ? electrons in same subshell**
  - **$(Z_{\text{eff}})_{\text{F}}$  ?  $(Z_{\text{eff}})_{\text{F}^-}$**
- **radius (F) ? radius (F<sup>-</sup>)**
- **Experiment: F: r=64 pm      F<sup>-</sup> : r=136 pm**

*(fig. 12.38)*

*(fig. 13.8)*

# For today



*no rest for the weary !!*



Monday, 17 October !!!  
*after midterm*



iClicker-Check-Up Video 4  
[Study Guide 4 I-IV](#)  
*the whole thing !*



**How's your  
CHEM1B-AL  
health?**



## worksheet IV : how do $Z_{\text{eff}}$ and $n$ vary across and down periodic table?

---

### I. General Periodic Trends

1. Atomic 'energies' and atomic 'size' are two important quantities in understanding the properties of atoms. Two relationships (taken from Bohr's treatment of the H atom) are:

gas phase energy of electron with  $n, Z_{\text{eff}}$ :  $E \approx -\left(2.18 \times 10^{-18} \text{ J}\right) \frac{Z_{\text{eff}}^2}{n^2}$  and

"Bohr" radius in gas phase  $r \approx (0.529 \times 10^{-10} \text{ m}) \frac{n^2}{Z_{\text{eff}}}$

- As  $n$  get higher the energy \_\_\_\_\_.
  - As  $Z_{\text{eff}}$  becomes larger (more positive) the energy \_\_\_\_\_.
  - As  $n$  gets larger the radius \_\_\_\_\_.
  - As  $Z_{\text{eff}}$  becomes larger (more positive) the radius \_\_\_\_\_.
2. An understanding of how  $n$  and  $Z_{\text{eff}}$  change as one adds protons and electrons is crucial. For the electrons in the 'outermost' shell:
- As one goes across a given row of the periodic table adding protons and electrons (i.e. as atomic number increases in neutral atoms) how does:  
 $n$  change \_\_\_\_\_  
 $Z_{\text{eff}}$  change \_\_\_\_\_
  - As one goes down a given column of the periodic table adding protons and electrons (i.e. as atomic number increases in neutral atoms) how does:  
 $n$  change \_\_\_\_\_  
 $Z_{\text{eff}}$  change \_\_\_\_\_



## worksheet IV: how do $Z_{\text{eff}}$ and $n$ compare for neutrals and ions?

---

- iii. From part i above. Why does  $Z_{\text{eff}}$  \_\_\_\_\_ for successive elements going across a given row of the periodic table?

- iv. From part ii above: Why is  $Z_{\text{eff}}$  \_\_\_\_\_ for successive elements going down a column of the periodic table?

Additional resource on trends in properties and periodicity:

<http://chemistry.about.com/od/periodictableelements/a/periodictrends.htm>

3. How do  $n$  and  $Z_{\text{eff}}$  for an ion compare to those for the neutral atom:

- i. Consider an anion where electrons have been added to attain a complete shell octet, e.g.  $\text{O}^{2-}$  from O.

How will  $n$  for the outer shell electrons in  $\text{O}^{2-}$  compare to that of the outer shells electrons in O?  $n$  for  $\text{O}^{2-}$  \_\_\_\_\_  $n$  for O

How will  $Z_{\text{eff}}$  for the outer shell electrons in  $\text{O}^{2-}$  compare to  $Z_{\text{eff}}$  for the outer shell electrons in O?  $Z_{\text{eff}}$  for  $\text{O}^{2-}$  \_\_\_\_\_  $Z_{\text{eff}}$  for O

- ii. Consider a cation where electrons have been removed to attain a complete shell octet, e.g.  $\text{Na}^+$  from Na.

How will  $n$  for the outer shell electrons in  $\text{Na}^+$  compare to that of the outer shells electrons in Na?  $n$  for  $\text{Na}^+$  \_\_\_\_\_  $n$  for Na

How will  $Z_{\text{eff}}$  for the outer shell electrons in  $\text{Na}^+$  compare to  $Z_{\text{eff}}$  for the outer shell electrons in Na?  $Z_{\text{eff}}$  for  $\text{Na}^+$  \_\_\_\_\_  $Z_{\text{eff}}$  for Na

## *more examples of comparing radii*

---

- Na vs Na<sup>+</sup>
- Ne vs Na<sup>+</sup>

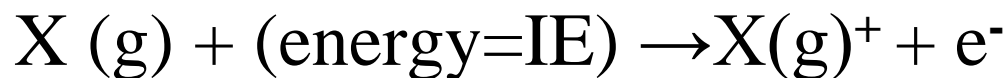
(note experimental data for Na<sup>+</sup>, fig. 13.8  
and Ne, fig. 12.38 not comparable see) ↓

- O<sup>2-</sup> vs F<sup>-</sup>
- O<sup>2-</sup> vs F

## *ionization energies (IE's)*

---

energy required to remove an electron from a gaseous atom (ion)



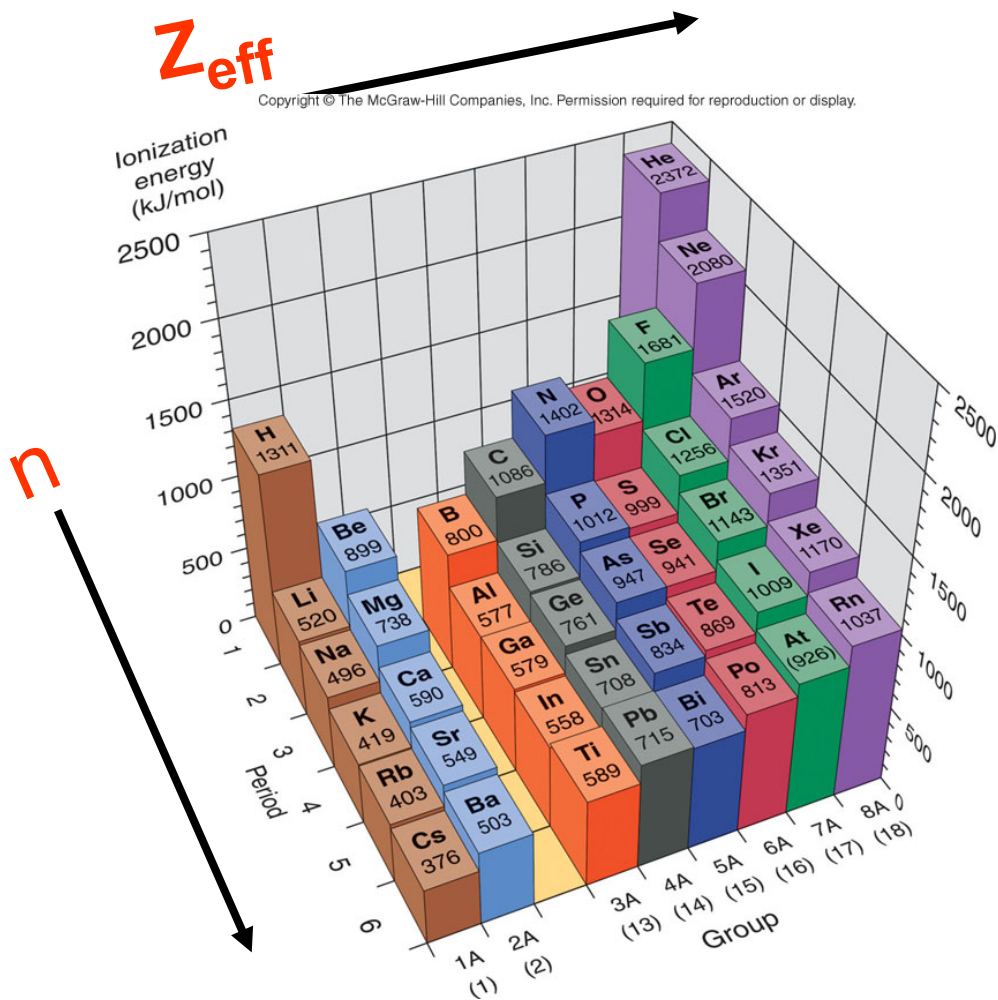
*as in chapter 9:*

energy positive (+) when absorbed in reaction (*endothermic*)

energy negative (−) when released in reaction (*exothermic*)

IE's generally positive

# ionization energies ( Zumdahl fig. 12.35, Silberberg, fig. 8.18)



gas phase energy of electron  
with  $n, Z_{\text{eff}}$

$$E \approx -\left(2.18 \times 10^{-18} \text{ J}\right) \frac{Z_{\text{eff}}^2}{n^2}$$

$$\text{IE} = -E$$

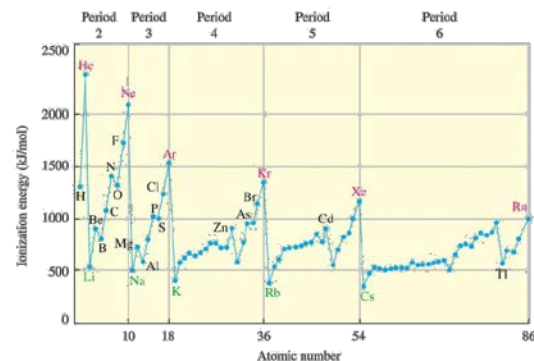
larger  $n \Rightarrow$  smaller IE

larger  $Z_{\text{eff}} \Rightarrow$  larger IE

exceptions ▢▢▢▢  $\rightarrow$

$\text{N} > \text{O}, \text{P} > \text{S}, \text{As} \approx \text{Se}$  why?

$\text{Be} > \text{B}, \text{Mg} > \text{Al}, \text{Ca} \approx \text{Ga}$  why?



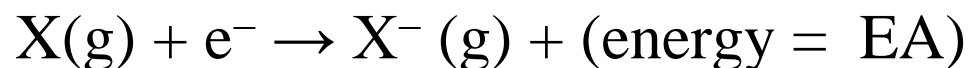
*successive gas phase ionization energies in kJ/mol (p572; S6)*

---



- successive IE's get larger (positively charged ions have greater  $Z_{\text{eff}}$ )
- large jumps in IE when n of electron removed changes

the energy of the reaction when an electron is added to  
an atom



negative EA means energy given off (exothermic)

positive EA means ion unstable relative to neutral atom

*(some older texts use opposite)*

# electron affinities (Zumdahl fig 12.36; Silb fig. 8.20)

$n$   $Z_{\text{eff}}$



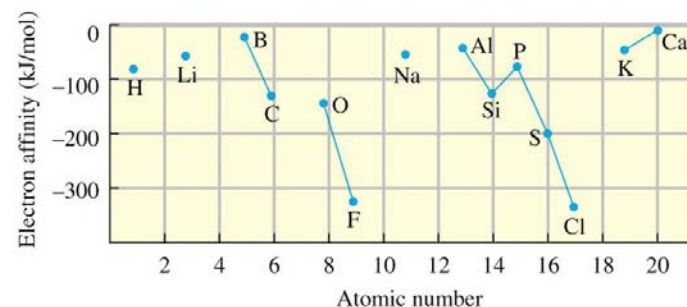
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1A (1)							8A (18)
H -72.8							He (0.0)
Li -59.6	2A (2) Be (+18)	3A (13) B -26.7	4A (14) C -122	5A (15) N +7	6A (16) O -141	7A (17) F -328	Ne (+29)
Na -52.9	Mg (+21)	Al -42.5	Si -134	P -72.0	S -200	Cl -349	Ar (+35)
K -48.4	Ca (+186)	Ga -28.9	Ge -119	As -78.2	Se -195	Br -325	Kr (+39)
Rb -46.9	Sr (+146)	In -28.9	Sn -107	Sb -103	Te -190	I -295	Xe (+41)
Cs -45.5	Ba (+46)	Tl -19.3	Pb -35.1	Bi -91.3	Po -183	At -270	Rn (+41)

higher  $n \Rightarrow$   
smaller (less negative) EA

larger  $Z_{\text{eff}} \Rightarrow$   
larger (more negative) EA

positive EA  $\Rightarrow$   
negative ion unstable



[harder to measure and "less regular" than I.E.'s]

# F vs Cl electron affinities (Zumdahl p 577)

$n$   $Z_{\text{eff}}$



higher  $n \Rightarrow$   
smaller (less negative) EA

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1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
H -72.8							He (0.0)
Li -59.6	Be (+18)	B -26.7	C -122	N +7	O -141	F -328	Ne (+29)
Na -52.9	Mg (+21)	Al -42.5	Si -134	P -72.0	S -200	Cl -349	Ar (+35)
K -48.4	Ca (+186)	Ga -28.9	Ge -119	As -78.2	Se -195	Br -325	Kr (+39)
Rb -46.9	Sr (+146)	In -28.9	Sn -107	Sb -103	Te -190	I -295	Xe (+41)
Cs -45.5	Ba (+46)	Tl -19.3	Pb -35.1	Bi -91.3	Po -183	At -270	Rn (+41)

small size of  $F^-$

**HW #3**  
**Prob 27a**





Journal of Fluorine Chemistry 116 (2002) 35–39

**JOURNAL OF  
FLUORINE  
CHEMISTRY**

[www.elsevier.com/locate/jfluchem](http://www.elsevier.com/locate/jfluchem)

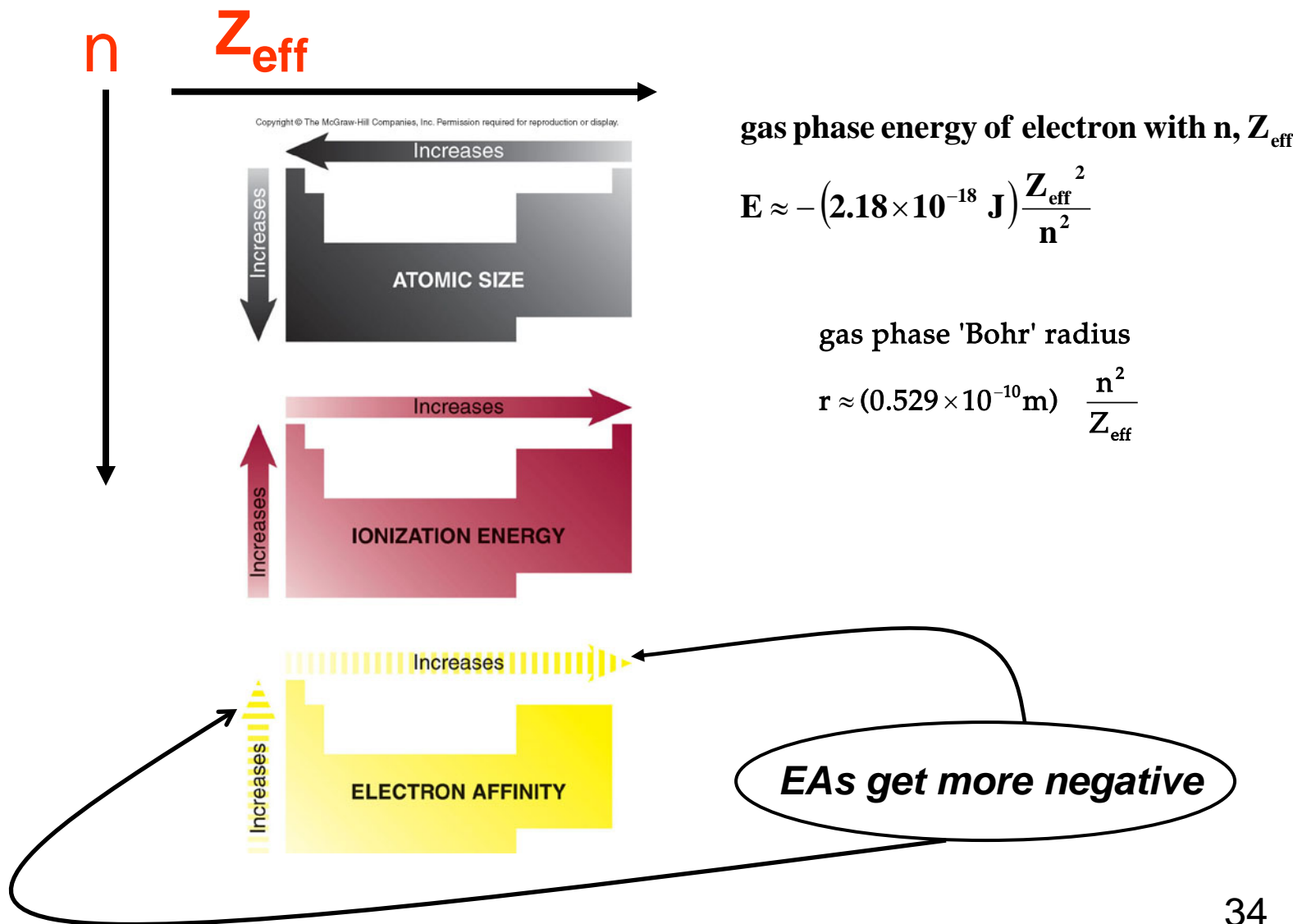
How anomalous are the anomalous properties of fluorine?  
Ionization energy and electron affinity revisited<sup>☆</sup>

Eric D. Balighian, Joel F. Liebman<sup>\*</sup>

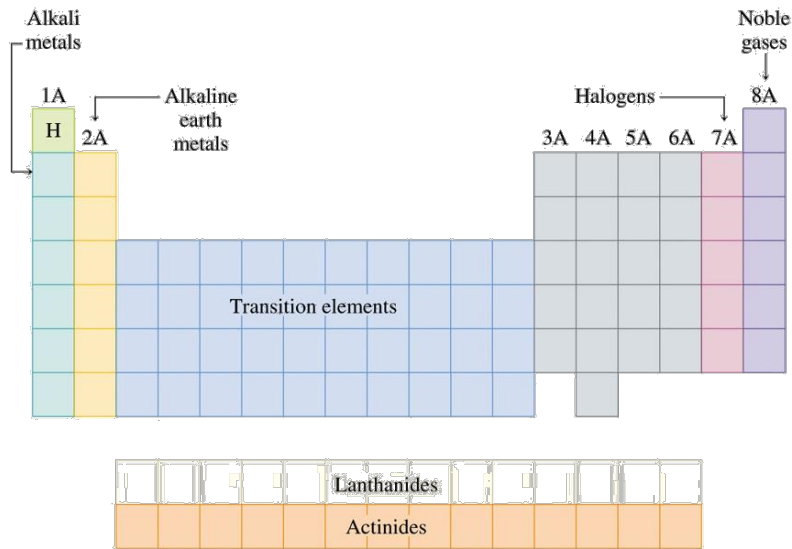
*Department of Chemistry and Biochemistry, University of Maryland, Baltimore County, Baltimore, MD 21250, USA*

Received 23 January 2002; received in revised form 7 March 2002; accepted 7 March 2002

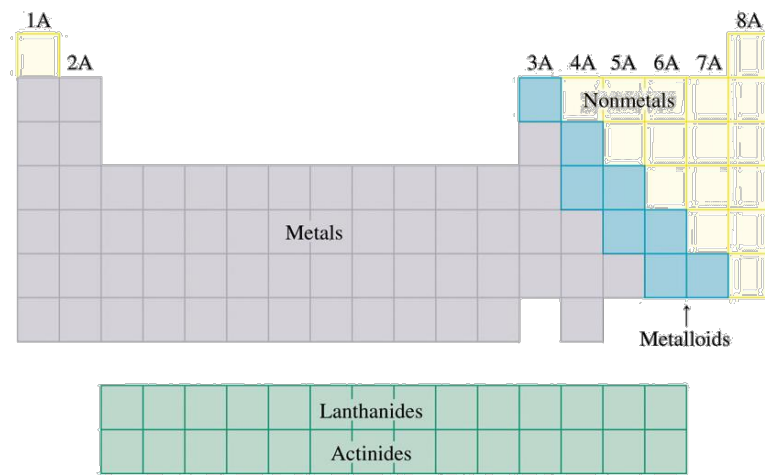
summary (Silb, fig. 8.21)



# Zumdahl (section 12.16, figure 12.39)



not responsible for  
pp. 580-582

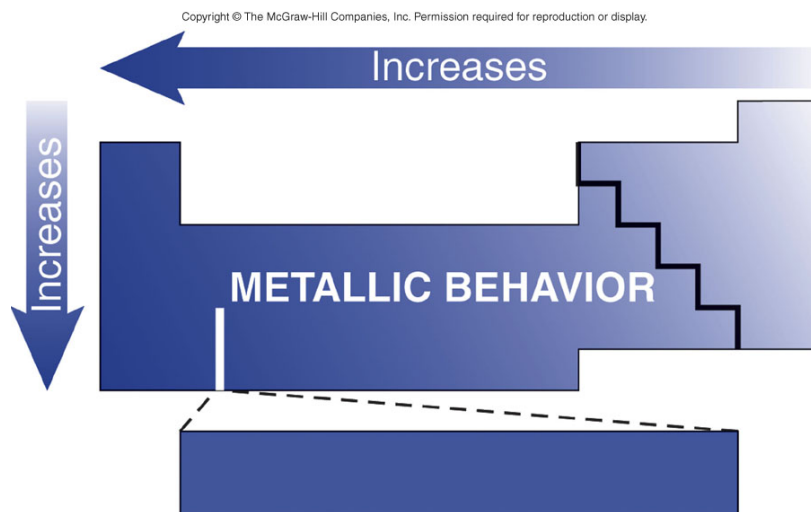


**BUT**



## metallic vs non-metallic behavior

- IE and EA      ➡
- melting point and conductivity      ➡
- acid-base behavior of oxides (*not responsible 1B before 1A*)



# periodic table of comic books

<http://www.uky.edu/Projects/Chemcomics/>



## THE PERIODIC TABLE of COMIC BOOKS



Welcome to the Periodic Table of Comic Books. Click on an element to see a list of comic book pages involving that element. Click on a thumbnail on the list to see a full comic book page. For technical information about an element, follow the link to Mark Winter's [WebElements](#). We recommend that you start with [oxygen](#) to see some of our best stuff. There's something for everyone [here!](#)

H																	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		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt										
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



$$IE = + \left( 2.18 \times 10^{-18} \text{ J} \right) \frac{Z_{\text{eff}}^2}{n^2}$$

$$r \approx \left( 0.529 \times 10^{-10} \text{ m} \right) \frac{n^2}{Z_{\text{eff}}}$$

END OF LECTURES  
ADVENTURES 7-8

# comparing $\text{Na}^+$ to Ne (similar experimental measures)

*American Mineralogist, Volume 80, pages 670–675, 1995*

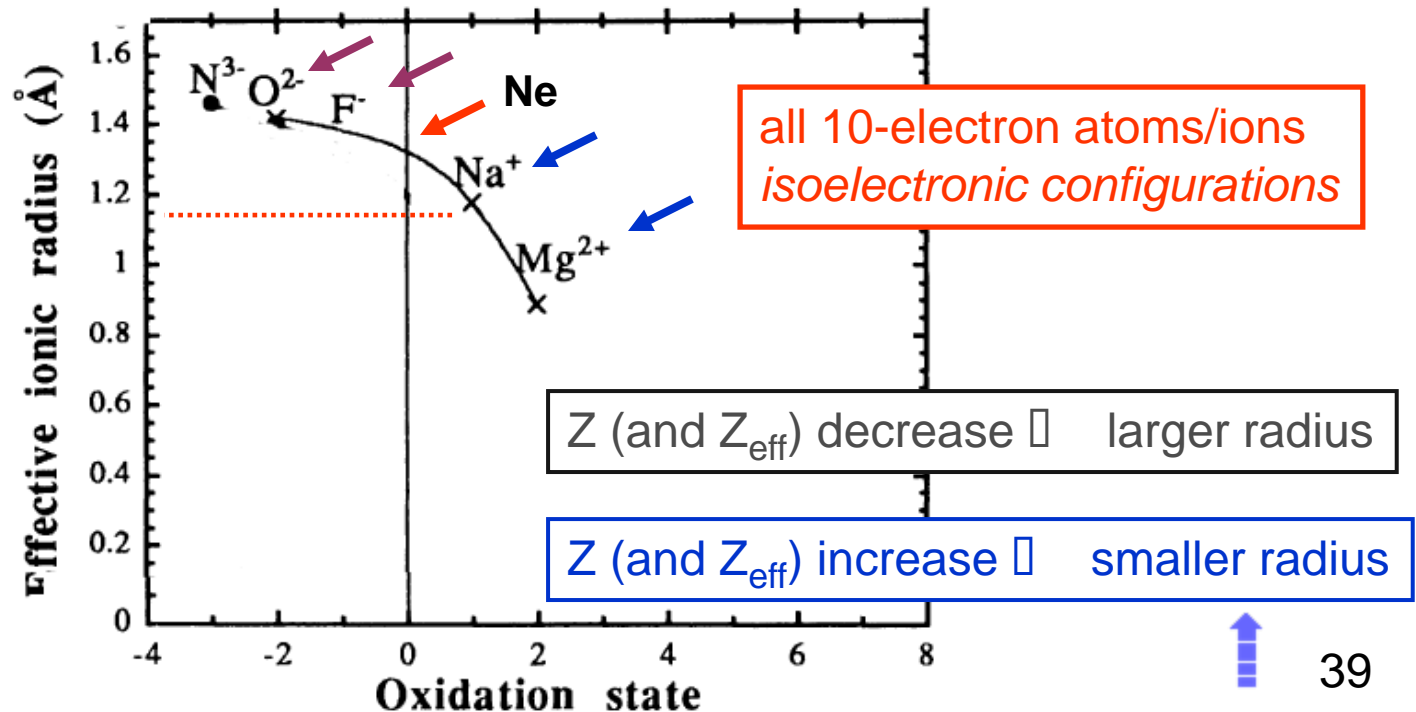
## Atomic radii of noble gas elements in condensed phases

TABLE 1. Radii (in ångströms) of noble gas elements given in the literature

Ref.	Description	He	Ne
1	univalent radii	0.93	1.12
2	radii in crystal lattice	1.78	1.60
3	van der Waals radii	1.22	1.60
4	covalent radii	~0.325	0.69
5	covalent radii	—	0.76

← Zum fig 12.38

Zum ~ fig 13.8  
 $\text{Na}^+$  95 pm



# figure Silberberg 9.1

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Key:

- Metals
- Nonmetals
- Metalloids

1A (1)	2A (2)																			7A (17)	8A (18)
Li	Be											B	C	N	O	F	Ne				
Na	Mg	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8) (9) (10)			1B (11)	2B (12)	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	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	110	111	112		114								
A																					
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu								
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr								

PROPERTY	METAL ATOM	NONMETAL ATOM
Atomic size	Larger	Smaller
$Z_{eff}$	Lower	Higher
IE	Lower	Higher
EA	Less negative	More negative

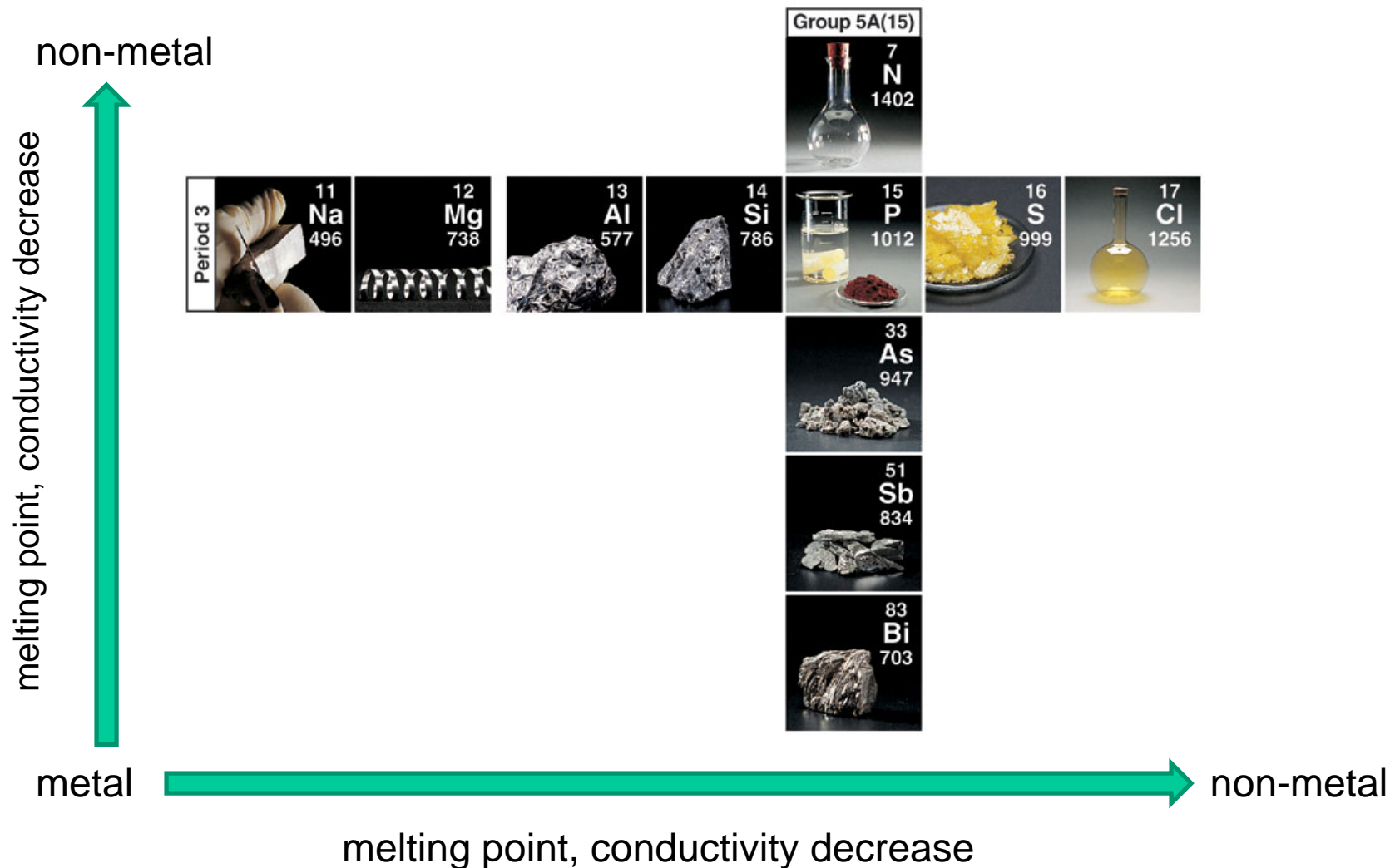
B Relative magnitudes of atomic properties within a period





# Silberberg figure 8.23

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**exceptions to ionization potential trend of increasing  
as one 'goes across periodic table' !!**

exceptions

**N > O, P > S, As  $\approx$  Se why? *team 1 in each section***

**Be > B, Mg > Al, Ca  $\approx$  Ga why? *team 2 in each section***

