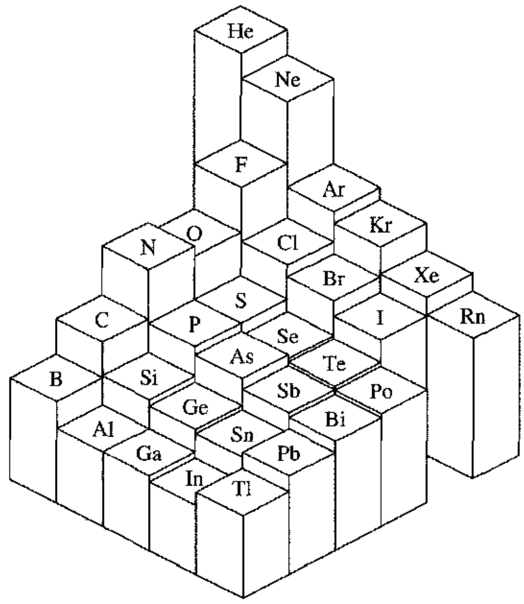
APPENDIX B



APPENDIX B-1 IONIC RADII

The values given are the crystal radii of Shannon, calculated using electron density maps and internuclear distances from X-ray data. Some of the trends that can be seen in these radii are the following:

1. Increase in size with increasing coordination number
2. Increase in size for a given coordination number with increasing Z within a periodic group
3. Decreasing size with increasing nuclear charge for isoelectronic ions
4. Decreasing size with increasing ionic charge for the same Z
5. Irregular, slowly decreasing size with increasing Z for transition metal, lanthanide, or actinide ions of the same charge
6. Larger size for high-spin ions than for low-spin ions of the same species and charge

Not shown in the table, but another apparent factor, is the decrease in anion size with increasing cation field strength, determined by the charge and size of the cation in the crystal. See O. Johnson, *Inorg. Chem.*, **1973**, *12*, 780, for the details.

Z		*Coordination Number* 2	4	6	8	10	12	14
1	H	−4						
2	He							
3	Li^{+}		73	90	106			
4	Be^{2+}		41	59				
5	B^{3+}		25					
6	C^{4+}		29					
7	N^{3-}		132					
8	O^{2-}	121	124	126	128			
	OH^{-}	118	121	123				
9	F^{-}	115	117	119				
10	Ne							
11	Na^{+}		113	116	132		153	
12	Mg^{2+}		71	86	103			
13	Al^{3+}		53	68				
14	Si^{4+}		40	54				
15	P^{3+}			58				
16	S^{2-}			170				
17	Cl^{-}			167				
18	Ar							
19	K^{+}		151	152	165	173	178	
20	Ca^{2+}			114	126	137	148	
21	Sc^{3+}			89	101			
22	Ti^{2+}			100				
	Ti^{3+}			81				
	Ti^{4+}		56	75	88			
23	V^{2+}			93				
	V^{3+}			78				
24	Cr^{2+}			hs 94				
	Cr^{2+}			ls 87				
	Cr^{3+}			76				
25	Mn^{2+}		hs 80	hs 97				
	Mn^{2+}			ls 81				
	Mn^{3+}			hs 79				
	Mn^{3+}			ls 72				
26	Fe^{2+}		hs 77	hs 92				
	Fe^{2+}			ls 75				
	Fe^{3+}		hs 63	hs 79				
	Fe^{3+}			ls 69				
27	Co^{2+}		hs 72	hs 89				
	Co^{2+}			ls 79				
	Co^{3+}			hs 75				
	Co^{3+}			ls 69				
28	Ni^{2+}		69	83				
	Ni^{2+}		sq 63					
	Ni^{3+}			hs 74				
	Ni^{3+}			ls 70				
29	Cu^{+}	60	74	91				
	Cu^{2+}		71	87				
30	Zn^{2+}		74	88	104			
31	Ga^{3+}		61	76				

Continued

Z	*Coordination Number*						
	2	*4*	*6*	*8*	*10*	*12*	*14*
32 Ge^{4+}		53	67				
33 As^{3+}			72				
As^{5+}		48	60				
34 Se^{2-}			184				
35 Br^{-}			182				
36 Kr							
37 Rb^{+}			166	175	180	186	197
38 Sr^{2+}			132	140	150	158	
39 Y^{3+}			104				
40 Zr^{4+}		73	86	98			
41 Nb^{3+}			86				
Nb^{4+}			82	93			
42 Mo^{3+}			83				
Mo^{4+}			79				
43 Tc^{4+}			79				
44 Ru^{3+}			82				
Ru^{4+}			76				
45 Rh^{3+}			81				
Rh^{4+}			74				
46 Pd^{2+}		sq 78	100				
47 Ag^{+}	81	114	129	142			
Ag^{+}		sq 116					
48 Cd^{2+}		92	109	124		145	
49 In^{3+}		76	94	106			
50 Sn^{4+}		69	83	95			
51 Sb^{3+}			90				
52 Te^{2-}			207				
53 I^{-}			206				
54 Xe							
55 Cs^{+}			181	188	195	202	
56 Ba^{2+}			149	156	166	175	
57 La^{3+}			117	130	141	150	
58 Ce^{3+}			115	128	139	148	
59 Pr^{3+}			113	127			
60 Nd^{3+}			112	125		141	
61 Pm^{3+}			111	123			
62 Sm^{3+}			110	122		138	
63 Eu^{3+}			109	121			
64 Gd^{3+}			108	119			
65 Tb^{3+}			106	118			
66 Dy^{3+}			105	117			
67 Ho^{3+}			104	116	126		
68 Er^{3+}			103	114			
69 Tm^{3+}			102	113			
70 Yb^{3+}			101	113			
71 Lu^{3+}			100	112			
72 Hf^{4+}		72	85	97			
73 Ta^{3+}			86				
Ta^{4+}			82				
74 W^{4+}			80				
75 Re^{4+}			77				
76 Os^{4+}			77				

Continued

Z	Coordination Number						
	2	*4*	*6*	*8*	*10*	*12*	*14*
77 Ir^{3+}			82				
Ir^{4+}			77				
78 Pt^{2+}		sq 74	94				
Pt^{4+}			77				
79 Au^{+}			151				
Au^{3+}		sq 82	99				
80 Hg^{2+}	83	110	116	128			
81 Tl^{3+}		89	103	112			
82 Pb^{2+}		112	133	143	154	163	
Pb^{4+}		79	92	108			
83 Bi^{3+}			117	131			
84 Po^{4+}			108	122			
85 At^{7+}			76				
86 Rn							
87 Fr^{+}			194				
88 Ra^{2+}				162		184	
89 Ac^{3+}			126				
90 Th^{4+}			108	119	127	135	

SOURCE: R. D. Shannon, *Acta Crystallogr.*, **1976**, *A32*, 751.

NOTE: hs = high spin, ls = low spin, sq = square planar.

Values for CN = 4 are for tetrahedral geometry unless designated square planar. All values are in picometers.

APPENDIX B-2 IONIZATION ENERGY

Atomic No.	*Element*	*eV*	*kJ mol*$^{-1}$	*Atomic No.*	*Element*	*eV*	*kJ mol*$^{-1}$
1	H	13.598	1,312.0	30	Zn	9.394	906.4
2	He	24.587	2,372.8	31	Ga	5.999	578.8
3	Li	5.392	520.2	32	Ge	7.899	762.1
4	Be	9.322	899.4	33	As	9.81	947
5	B	8.298	800.6	34	Se	9.752	940.9
6	C	11.260	1,086.5	35	Br	11.814	1,139.9
7	N	14.534	1,402.3	36	Kr	13.999	1,350.7
8	O	13.618	1,314.0	37	Rb	4.177	403.0
9	F	17.422	1,681.0	38	Sr	5.695	549.5
10	Ne	21.564	2,080.6	39	Y	6.38	616
11	Na	5.139	495.8	40	Zr	6.84	660
12	Mg	7.646	737.8	41	Nb	6.88	664
13	Al	5.986	577.6	42	Mo	7.099	684.9
14	Si	8.151	786.5	43	Tc	7.28	702
15	P	10.486	1,011.7	44	Ru	7.37	711
16	S	10.360	999.6	45	Rh	7.46	720
17	Cl	12.967	1,251.1	46	Pd	8.34	805
18	Ar	15.759	1,520.5	47	Ag	7.576	731.0
19	K	4.341	418.8	48	Cd	8.993	867.7
20	Ca	6.113	589.8	49	In	5.786	558.3
21	Sc	6.54	631	50	Sn	7.344	708.6
22	Ti	6.82	658	51	Sb	8.641	833.7
23	V	6.74	650	52	Te	9.009	869.2
24	Cr	6.766	652.8	53	I	10.451	1,008.4
25	Mn	7.435	717.4	54	Xe	12.130	1,170.4
26	Fe	7.870	759.3	55	Cs	3.894	375.7
27	Co	7.86	758	56	Ba	5.212	502.9
28	Ni	7.635	736.7	57	La	5.577	538.1
29	Cu	7.726	745.5	58	Ce	5.47	528

Continued

Atomic No.	*Element*	*eV*	*kJ mol*$^{-1}$	*Atomic No.*	*Element*	*eV*	*kJ mol*$^{-1}$
59	Pr	5.42	523	81	Tl	6.108	589.3
60	Nd	5.49	530	82	Pb	7.416	715.5
61	Pm	5.55	535	83	Bi	7.289	703.3
62	Sm	5.63	543	84	Po	8.42	812
63	Eu	5.67	547	85	At	7.289	703.3
64	Gd	6.14	592	86	Rn	10.748	1,037.1
65	Tb	5.85	564	87	Fr	4	400
66	Dy	5.93	572	88	Ra	5.279	509.3
67	Ho	6.02	581	89	Ac	6.9	666
68	Er	6.10	589	90	Th	6.1	590
69	Tm	6.18	596	91	Pa	5.9	570
70	Yb	6.254	603.4	92	U	6.1	590
71	Lu	5.426	523.5	93	Np	6.2	600
72	Hf	7.0	675	94	Pu	6.06	585
73	Ta	7.89	761	95	Am	5.99	578
74	W	7.98	770	96	Cm	6.02	581
75	Re	7.88	760	97	Bk	6.23	601
76	Os	8.7	839	98	Cf	6.30	608
77	Ir	9.1	878	99	Es	6.42	619
78	Pt	9.0	868	100	Fm	6.50	627
79	Au	9.225	890.1	101	Md	6.58	635
80	Hg	10.437	1,007.0	102	No	6.65	642

SOURCE: C. E. Moore, *Ionization Potentials and Limits Derived from the Analyses of Optical Spectra*, NSRDS-NBS 34, National Bureau of Standards, Washington, DC, 1970; W. C. Martin, L. Hagan, J. Reador and J. Sugar, *J. Phys. Chem. Ref. Data*, **1974**, *3*, 771; and J. Sugar, *J. Opt. Soc. Am.*, **1975**, *65*, 1366.

NOTE: 1 eV = 96.4853 kJ mol^{-1}.

APPENDIX B-3 ELECTRON AFFINITY

Atomic No.	*Element*	*eV*	*kJ mol*$^{-1}$	*Atomic No.*	*Element*	*eV*	*kJ mol*$^{-1}$
1	H	0.754	72.8	23	V	0.525	50.7
2	He	−0.5*	−50	24	Cr	0.666	64.3
3	Li	0.618	59.6	25	Mn	<0	<0.0
4	Be	−0.5*	−50	26	Fe	0.163	15.7
5	B	0.277	26.7	27	Co	0.661	63.8
6	C	1.263	121.9	28	Ni	1.156	111.5
7	N	−0.07	−7	29	Cu	1.228	118.5
8	O	1.461	141.0	30	Zn	−0.6*	−58
9	F	3.399	328.0	31	Ga	0.3	29
10	Ne	−1.2*	−116	32	Ge	1.2	115.8
11	Na	0.548	52.9	33	As	0.81	78
12	Mg	−0.4*	−39	34	Se	2.021	195.0
13	Al	0.441	42.6	35	Br	3.365	324.7
14	Si	1.385	133.6	36	Kr	−1.0*	−97
15	P	0.747	72.0	37	Rb	0.486	46.9
16	S	2.077	200.4	38	Sr	−0.3*	−29
17	Cl	3.617	349.0	39	Y	0.307	29.6
18	Ar	−1.0*	−97	40	Zr	0.426	41.1
19	K	0.501	48.4	41	Nb	0.893	86.2
20	Ca	−0.3*	−29	42	Mo	0.746	72.0
21	Sc	0.188	18.1	43	Tc	0.55	53.1
22	Ti	0.079	7.6	44	Ru	1.05	101.3

Continued

Atomic No.	*Element*	*eV*	*kJ mol*$^{-1}$	*Atomic No.*	*Element*	*eV*	*kJ mol*$^{-1}$
45	Rh	1.137	109.7	67	Ho	<0.5[a]	<48
46	Pd	0.557	53.7	68	Er	<0.5[a]	<48
47	Ag	1.302	125.6	69	Tm	<0.5[a]	<48
48	Cd	−0.7*	−68	70	Yb	<0.5[a]	<48
49	In	0.3	29	71	Lu	<0.5[a]	<48
50	Sn	1.2	116	72	Hf	~0	~0
51	Sb	1.07	103	73	Ta	0.322	31.1
52	Te	1.971	190.2	74	W	0.815	78.6
53	I	3.059	295.2	75	Re	0.15	14.5
54	Xe	−0.8*	−77	76	Os	1.1	106.1
55	Cs	0.472	45.5	77	Ir	1.565	151.0
56	Ba	−0.3*	−29	78	Pt	2.128	205.3
57	La	0.5	48	79	Au	2.309	222.8
58	Ce	<0.5[a]	<48	80	Hg	−0.5*	−48
59	Pr	<0.5[a]	<48	81	Tl	0.2	19
60	Nd	<0.5[a]	<48	82	Pb	0.364	35.1
61	Pm	<0.5[a]	<48	83	Bi	0.946	91.3
62	Sm	<0.5[a]	<48	84	Po	1.9	183
63	Eu	<0.5[a]	<48	85	At	2.8	270
64	Gd	<0.5[a]	<48	86	Rn	−0.7*	−68
65	Tb	<0.5[a]	<48	87	Fr	0.6*	58
66	Dy	<0.5[a]	<48	88	Ra	−0.3*	−29

SOURCE: All data from W. Hotop and W. C. Lineberger, *J. Phys. Chem. Ref. Data*, **1985**, *14*, 731, except those marked *, which are from S. G. Bratsch and J. J. Lagowski, *Polyhedron*, **1986**, 5, 1763.

NOTE: Many of these data are known to greater accuracy than shown in the table, some to 10 significant figures.

[a] Estimated values.

APPENDIX B-4
ELECTRONEGATIVITY[a]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H 2.300																	He 4.160
Li 0.912	Be 1.576											B 2.051	C 2.544	N 3.066	O 3.610	F 4.193	Ne 4.787
Na 0.869	Mg 1.293											Al 1.613	Si 1.916	P 2.253	S 2.589	Cl 2.869	Ar 3.242
K 0.734	Ca 1.034	Sc 1.19	Ti 1.38	V 1.53	Cr 1.65	Mn 1.75	Fe 1.80	Co 1.84	Ni 1.88	Cu 1.85	Zn 1.588	Ga 1.756	Ge 1.994	As 2.211	Se 2.424	Br 2.685	Kr 2.966
Rb 0.706	Sr 0.963	Y 1.12	Zr 1.32	Nb 1.41	Mo 1.47	Tc 1.51	Ru 1.54	Rh 1.56	Pd 1.58	Ag 1.87	Cd 1.521	In 1.656	Sn 1.824	Sb 1.984	Te 2.158	I 2.359	Xe 2.582
Cs 0.659	Ba 0.881	Lu 1.09	Hf 1.16	Ta 1.34	W 1.47	Re 1.60	Os 1.65	Ir 1.68	Pt 1.72	Au 1.92	Hg 1.765	Tl 1.789	Pb 1.854	Bi (2.01)	Po (2.19)	At (2.39)	Rn (2.60)

SOURCE: J. B. Mann, T. L. Meek, and L. C. Allen, *J. Am. Chem. Soc.*, **2000**, *122*, 2780, and J. B. Mann, T. L. Meek, E. T. Knight, J. F. Capitani, and L. C. Allen, *J. Am. Chem. Soc.*, **2000**, *122*, 5132.

[a] The shaded elements are metalloids, based on their electronegativities.

APPENDIX B-5 ABSOLUTE HARDNESS PARAMETERS

Hardness Parameters for Cations (all in eV)

	Ion or Molecule	I	A	χ	η
Cations	B^{3+}	259.37	37.93	148.65	110.72
	Be^{2+}	153.89	18.21	86.05	67.84
	Al^{3+}	119.99	28.45	74.22	45.77
	Li^{+}	75.64	5.39	40.52	35.12
	Mg^{2+}	80.14	15.04	47.59	32.55
	Na^{+}	47.29	5.14	26.21	21.08
	Ca^{2+}	50.91	11.87	31.39	19.52
	Sr^{2+}	43.6	11.03	27.3	16.3
	K^{+}	31.63	4.34	17.99	13.64
	Fe^{3+}	54.8	30.65	42.73	12.08
	Rb^{+}	27.28	4.18	15.77	11.55
	Rh^{3+}	53.4	31.1	42.4	11.2
	Zn^{2+}	39.72	17.96	28.84	10.88
	Cs^{+}	25.1	3.89	14.5	10.6
	Cd^{2+}	37.48	16.91	27.20	10.29
	Cr^{3+}	49.1	30.96	40.0	9.1
	Mn^{2+}	33.67	15.64	24.66	9.02
	Mn^{3+}	51.2	33.67	42.4	8.8
	Co^{3+}	51.3	33.50	42.4	8.9
	V^{3+}	46.71	29.31	38.01	8.70
	Ni^{2+}	35.17	18.17	26.67	8.50
	Pb^{2+}	31.94	15.03	23.49	8.46
	Au^{3+}	54.1	37.4	45.8	8.4
	Cu^{2+}	36.83	20.29	28.56	8.27
	Co^{2+}	33.50	17.06	25.28	8.22
	Pt^{2+}	35.2	19.2	27.2	8.0
	Sn^{2+}	30.50	14.63	22.57	7.94
	Ir^{3+}	45.3	29.5	37.4	7.9
	Hg^{2+}	34.2	18.76	26.5	7.7
	V^{2+}	29.31	14.65	21.98	7.33
	Fe^{2+}	30.65	16.18	23.42	7.24
	Cr^{2+}	30.96	16.50	23.73	7.23
	Ag^{+}	21.49	7.58	14.53	6.96
	Ti^{2+}	27.49	13.58	20.54	6.96
	Pd^{2+}	32.93	19.43	26.18	6.75
	Rh^{2+}	31.06	18.08	24.57	6.49
	Cu^{+}	20.29	7.73	14.01	6.28
	Sc^{2+}	24.76	12.80	18.78	5.98
	Ru^{2+}	28.47	16.76	22.62	5.86
	Au^{+}	20.5	9.23	14.90	5.6
Molecules	BF_3	15.81	−3.5	6.2	9.7
	H_2O	12.6	−6.4	3.1	9.5
	N_2	15.58	−2.2	6.70	8.9
	NH_3	10.7	−5.6	2.6	8.2
	CH_3CN	12.2	−2.8	4.7	7.5
	C_2H_2	11.4	−2.6	4.4	7.0
	PF_3	12.3	−1.0	5.7	6.7
	$(CH_3)_3N$	7.8	−4.8	1.5	6.3
	C_2H_4	10.5	−1.8	4.4	6.2
	PH_3	10.0	−1.9	4.1	6.0
	O_2	12.2	0.4	6.3	5.9
	$(CH_3)_3P$	8.6	−3.1	2.8	5.9
	$(CH_3)_3As$	8.7	−2.7	3.0	5.7
	SO_2	12.3	1.1	6.7	5.6
	SO_3	12.7	1.7	7.2	5.5
	C_6H_6	9.3	−1.2	4.1	5.3
	C_5H_5N	9.3	−0.6	4.4	5.0
	Butadiene	9.1	−0.6	4.3	4.9
	PCl_3	10.2	0.8	5.5	4.7
	PBr_3	9.9	1.6	5.6	4.2

Hardness Parameters for Atoms and Radicals (all in eV)[a]

Atom or Radical	*I*	*A*	χ	η
F	17.42	3.40	10.41	7.01
H	13.60	0.75	7.18	6.43
OH	13.17	1.83	7.50	5.67
NH_2	11.40	0.74	6.07	5.33
CN	14.02	3.82	8.92	5.10
CH_3	9.82	0.08	4.96	4.87
Cl	13.01	3.62	8.31	4.70
C_2H_5	8.38	−0.39	4.00	4.39
Br	11.84	3.36	7.60	4.24
C_6H_5	9.20	1.1	5.2	4.1
NO_2	>10.1	2.30	>6.2	>3.9
I	10.45	3.06	6.76	3.70
SiH_3	8.14	1.41	4.78	3.37
C_6H_5O	8.85	2.35	5.60	3.25
$Mn(CO)_5$	8.44	2.0	5.2	3.2
CH_3S	8.06	1.9	5.0	3.1
C_6H_5S	8.63	2.47	5.50	3.08

SOURCE: R. G. Pearson, *Inorg. Chem.*, **1988**, *27*, 734.

[a] The hardness values approximate those of the corresponding anions.

APPENDIX B-6
C_A, E_A, C_B, AND E_B VALUES

Acid	C_A	E_A
Trimethylboron, $B(CH_3)_3$	1.70	6.14
Boron trifluoride (gas), BF_3	1.62	9.88
Trimethylaluminum, $Al(CH_3)_3$	1.43	16.9
Iodine (standard), I_2	1.00[a]	1.00[a]
Trimethylgallium, $Ga(CH_3)_3$	0.881	13.3
Iodine monochloride, ICl	0.830	5.10
Sulfur dioxide, SO_2	0.808	0.920
Phenol, C_6H_5OH	0.442	4.33
tert-Butyl alcohol, C_4H_9OH	0.300	2.04
Pyrrole, C_4H_4NH	0.295	2.54
Chloroform, $CHCl_3$	0.159	3.02
Base	C_B	E_B
1-Azabicyclo[2.2.2] octane, $HC(C_2H_4)_3N$ (quinuclidine)	13.2	0.704
Trimethylamine, $(CH_3)_3N$	11.54	0.808
Triethylamine, $(C_2H_5)_3N$	11.09	0.991
Dimethylamine, $(CH_3)_2NH$	8.73	1.09
Diethyl sulfide, $(C_2H_5)_2S$	7.40[a]	0.339
Pyridine, C_5H_5N	6.40	1.17
Methylamine, CH_3NH_2	5.88	1.30
Pyridine-N-oxide, C_5H_5NO	4.52	1.34
Tetrahydrofuran, C_4H_8O	4.27	0.978
7-Oxabicyclo[2.2.1] heptane, $C_6H_{10}O$	3.76	1.08
Ammonia, NH_3	3.46	1.36
Diethyl ether, $(C_2H_5)_2O$	3.25	0.963
Dimethyl sulfoxide, $(CH_3)_2SO$	2.85	1.34
N,N-dimethylacetamide, $(CH_3)_2NCOCH_3$	2.58	1.32[a]
p-Dioxane, $O(C_2H_4)_2O$	2.38	1.09
Acetone, CH_3COCH_3	2.33	0.987
Acetonitrile, CH_3CN	1.34	0.886
Benzene, C_6H_6	0.681	0.525

SOURCE: R. S. Drago, *J. Chem. Educ.*, **1974**, *51*, 300.

[a] Reference values.

APPENDIX B-7 LATIMER DIAGRAMS FOR SELECTED ELEMENTS[1]

ACIDIC SOLUTION

$$H^+ \xrightarrow{0} H_2 \xrightarrow{-2.25} H^-$$

GROUP 1

$$Li^+ \xrightarrow{-3.04} Li \quad Na^+ \xrightarrow{-2.71} Na \quad K^+ \xrightarrow{-2.92} K \quad Rb^+ \xrightarrow{-2.92} Rb \quad Cs^+ \xrightarrow{-2.92} Cs$$

GROUP 2

$$Be^{2+} \xrightarrow{-1.97} Be \quad Mg^{2+} \xrightarrow{-2.36} Mg \quad Ca^{2+} \xrightarrow{-2.84} Ca \quad Sr^{2+} \xrightarrow{-2.89} Sr \quad Ba^{2+} \xrightarrow{-2.92} Ba$$

GROUP 3

$$Sc^{3+} \xrightarrow{-2.03} Sc \quad Y^{3+} \xrightarrow{-2.37} Y \quad La^{3+} \xrightarrow{-2.38} La \quad Ac^{3+} \xrightarrow{-2.13} Ac$$

GROUP 4

$$TiO^{2+} \xrightarrow{0.10} Ti^{3+} \xrightarrow{-0.37} Ti^{2+} \xrightarrow{-1.63} Ti$$

GROUP 5

$$V(OH)_4^+ \xrightarrow{1.00} VO^{2+} \xrightarrow{0.34} V^{3+} \xrightarrow{-0.26} V^{2+} \xrightarrow{-1.13} V$$

GROUP 6

$$Cr_2O_7^{2-} \xrightarrow{1.38} Cr^{3+} \xrightarrow{-0.42} Cr^{2+} \xrightarrow{-0.90} Cr$$

GROUP 7

$$MnO_4^- \xrightarrow{0.564} MnO_4^{2-} \xrightarrow{0.274} MnO_4^{3-} \xrightarrow{4.27} MnO_2 \xrightarrow{0.95} Mn^{3+} \xrightarrow{1.51} Mn^{2+} \xrightarrow{-1.18} Mn$$

$$MnO_4^- \xrightarrow{1.507} Mn^{2+}$$

$$MnO_4^- \xrightarrow{1.70} MnO_2$$

GROUP 8

$$FeO_4^{2-} \xrightarrow{2.20} Fe^{3+} \xrightarrow{0.771} Fe^{2+} \xrightarrow{-0.44} Fe$$

GROUP 9

$$CoO_2 \xrightarrow{1.416} Co^{3+} \xrightarrow{1.92} Co^{2+} \xrightarrow{-0.277} Co$$

GROUP 10

$$NiO_4^{2-} \xrightarrow{>1.8} NiO_2 \xrightarrow{1.59} Ni^{2+} \xrightarrow{-0.257} Ni$$

$$NiO_4^{2-} \xrightarrow{>1.6} Ni$$

GROUP 11

$$CuO^{2+} \xrightarrow{1.8} Cu^{2+} \xrightarrow{0.159} Cu^+ \xrightarrow{0.521} Cu$$

$$Cu^{2+} \xrightarrow{0.340} Cu$$

[1]Data from A. J. Bard, R. Parsons, and J. Jordan, eds., *Standard Potentials in Aqueous Solution*, Marcel Dekker, New York, 1985; A. Kaczmarcyzk, W. C. Nichols, W. H. Stockmayer, and T. B. Ames, *Inorg. Chem.*, **1968**, *7*, 1057; M. Pourbaix, *Atlas of Electrochemical Equilibria in Aqueous Solution*, 2d ed., translated by J. A. Franklin, National Association of Corrosion Engineers, Houston, TX, 1974.

GROUP 12

$Zn^{2+} \xrightarrow{-0.763} Zn$ $\quad$ $Cd^{2+} \xrightarrow{-0.403} Cd$ $\quad$ $Hg^{2+} \xrightarrow{0.911} Hg_2^{2+} \xrightarrow{0.796} Hg$

GROUP 13

$$B(OH)_3 \xrightarrow{-0.890} B \xrightarrow{0.08} B_{12}H_{12}^{2-} \xrightarrow{0.32} B_{10}H_{10}^{2-} \xrightarrow{-0.50} B_{10}H_{14} \xrightarrow{0.16} B_2H_6 \xrightarrow{0.36} BH_4^-$$

$$B(OH)_3 \xrightarrow{0.47} BH_4^- \qquad B(OH)_3 \xrightarrow{0.69} B_{10}H_{10}^{2-} \qquad B(OH)_3 \xrightarrow{0.67} B_{12}H_{12}^{2-} \qquad B_{12}H_{12}^{2-} \xrightarrow{0.24} BH_4^-$$

$Al^{3+} \xrightarrow{-1.68} Al$ $\quad$ $Ga^{3+} \xrightarrow{-0.65} Ga^{2+} \xrightarrow{-0.45} Ga$ $\quad$ $In^{3+} \xrightarrow{-0.49} In^{2+} \xrightarrow{-0.40} In^+ \xrightarrow{-0.126} In$

$$Tl^{3+} \xrightarrow{0.30} Tl^{2+} \xrightarrow{2.22} Tl^+ \xrightarrow{-0.34} Tl \qquad Tl^{3+} \xrightarrow{1.25} Tl^+$$

GROUP 14

$$CO_2 \xrightarrow{-0.106} CO \xrightarrow{0.517} C \xrightarrow{0.132} CH_4$$

$$SiO_2 \xrightarrow{-0.848} Si \xrightarrow{-0.143} SiH_4$$

$$GeO_2 \xrightarrow{-0.50} Ge^{2+} \xrightarrow{0.25} Ge \xrightarrow{-0.42} GeH_4 \qquad GeO_2 \xrightarrow{-0.25} Ge$$

$$Sn^{4+} \xrightarrow{0.15} Sn^{2+} \xrightarrow{-0.137} Sn$$

$$PbO_2 \xrightarrow{1.46} Pb^{2+} \xrightarrow{-0.125} Pb$$

GROUP 15

$$NO_3^- \xrightarrow{0.803} N_2O_4 \xrightarrow{1.07} HNO_2 \xrightarrow{0.996} NO \xrightarrow{1.5} N_2O \xrightarrow{1.77} N_2 \xrightarrow{-1.87} NH_3OH^+ \xrightarrow{1.41} N_2H_5^+ \xrightarrow{1.275} NH_4^+$$

$$NO_3^- \xrightarrow{0.94} HNO_2 \qquad NO \xrightarrow{0.71} H_2N_2O_2 \xrightarrow{0.265} N_2 \qquad N_2 \xrightarrow{0.275} NH_4^+$$

$$H_3PO_4 \xrightarrow{-0.276} H_3PO_3 \xrightarrow{-0.499} H_3PO_2 \xrightarrow{-0.365} P_4 \xrightarrow{-0.100} P_2H_4 \xrightarrow{-0.006} PH_3 \qquad P_4 \xrightarrow{-0.063} PH_3$$

$$H_3AsO_4 \xrightarrow{0.560} H_3AsO_3 \xrightarrow{0.240} As \xrightarrow{-0.225} AsH_3$$

$$Sb_2O_5 \xrightarrow{0.605} SbO^+ \xrightarrow{0.204} Sb \xrightarrow{-0.510} SbH_3$$

$$Bi_2O_5 \xrightarrow{1.60} BiO^+ \xrightarrow{0.317} Bi \xrightarrow{-0.97} BiH_3$$

GROUP 16

$$O_3 \xrightarrow{2.075} O_2 \xrightarrow{-0.125} HO_2 \xrightarrow{1.51} H_2O_2 \xrightarrow{1.763} H_2O \qquad O_2 \xrightarrow{0.695} H_2O_2 \qquad O_2 \xrightarrow{1.229} H_2O$$

$$SO_4^{2-} \xrightarrow{-0.25} S_2O_6^{2-} \xrightarrow{0.57} SO_2 \xrightarrow{0.51} S_4O_6^{2-} \xrightarrow{0.07} S_2O_3^{2-} \xrightarrow{0.60} S \xrightarrow{0.14} H_2S \qquad SO_4^{2-} \xrightarrow{0.16} SO_2 \qquad SO_2 \xrightarrow{0.45} S$$

$$SeO_4^{2-} \xrightarrow{1.1} H_2SeO_3 \xrightarrow{0.74} Se \xrightarrow{-0.11} H_2Se$$

$$H_2TeO_4 \xrightarrow{1.00} TeO_2(s) \xrightarrow{0.53} Te \xrightarrow{-0.64} H_2Te$$

GROUP 17

$$F_2 \xrightarrow{2.87} F^-$$

$$ClO_4^- \xrightarrow{1.201} ClO_3^- \xrightarrow{1.18} HClO_2 \xrightarrow{1.70} HClO \xrightarrow{1.63} Cl_2 \xrightarrow{1.358} Cl^-$$

$$BrO_4^- \xrightarrow{1.85} BrO_3^- \xrightarrow{1.45} HBrO \xrightarrow{1.60} Br_2(l) \xrightarrow{1.065} Br^-$$

$$H_5IO_6 \xrightarrow{1.60} IO_3^- \xrightarrow{1.13} HIO \xrightarrow{1.44} I_2(s) \xrightarrow{0.535} I^-$$

BASIC SOLUTION

GROUP 1

$$H_2O \xrightarrow{-0.828} H_2 \xrightarrow{-2.25} H^-$$

GROUP 2

$$Be_2O_3^{2-} \xrightarrow{2.62} Be \qquad Mg(OH)_2 \xrightarrow{-2.69} Mg \qquad Ca(OH)_2 \xrightarrow{-3.03} Ca \qquad Sr(OH)_2 \xrightarrow{-2.88} Sr \qquad Ba(OH)_2 \xrightarrow{-2.81} Ba$$

GROUP 3

$$Sc(OH)_3 \xrightarrow{-2.6} Sc \qquad Y(OH)_3 \xrightarrow{-2.85} Y \qquad La(OH)_3 \xrightarrow{-2.80} La$$

GROUP 4

$$TiO_2 \xrightarrow{-1.90} Ti \qquad H_3ZrO_4 \xrightarrow{-2.36} Zr \qquad HfO(OH)_2 \xrightarrow{-2.50} Hf$$

GROUP 5

$$VO_4^{3-} \xrightarrow{0.120} V$$

GROUP 6

$$CrO_4^{2-} \xrightarrow{-0.11} Cr(OH)_3 \xrightarrow{-1.1} Cr(OH)_2 \xrightarrow{-1.4} Cr$$

$$CrO_4^{2-} \xrightarrow{-0.72} Cr(OH)_4^- \xrightarrow{-1.33} Cr$$

GROUP 7

$$MnO_4^- \xrightarrow{0.564} MnO_4^{2-} \xrightarrow{0.27} MnO_4^{3-} \xrightarrow{0.96} MnO_2 \xrightarrow{0.15} Mn_2O_3 \xrightarrow{-0.25} Mn(OH)_2 \xrightarrow{-1.56} Mn$$

GROUP 8

$$FeO_4^{2-} \xrightarrow{0.72} Fe(OH)_3 \xrightarrow{-0.56} Fe(OH)_2 \xrightarrow{-0.887} Fe$$

GROUP 9

$$CoO_2 \xrightarrow{0.7} Co(OH)_3 \xrightarrow{0.17} Co(OH)_2 \xrightarrow{-0.73} Co$$

GROUP 10

$$NiO_2^{2-} \xrightarrow{>0.4} NiO_2 \xrightarrow{0.49} Ni(OH)_2 \xrightarrow{-0.72} Ni$$

GROUP 11

$$CuO \xrightarrow{-0.29} Cu_2O \xrightarrow{-0.365} Cu$$

GROUP 12

$$ZnO_2^{2-} \xrightarrow{-1.285} Zn$$

GROUP 13

$$B_4O_7^{2-} \xrightarrow{-0.76} B \xrightarrow{-1.04} B_{12}H_{12}^{2-} \xrightarrow{0.32} B_{10}H_{10}^{2-} \xrightarrow{1.15} B_{10}H_{14}(s) \xrightarrow{0.98} B_2H_6 \xrightarrow{0.78} BH_4^-$$

$$H_2AlO_3^- \xrightarrow{-2.31} Al$$

$$H_2GaO_3^- \xrightarrow{-1.22} Ga$$

$$In(OH)_3 \xrightarrow{1.0} In$$

$$Tl(OH)_3 \xrightarrow{-0.05} Tl(OH) \xrightarrow{-0.34} Tl$$

GROUP 14

$$CO_3^{2-} \xrightarrow{-1.01} HCO_2^- \xrightarrow{-0.52} C \xrightarrow{-0.70} CH_4$$

$$SiO_3^{2-} \xrightarrow{-1.69} Si \xrightarrow{-0.93} SiH_4$$

$$HGeO_3^- \xrightarrow{-0.89} Ge \xrightarrow{<-1.1} GeH_4$$

$$Sn(OH)_6^{2-} \xrightarrow{-0.90} HSnO_2^- \xrightarrow{-0.91} Sn$$

$$PbO_2 \xrightarrow{0.25} PbO \xrightarrow{-0.58} Pb$$

GROUP 15

$$NO_3^- \xrightarrow{-0.86} N_2O_4 \xrightarrow{0.867} NO_2^- \xrightarrow{-0.46} NO \xrightarrow{0.76} N_2O \xrightarrow{0.94} N_2 \xrightarrow{-3.04} NH_2OH \xrightarrow{0.73} N_2H_4 \xrightarrow{0.1} NH_3$$

$$PO_4^{3-} \xrightarrow{-1.12} HPO_3^{2-} \xrightarrow{-1.57} H_2PO_2^- \xrightarrow{-2.05} P_4 \xrightarrow{-0.89} PH_3$$

$$AsO_4^{3-} \xrightarrow{-0.67} H_2AsO_3^- \xrightarrow{-0.68} As \xrightarrow{-1.37} AsH_3$$

$$Sb(OH)_6^- \xrightarrow{-0.465} SbO_2^- \xrightarrow{-0.639} Sb \xrightarrow{-1.34} SbH_3$$

$$Bi_2O_5 \xrightarrow{0.78} Bi_2O_4 \xrightarrow{0.56} Bi_2O_3 \xrightarrow{-0.46} Bi \xrightarrow{<-1.6} BiH_3$$

GROUP 16

$$O_3 \xrightarrow{2.075} O_2 \xrightarrow{-0.069} HO_2^- \xrightarrow{0.867} OH^-$$

$$SO_4^{2-} \xrightarrow{-0.94} SO_3^{2-} \xrightarrow{0.79} S_4O_6^{2-} \xrightarrow{0.08} S_2O_3^{2-} \xrightarrow{-0.74} S \xrightarrow{-0.45} S^{2-}$$

$$SO_3^{2-} \xrightarrow{-0.66} S$$

$$SeO_4^{2-} \xrightarrow{0.03} SeO_3^{2-} \xrightarrow{-0.36} Se \xrightarrow{-0.67} Se^{2-}$$

$$TeO_2(OH)_4^{2-} \xrightarrow{0.07} TeO_3^{2-} \xrightarrow{-0.42} Te \xrightarrow{-1.14} Te^{2-}$$

GROUP 17

$$F_2 \xrightarrow{2.87} F^-$$

$$ClO_4^- \xrightarrow{0.374} ClO_3^- \xrightarrow{-0.48} ClO_2 \xrightarrow{1.07} ClO_2^- \xrightarrow{0.681} ClO^- \xrightarrow{0.421} Cl_2 \xrightarrow{1.358} Cl^-$$

$$ClO_3^- \xrightarrow{0.295} ClO_2^-$$

$$BrO_4^- \xrightarrow{1.025} BrO_3^- \xrightarrow{0.49} BrO^- \xrightarrow{0.455} Br_2(l) \xrightarrow{1.065} Br^-$$

$$H_3IO_6^{2-} \xrightarrow{0.65} IO_3^- \xrightarrow{0.15} IO^- \xrightarrow{0.42} I_2(s) \xrightarrow{0.535} I^-$$

GROUP 18

$$HXeO_6^{3-} \xrightarrow{0.94} HXeO_4^- \xrightarrow{1.24} Xe$$

Index*

*Greek characters have been alphabetized according to their English phonetic spelling, isotopes are alphabetized according to the element symbol, and compounds are alphabetized disregarding numbers and symbols.

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