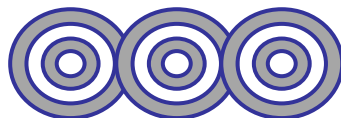




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Chapter 8

Periodic Relationships Among the Elements

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8.2

Periodic classification of the elements

When the Elements Were Discovered

1 H Hydrogen 1766 Cavendish	2 He Helium 1868 J.J. Thomson, Lord Rayleigh																
3 Li Lithium 1817 Arfwedson	4 Be Beryllium 1798 Vauquelin	5 B Boron 1808 Gay-Lussac, Thénard	6 C Carbon Ancient	7 N Nitrogen 1772 Rutherford	8 O Oxygen 1771 Scheele	9 F Fluorine 1810 Ampère	10 Ne Neon 1898 Ramsay, Travers										
11 Na Sodium 1807 Davy	12 Mg Magnesium 1755 Black	13 Al Aluminum 1825 Ørsted	14 Si Silicon 1823 Berzelius	15 P Phosphorus 1669 Brand	16 S Sulfur Ancient	17 Cl Chlorine 1774 Scheele	18 Ar Argon 1894 Rayleigh, Ramsay										
19 K Potassium 1807 Davy	20 Ca Calcium 1808 Davy	21 Sc Scandium 1879 Nilson	22 Ti Titanium 1791 Gregor	23 V Vanadium 1801 M. Del Rio	24 Cr Chromium 1794 Vauquelin	25 Mn Manganese 1774 Scheele	26 Fe Iron Ancient	27 Co Cobalt 1735 Brandt	28 Ni Nickel 1751 Cronstedt	29 Cu Copper Ancient	30 Zn Zinc Ancient	31 Ga Gallium 1875 P.E.L. de Boisbaudran	32 Ge Germanium 1886 Winkler	33 As Arsenic Ancient	34 Se Selenium 1817 Berzelius Gahn	35 Br Bromine 1825 Balard, Löwig	36 Kr Krypton 1898 Ramsay, Travers
37 Rb Rubidium 1861 Bunsen, Kirchhoff	38 Sr Strontium 1787 Cruikshank	39 Y Yttrium 1794 Gadolin	40 Zr Zirconium 1789 Klaproth	41 Nb Niobium 1801 Hatchett	42 Mo Molybdenum 1778 Scheele	43 Tc Technetium 1937 Perrier, Segrè	44 Ru Ruthenium 1844 Claus	45 Rh Rhodium 1804 Wollaston	46 Pd Palladium 1802 Wollaston	47 Ag Silver Ancient	48 Cd Cadmium 1817 Hermann, Stromeyer, Roloff	49 In Indium 1863 Richter, Reichow	50 Sn Tin Ancient	51 Sb Antimony Ancient	52 Te Tellurium 1782 Müller von Reichenstein	53 I Iodine 1811 Courtois	54 Xe Xenon 1898 Ramsay, Travers
55 Cs Cesium 1860 Bunsen, Kirchhoff	56 Ba Barium 1772 Scheele	72 Hf Hafnium 1922 Coster, de Hevesy	73 Ta Tantalum 1802 Ekeberg	74 W Tungsten 1781 Scheele	75 Re Rhenium 1908 Ogawa	76 Os Osmium 1803 Tennant	77 Ir Iridium 1803 Tennant	78 Pt Platinum 1735 de Ulloa	79 Au Gold Ancient	80 Hg Mercury Ancient	81 Tl Thallium 1861 Crookes	82 Pb Lead Ancient	83 Bi Bismuth 1753 Geoffroy	84 Po Polonium 1898 P. and M. Curie	85 At Astatine 1940 Corson, MacKenzie, Segrè	86 Rn Radon 1899 Rutherford, Owens	
87 Fr Francium 1939 Perey	88 Ra Radium 1898 P. and M. Curie	104 Rf Rutherfordium 1969 Berkeley Radiation JINR (Dubna)	105 Db Dubnium 1970 Berkeley Radiation JINR (Dubna)	106 Sg Seaborgium 1974 Berkeley Radiation	107 Bh Bohrium 1981 GSI (Darmstadt)	108 Hs Hassium 1984 GSI (Darmstadt)	109 Mt Meitnerium 1982 GSI (Darmstadt)	110 Ds Darmstadtium 1994 GSI (Darmstadt)	111 Rg Roentgenium 1994 GSI (Darmstadt)	112 Cn Copernicium 1996 GSI (Darmstadt)	113 Nh Nihonium 2003 JINR (Dubna), RIKEN (Wako)	114 Fl Flerovium 1999 JINR (Dubna)	115 Mc Moscovium 2003 JINR (Dubna)	116 Lv Livermorium 1999 JINR (Dubna)	117 Ts Tennessine 2009 JINR (Dubna)	118 Og Oganesson 2002 JINR (Dubna)	
57 La Lanthanum 1838 Mosander	58 Ce Cerium 1803 Klaproth, Berzelius, Hisinger	59 Pr Praseodymium 1885 Auer von Welsbach	60 Nd Neodymium 1885 Auer von Welsbach	61 Pm Promethium 1942 Wu, Segrè, Bethe	62 Sm Samarium 1879 P.E.L. de Boisbaudran	63 Eu Europium 1896 Biemericy	64 Gd Gadolinium 1880 J. C. G. de Marignac	65 Tb Terbium 1843 Mosander	66 Dy Dysprosium 1886 P.E.L. de Boisbaudran	67 Ho Holmium 1878 Soret	68 Er Erbium 1843 Mosander	69 Tm Thulium 1879 Cleve	70 Yb Ytterbium 1878 J. C. G. de Marignac	71 Lu Lutetium 1906 Auer von Welsbach, Urbain			
89 Ac Actinium 1902 Giesel	90 Th Thorium 1829 Berzelius	91 Pa Protactinium 1913 Göhring, Fajans	92 U Uranium 1789 Klaproth	93 Np Neptunium 1940 McMillan, Abelson	94 Pu Plutonium 1940 Seaborg, Wahl, Kennedy, McMillan	95 Am Americium 1944 Seaborg, James, Ghiorso	96 Cm Curium 1944 Seaborg, James, Ghiorso	97 Bk Berkelium 1949 UC Berkeley	98 Cf Californium 1950 UC Berkeley	99 Es Einsteinium 1952 UC Berkeley, Argonne, Los Alamos	100 Fm Fermium 1952 UC Berkeley, Argonne, Los Alamos	101 Md Mendelevium 1955 Berkeley Radiation Laboratory	102 No Nobelium 1958 JINR (Dubna)	103 Lr Lawrencium 1961 Berkeley Radiation Laboratory			



A periodic table of elements with color-coded groups. The table is organized into several distinct color regions: 1. Representative elements (grey), 2. Noble gases (green), 3. Transition metals (light blue), 4. Zinc, Cadmium, Mercury (yellow-green), 5. Lanthanides (olive green), 6. Actinides (orange-red), 7. Other elements (light tan). The main table shows elements from Hydrogen (H) to Oganesson (Og). The Lanthanide and Actinide series are shown as insets below the main table, connected by lines. Labels for groups and periods are provided throughout the table.

																	18 8A								
1 1A																2 He									
1 H	2 2A											13 3A	14 4A	15 5A	16 6A	17 7A	18 8A								
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne								
11 Na	12 Mg	3 3B	4 4B	5 5B	6 6B	7 7B	8	9	10	11 1B	12 2B	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar								
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	57 La	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	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og								
												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	71 Lu
												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	103 Lr

Classification of the elements.

Ground State Electron Configurations of the Elements

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

The ground-state electron configurations of the elements. For simplicity, only the configurations of the outer electrons are shown.

1	1A 1 H 1s ¹	2A 2 He 1s ²											3A 3 B 2s ² 2p ¹	4A 4 C 2s ² 2p ²	5A 5 N 2s ² 2p ³	6A 6 O 2s ² 2p ⁴	7A 7 F 2s ² 2p ⁵	8A 8 Ne 2s ² 2p ⁶
2	3 Li 2s ¹	4 Be 2s ²	3B 3 B 3s ² 3d ¹	4B 4 C 3s ² 3d ²	5B 5 N 3s ² 3d ³	6B 6 O 3s ² 3d ⁴	7B 7 F 3s ² 3d ⁵	8B 8 Ne 3s ² 3d ⁶	9 9 Na 3s ² 3d ⁷	10 10 Mg 3s ² 3d ⁸	11 11 Al 3s ² 3d ⁹	12 12 Si 3s ² 3d ¹⁰	3A 3 B 3s ² 3p ¹	4A 4 C 3s ² 3p ²	5A 5 N 3s ² 3p ³	6A 6 O 3s ² 3p ⁴	7A 7 F 3s ² 3p ⁵	8A 8 Ar 3s ² 3p ⁶
3	4 K 4s ¹	5 Ca 4s ²	21 Sc 4s ² 3d ¹	22 Ti 4s ² 3d ²	23 V 4s ² 3d ³	24 Cr 4s ¹ 3d ⁵	25 Mn 4s ² 3d ⁵	26 Fe 4s ² 3d ⁶	27 Co 4s ² 3d ⁷	28 Ni 4s ² 3d ⁸	29 Cu 4s ¹ 3d ¹⁰	30 Zn 4s ² 3d ¹⁰	31 Ga 4s ² 3d ¹⁰ 4p ¹	32 Ge 4s ² 3d ¹⁰ 4p ²	33 As 4s ² 3d ¹⁰ 4p ³	34 Se 4s ² 3d ¹⁰ 4p ⁴	35 Br 4s ² 3d ¹⁰ 4p ⁵	36 Kr 4s ² 3d ¹⁰ 4p ⁶
4	37 Rb 5s ¹	38 Sr 5s ²	39 Y 5s ² 4d ¹	40 Zr 5s ² 4d ²	41 Nb 5s ¹ 4d ⁴	42 Mo 5s ¹ 4d ⁵	43 Tc 5s ² 4d ⁵	44 Ru 5s ¹ 4d ⁷	45 Rh 5s ¹ 4d ⁸	46 Pd 4d ¹⁰	47 Ag 5s ¹ 4d ¹⁰	48 Cd 5s ² 4d ¹⁰	49 In 5s ² 4d ¹⁰ 5p ¹	50 Sn 5s ² 4d ¹⁰ 5p ²	51 Sb 5s ² 4d ¹⁰ 5p ³	52 Te 5s ² 4d ¹⁰ 5p ⁴	53 I 5s ² 4d ¹⁰ 5p ⁵	54 Xe 5s ² 4d ¹⁰ 5p ⁶
5	55 Cs 6s ¹	56 Ba 6s ²	57 La 6s ² 5d ¹	72 Hf 6s ² 5d ²	73 Ta 6s ² 5d ³	74 W 6s ² 5d ⁴	75 Re 6s ² 5d ⁵	76 Os 6s ² 5d ⁶	77 Ir 6s ² 5d ⁷	78 Pt 6s ¹ 5d ⁹	79 Au 6s ¹ 5d ¹⁰	80 Hg 6s ² 5d ¹⁰	81 Tl 6s ² 5d ¹⁰ 6p ¹	82 Pb 6s ² 5d ¹⁰ 6p ²	83 Bi 6s ² 5d ¹⁰ 6p ³	84 Po 6s ² 5d ¹⁰ 6p ⁴	85 At 6s ² 5d ¹⁰ 6p ⁵	86 Rn 6s ² 5d ¹⁰ 6p ⁶
6	87 Fr 7s ¹	88 Ra 7s ²	89 Ac 7s ² 6d ¹	104 Rf 7s ² 6d ²	105 Db 7s ² 6d ³	106 Sg 7s ² 6d ⁴	107 Bh 7s ² 6d ⁵	108 Hs 7s ² 6d ⁶	109 Mt 7s ² 6d ⁷	110 Ds 7s ² 6d ⁸	111 Rg 7s ² 6d ⁹	112 Cn 7s ² 6d ¹⁰	113 Nh 7s ² 6d ¹⁰ 7p ¹	114 Fl 7s ² 6d ¹⁰ 7p ²	115 Mc 7s ² 6d ¹⁰ 7p ³	116 Lv 7s ² 6d ¹⁰ 7p ⁴	117 Ts 7s ² 6d ¹⁰ 7p ⁵	118 Og 7s ² 6d ¹⁰ 7p ⁶

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

Electron Configurations of Cations and Anions

Ions Derived from Representative Elements

Atoms lose or gain electrons so that cation or anions have a noble-gas outer electron configuration.

In the formation of a cation from the atom of a representative element, one or more electrons are removed from the highest occupied n shell.

Na: [Ne] $3s^1$	Na ⁺ : [Ne]
Ca: [Ar] $4s^2$	Ca ²⁺ : [Ar]
Al: [Ne] $3s^2 3p^1$	Al ³⁺ : [Ne]

H: $1s^1$	H ⁻ : $1s^2$ or [He]
F: $1s^2 2s^2 2p^5$	F ⁻ : $1s^2 2s^2 2p^6$ or [Ne]
O: $1s^2 2s^2 2p^4$	O ²⁻ : $1s^2 2s^2 2p^6$ or [Ne]
N: $1s^2 2s^2 2p^3$	N ³⁻ : $1s^2 2s^2 2p^6$ or [Ne]

In the formation of an anion, one or more electrons are added to the highest partially filled n shell.

Cations and Anions Of Representative Elements

	+1 1 1A	+2 2 2A											+3 3 3A	14 4A	-3 15 5A	-2 16 6A	-1 17 7A	18 8A
1	1 H 1s ¹												13 B 2s ² 2p ¹	14 C 2s ² 2p ²	15 N 2s ² 2p ³	16 O 2s ² 2p ⁴	17 F 2s ² 2p ⁵	18 Ne 2s ² 2p ⁶
2	3 Li 2s ¹	4 Be 2s ²											13 Al 3s ² 3p ¹	14 Si 3s ² 3p ²	15 P 3s ² 3p ³	16 S 3s ² 3p ⁴	17 Cl 3s ² 3p ⁵	18 Ar 3s ² 3p ⁶
3	11 Na 3s ¹	12 Mg 3s ²	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	31 Ga 4s ² 4p ¹	32 Ge 4s ² 4p ²	33 As 4s ² 4p ³	34 Se 4s ² 4p ⁴	35 Br 4s ² 4p ⁵	36 Kr 4s ² 4p ⁶
4	19 K 4s ¹	20 Ca 4s ²	21 Sc 4s ² 3d ¹	22 Ti 4s ² 3d ²	23 V 4s ² 3d ³	24 Cr 4s ¹ 3d ⁵	25 Mn 4s ² 3d ⁵	26 Fe 4s ² 3d ⁶	27 Co 4s ² 3d ⁷	28 Ni 4s ² 3d ⁸	29 Cu 4s ¹ 3d ¹⁰	30 Zn 4s ² 3d ¹⁰	31 Ga 4s ² 4p ¹	32 Ge 4s ² 4p ²	33 As 4s ² 4p ³	34 Se 4s ² 4p ⁴	35 Br 4s ² 4p ⁵	36 Kr 4s ² 4p ⁶
5	37 Rb 5s ¹	38 Sr 5s ²	39 Y 5s ² 4d ¹	40 Zr 5s ² 4d ²	41 Nb 5s ¹ 4d ⁴	42 Mo 5s ¹ 4d ⁵	43 Tc 5s ² 4d ⁵	44 Ru 5s ¹ 4d ⁷	45 Rh 5s ¹ 4d ⁸	46 Pd 4d ¹⁰	47 Ag 5s ¹ 4d ¹⁰	48 Cd 5s ² 4d ¹⁰	49 In 5s ² 5p ¹	50 Sn 5s ² 5p ²	51 Sb 5s ² 5p ³	52 Te 5s ² 5p ⁴	53 I 5s ² 5p ⁵	54 Xe 5s ² 5p ⁶
6	55 Cs 6s ¹	56 Ba 6s ²	57 La 6s ² 5d ¹	72 Hf 6s ² 5d ²	73 Ta 6s ² 5d ³	74 W 6s ² 5d ⁴	75 Re 6s ² 5d ⁵	76 Os 6s ² 5d ⁶	77 Ir 6s ² 5d ⁷	78 Pt 6s ¹ 5d ⁹	79 Au 6s ¹ 5d ¹⁰	80 Hg 6s ² 5d ¹⁰	81 Tl 6s ² 5p ¹	82 Pb 6s ² 6p ²	83 Bi 6s ² 5p ³	84 Po 6s ² 5p ⁴	85 At 6s ² 5p ⁵	86 Rn 6s ² 6p ⁶
7	87 Fr 7s ¹	88 Ra 7s ²	89 Ac 7s ² 6d ¹	104 Rf 7s ² 6d ²	105 Db 7s ² 6d ³	106 Sg 7s ² 6d ⁴	107 Bh 7s ² 6d ⁵	108 Hs 7s ² 6d ⁶	109 Mt 7s ² 6d ⁷	110 Ds 7s ² 6d ⁸	111 Rg 7s ² 6d ⁹	112 Cn 7s ² 6d ¹⁰	113 Nh 7s ² 7p ¹	114 Fl 7s ² 7p ²	115 Mc 7s ² 7p ³	116 Lv 7s ² 7p ⁴	117 Ts 7s ² 7p ⁵	118 Og 7s ² 7p ⁶

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

Isoelectronic atoms have the same number of electrons, and hence the same ground-state electron configuration.

For example:

H⁻ and He are isoelectronic.

For example:

Na⁺: [Ne]

Al³⁺: [Ne]

F⁻: 1s²2s²2p⁶ or [Ne]

O²⁻: 1s²2s²2p⁶ or [Ne]

N³⁻: 1s²2s²2p⁶ or [Ne]

Na⁺, Al³⁺, F⁻, O²⁻, and N³⁻ are all isoelectronic with Ne.

Electron Configurations of Cations and Anions

Cations Derived from Transition Metals

When a cation is formed from an atom of a transition metal, electrons are always removed first from the ***ns*** orbital and then from the ***(n-1)d*** orbitals.

For example:



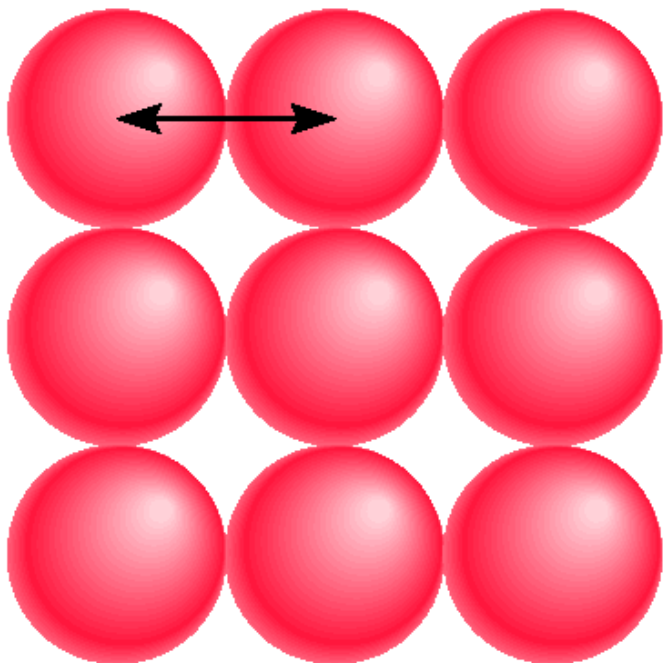
For example:



8.3

Periodic variation in physical properties

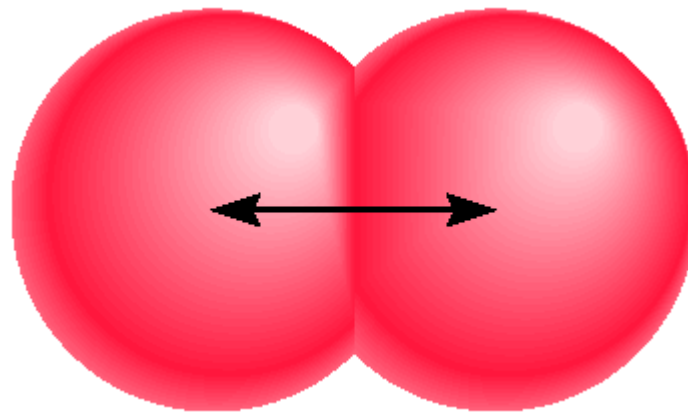
Atomic Radii



metallic radius

In metals such as beryllium, the atomic radius is defined as one-half the distance between the centers of two adjacent atoms.

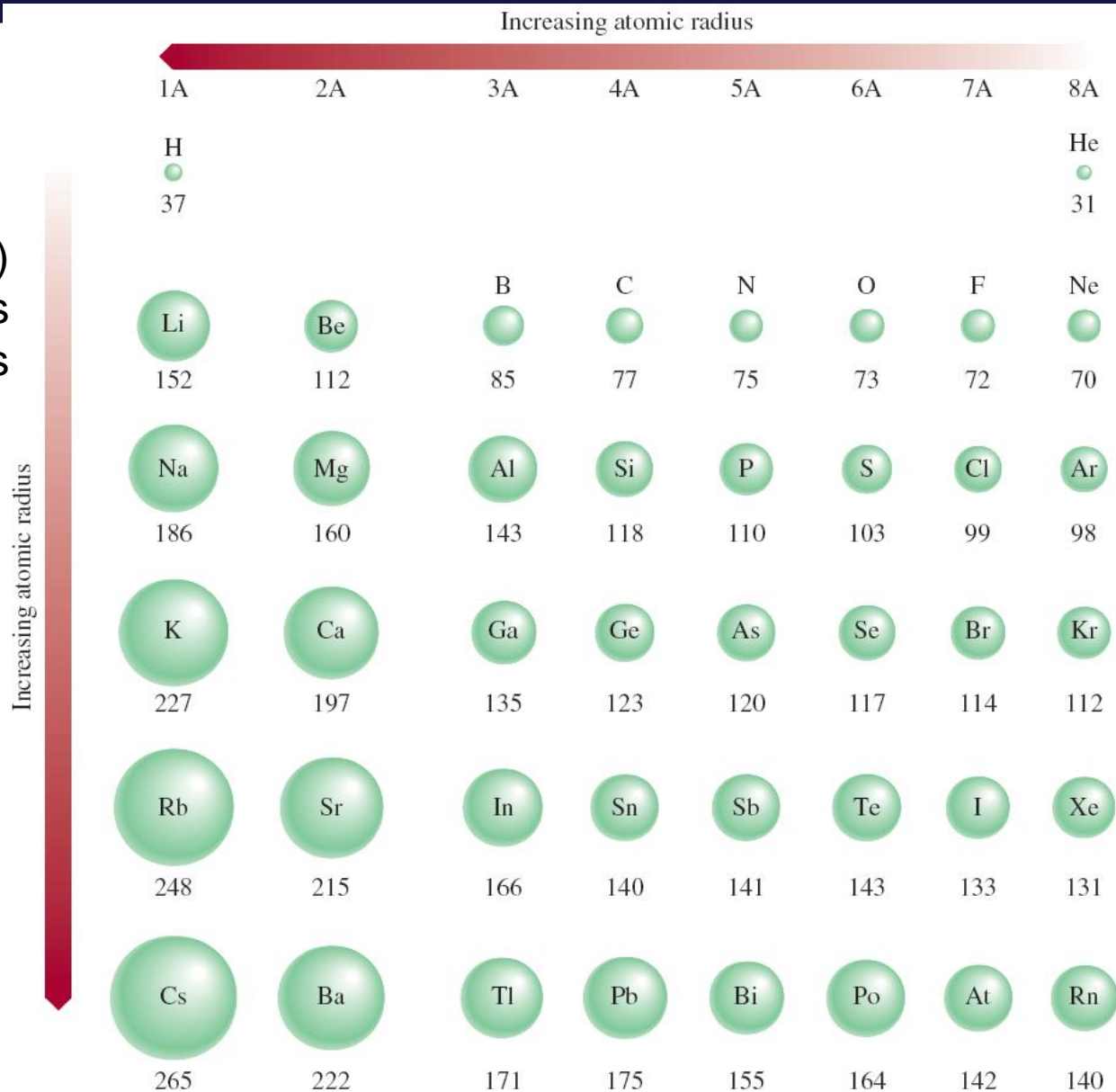
For elements that exist as diatomic molecules, such as iodine, the radius of the atom is defined as one-half the distance between the centers of the atoms in the molecule.



covalent radius

Trends in Atomic Radii

Atomic radii (in picometers) of representative elements according to their positions in the periodic table.



Note that there is no general agreement on the size of atomic radii. We focus only on the trends in atomic radii, not on their precise values.

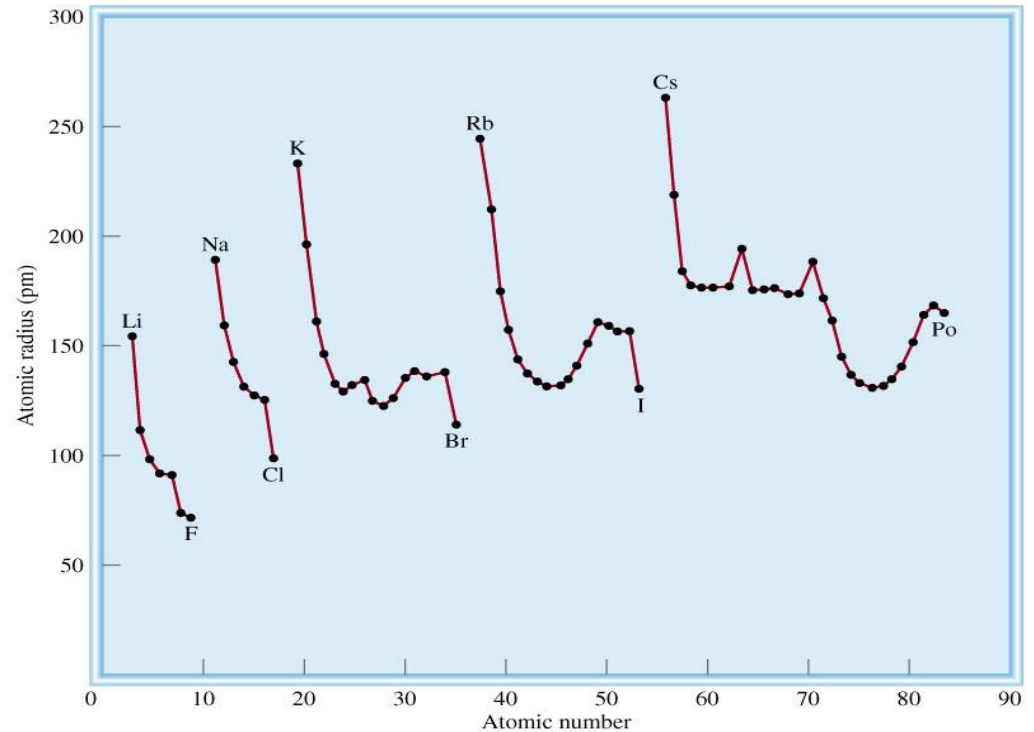
Atomic Radius Increase

1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 18.99	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium [98]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [268]	106 Sg Seaborgium [266]	107 Bh Bohrium [270]	108 Hs Hassium [277]	109 Mt Meitnerium [276]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [282]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [288]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

Atomic Radius Increase

General Trends in Atomic Radius

Plot of atomic radii (in picometers) of elements against their atomic numbers.



EXAMPLE

Referring to a periodic table, arrange the following atoms in order of increasing atomic radius: P, Si, N.

Solution

N and P are in the same group (Group 5A). Therefore, the radius of N is smaller than that of P (atomic radius increases as we go down a group).

Both Si and P are in the third period, and Si is to the left of P. Therefore, the radius of P is smaller than that of Si (atomic radius decreases as we move from left to right across a period).

Thus, the order of increasing radius is:



Practice Exercise

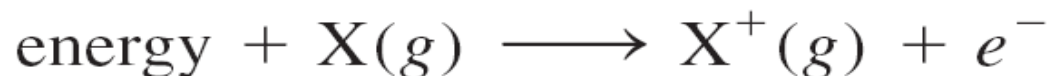
Arrange the following atoms in order of decreasing radius: C, Li, Be.

8.4

ionization energy

Ionization energy

Ionization energy is the minimum energy (kJ/mol) required to remove an electron from a gaseous atom in its ground state.



When an electron is removed from an atom, the repulsion among the remaining electrons decreases. Because the nuclear charge remains constant, more energy is needed to remove another electron from the positively charged ion. Thus, ionization energies always increase in the following order:

$$I_1 < I_2 < I_3 < \dots$$

The ionization energies (kJ/mol) of the first 20 elements

Z	Element	First	Second	Third	Fourth	Fifth	Sixth
1	H	1,312					
2	He	2,373	5,251				
3	Li	520	7,300	11,815			
4	Be	899	1,757	14,850	21,005		
5	B	801	2,430	3,660	25,000	32,820	
6	C	1,086	2,350	4,620	6,220	38,000	47,261
7	N	1,400	2,860	4,580	7,500	9,400	53,000
8	O	1,314	3,390	5,300	7,470	11,000	13,000
9	F	1,680	3,370	6,050	8,400	11,000	15,200
10	Ne	2,080	3,950	6,120	9,370	12,200	15,000
11	Na	495.9	4,560	6,900	9,540	13,400	16,600
12	Mg	738.1	1,450	7,730	10,500	13,600	18,000
13	Al	577.9	1,820	2,750	11,600	14,800	18,400
14	Si	786.3	1,580	3,230	4,360	16,000	20,000
15	P	1,012	1,904	2,910	4,960	6,240	21,000
16	S	999.5	2,250	3,360	4,660	6,990	8,500
17	Cl	1,251	2,297	3,820	5,160	6,540	9,300
18	Ar	1,521	2,666	3,900	5,770	7,240	8,800
19	K	418.7	3,052	4,410	5,900	8,000	9,600
20	Ca	589.5	1,145	4,900	6,500	8,100	11,000

Ionization Energy Increase

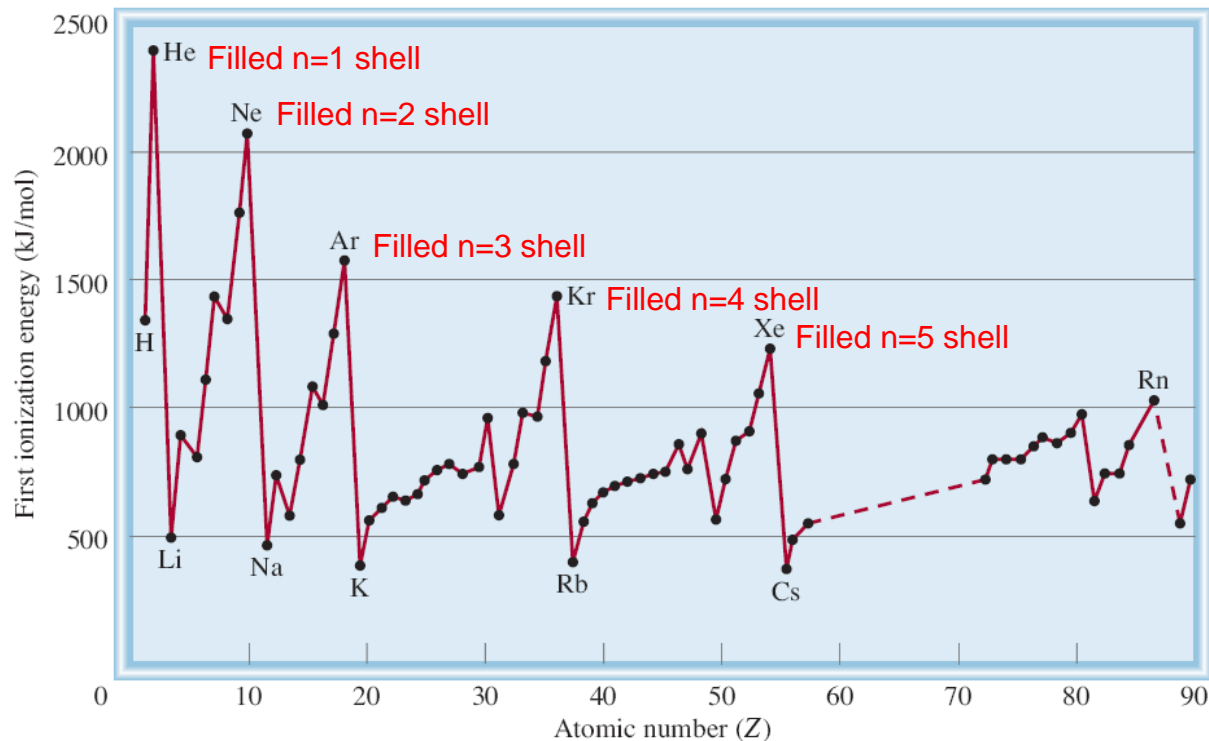
Ionization Energy Increase →																	
1																	2
H Hydrogen 1.01																	He Helium 4.00
3	4															9	10
Li Lithium 0.34	Be Beryllium 0.91															F Fluorine 1.68	Ne Neon 2.08
11	12															17	18
Na Sodium 2.20	Mg Magnesium 2.30															Cl Chlorine 3.16	Ar Argon 3.84
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K Potassium 0.90	Ca Calcium 1.09	Sc Scandium 1.63	Ti Titanium 1.69	V Vanadium 1.64	Cr Chromium 1.67	Mn Manganese 1.51	Fe Iron 1.56	Co Cobalt 1.55	Ni Nickel 1.51	Cu Copper 1.55	Zn Zinc 1.56	Ga Gallium 1.62	Ge Germanium 1.63	As Arsenic 1.62	Se Selenium 1.63	Br Bromine 1.63	Kr Krypton 1.63
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb Rubidium 0.72	Sr Strontium 0.72	Y Yttrium 0.93	Zr Zirconium 1.22	Nb Niobium 1.59	Mo Molybdenum 1.65	Tc Technetium [1.6]	Ru Ruthenium 1.62	Rh Rhodium 1.64	Pd Palladium 1.64	Ag Silver 1.07	Cd Cadmium 1.01	In Indium 1.14	Sn Tin 1.17	Sb Antimony 1.07	Te Tellurium 1.26	I Iodine 1.06	Xe Xenon 1.21
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs Cesium 1.38	Ba Barium 1.38	Lanthanides	Hf Hafnium 1.76	Ta Tantalum 1.84	W Tungsten 1.84	Re Rhenium 1.82	Os Osmium 1.82	Ir Iridium 1.82	Pt Platinum 1.82	Au Gold 1.94	Hg Mercury 2.00	Tl Thallium 2.04	Pb Lead 2.02	Bi Bismuth 2.04	Po Polonium [2.0]	At Astatine [2.1]	Rn Radon [2.2]
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr Francium [2.3]	Ra Radium [2.4]	Actinides	Rf Rutherfordium [2.7]	Db Dubnium [2.8]	Sg Seaborgium [2.8]	Bh Bohrium [2.7]	Hs Hassium [2.7]	Mt Meitnerium [2.7]	Ds Darmstadtium [2.8]	Rg Roentgenium [2.8]	Cn Copernicium [2.8]	Nh Nihonium [2.8]	Fl Flerovium [2.8]	Mc Moscovium [2.8]	Lv Livermorium [2.8]	Ts Tennessine [2.8]	Og Oganesson [2.8]

Ionization Energy Increase

General Trends in First Ionization Energies

The increase in first ionization energy from left to right across a period and from bottom to top in a group for representative elements.

Variation of the first ionization energy with atomic number. Note that the noble gases have high ionization energies, whereas the alkali metals and alkaline earth metals have low ionization energies.



EXAMPLE

- (a) Which atom should have a smaller first ionization energy: O or S?
- (b) Which atom should have a higher second ionization energy: Li or Be?

Solution

(a) Sulfur should have a smaller first ionization energy.

First ionization energy decreases as we go down a group because the outermost electron is farther away from the nucleus and feels less attraction.

(b) The electron configurations of Li and Be are $1s^2 2s^1$ and $1s^2 2s^2$, respectively. Therefore, it should be easier to remove a 2s electron from Be^+ than to remove a 1s electron from Li^+ .

Removal of the outermost electron requires less energy if it is shielded by a filled inner shell.

Practice Exercise

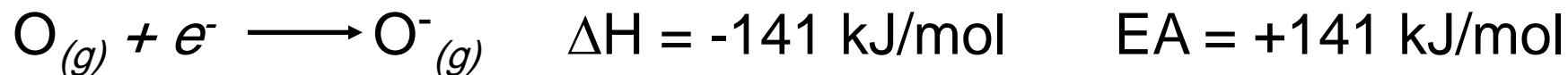
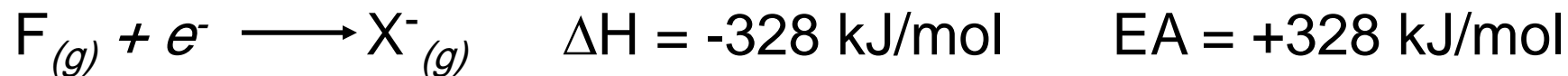
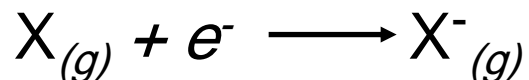
- (a) Which of the following atoms have a larger 1st ionization energy: N or P?
- (b) Which of the following atoms have a smaller 2nd ionization energy: Na or Mg?

8.5

Electron affinity

Electron affinity

Electron affinity is the negative of the energy change that occurs when an electron is accepted by an atom in the gaseous state to form an anion.



The more positive is the electron affinity of an element, the greater is the affinity of an atom of the element to accept an electron.

Electron affinities (kJ/mol) of some representative elements and the noble gases

1A	2A	3A	4A	5A	6A	7A	8A
H							He
73							< 0
Li	Be	B	C	N	O	F	Ne
60	≤ 0	27	122	0	141	328	< 0
Na	Mg	Al	Si	P	S	Cl	Ar
53	≤ 0	44	134	72	200	349	< 0
K	Ca	Ga	Ge	As	Se	Br	Kr
48	2.4	29	118	77	195	325	< 0
Rb	Sr	In	Sn	Sb	Te	I	Xe
47	4.7	29	121	101	190	295	< 0
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
45	14	30	110	110	?	?	< 0

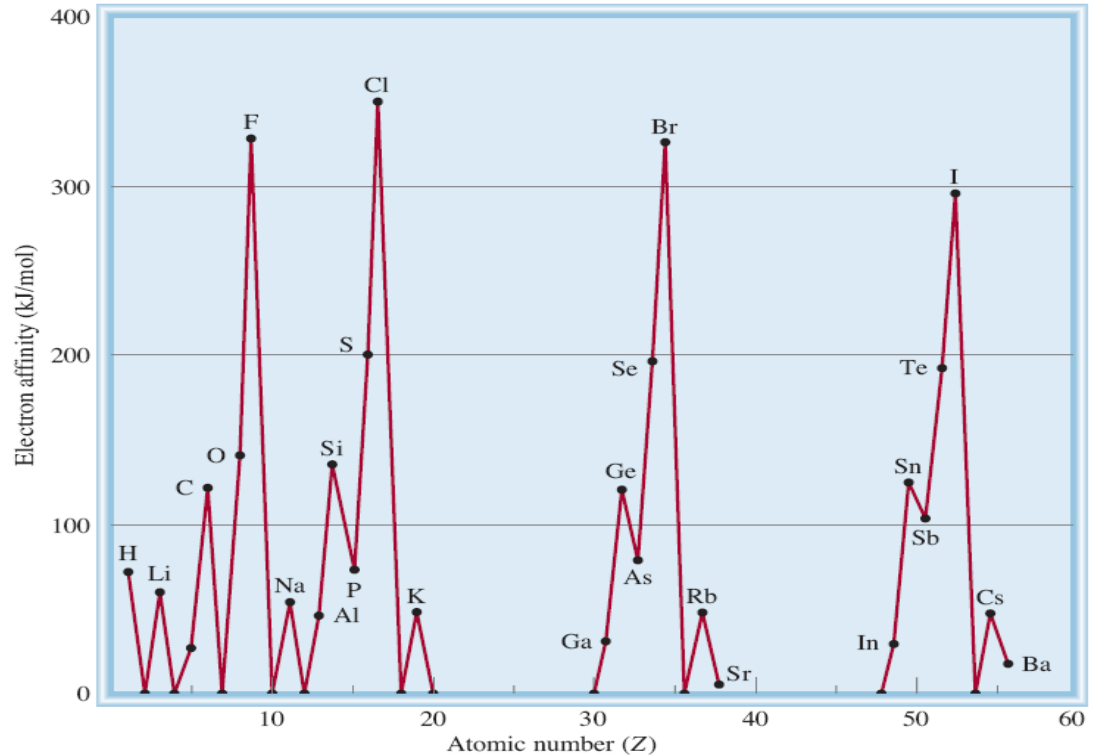
Electron Affinity Increase

1 H Hydrogen 1.01																	2 He Helium 4.00						
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19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 83.80						
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium [98]	44 Ru Ruthenium 101.07	45 Rh Rhodium 101.07	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29						
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]						
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [261]	106 Sg Seaborgium [263]	107 Bh Bohrium [264]	108 Hs Hassium [277]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [282]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]						

Electron Affinity Increase

General Trends in Electron Affinities

Variation of electron affinity with atomic number from hydrogen to barium.

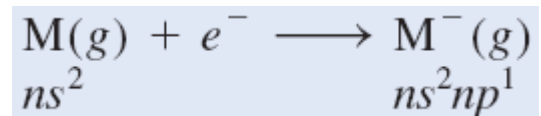


EXAMPLE

Why are the electron affinities of the alkaline earth metals, shown in the Table (above), either negative or small positive values?

Solution

The valence electron configuration of the alkaline earth metals is ns^2 , where n is the highest principal quantum number. For the process



where M denotes a member of the Group 2A family, the extra electron must enter the np subshell, which is effectively shielded by the two ns electrons (the ns electrons are more penetrating than the np electrons) and the inner electrons. Consequently, alkaline earth metals have little tendency to pick up an extra electron.

Practice Exercise

Is it likely that Ar will form the anion Ar^- ?

