Table 4.4

Effective ionic radii of the elements[a]

Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm
Ac^{3+}	6	126	Bk^{4+}	6	97	Co^{4+}	4	54
Ag^{1+}	2	81		8	107		6 HS	67
	4	114	Br^{1-}	6	182	Cr^{2+}	6 LS	87
	4 SQ	116	Br^{3+}	4 SQ	73		HS	94
	5	123	Br^{5+}	3 PY	45	Cr^{3+}	6	75.5
	6	129	Br^{7+}	4	39	Cr^{4+}	4	55
	7	136		6	53		6	69
	8	142	C^{4+}	3	6	Cr^{5+}	4	48.5
Ag^{2+}	4 SQ	93		4	29		6	63
	6	108		6	30		8	71
Ag^{3+}	4 SQ	81	Ca^{2+}	6	114	Cr^{6+}	4	40
	6	89		7	120		6	58
Al^{3+}	4	53		8	126	Cs^{1+}	6	181
	5	62		9	132		8	188
	6	67.5		10	137		9	192
Am^{2+}	7	135		12	148		10	195
	8	140	Cd^{2+}	4	92		11	199
	9	145		5	101		12	202
Am^{3+}	6	111.5		6	109	Cs^{1-}	10	348[c]
	8	123		7	117	Cu^{1+}	2	60
Am^{4+}	6	99		8	124		4	74
	8	109		12	145		6	91
As^{3-}	6	210[d]	Ce^{3+}	6	115	Cu^{2+}	4	71
As^{3+}	6	72		7	121		4 SQ	71
As^{5+}	4	47.5		8	128.3		5	79
	6	60		9	133.6		6	87
At^{7+}	6	76		10	139	Cu^{3+}	6 LS	68
Au^{1+}	6	151		12	148	Dy^{1+}	2	4
Au^{3+}	4 SQ	82	Ce^{4+}	6	101	Dy^{2+}	6	121
	6	99		8	111		7	127
Au^{5+}	6	71		10	121		8	133
B^{3+}	3	15		12	128	Dy^{3+}	6	105.2
	4	25	Cf^{3+}	6	109		7	111
	6	41	Cf^{4+}	6	96.1		8	116.7
Ba^{2+}	6	149		8	106		9	122.3
	7	152	Cl^{1-}	6	167	Er^{3+}	6	103
	8	156	Cl^{5+}	3 PY	26		7	108.5
	9	161	Cl^{7+}	4	22		8	114.4
	10	166		6	41		9	120.2
	11	171	Cm^{3+}	6	111	Eu^{2+}	6	131
	12	175	Cm^{4+}	6	99		7	134
Be^{2+}	3	30		8	109		8	139
	4	41	Co^{2+}	4 HS[b]	72		9	144
	6	59		5	81		10	149
Bi^{3+}	5	110		6 LS[c]	79	Eu^{3+}	6	108.7
	6	117		HS	88.5		7	115
	8	131		8	104		8	120.6
Bi^{5+}	6	90	Co^{3+}	6 LS	68.5		9	126
Bk^{3+}	6	110		HS	75	F^{1-}	2	114.5

Continued

Table 4.4 (*Continued*)

Effective ionic radii of the elements[a]

Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm
	3	116	In^{3+}	4	76		6	75
	4	117		6	94	Mo^{6+}	4	55
	6	119		8	106		5	64
F^{7+}	6	22	Ir^{3+}	6	82		6	73
Fe^{2+}	4 HS	77	Ir^{4+}	6	76.5		7	87
	4 SQ HS	78	Ir^{5+}	6	71	N^{3-}	4	132
	6 LS	75	K^{1-}	—	313[c]	N^{3+}	6	30
	HS	92	K^{1+}	4	151	N^{5+}	3	4.4
	8 HS	106		6	152		6	27
Fe^{3+}	4 HS	63		7	160	Na^{1-}	—	276[c]
	5	72		8	165	Na^{1+}	4	113
	6 LS	69		9	169		5	114
	HS	78.5		10	173		6	116
	8 HS	92		12	178		7	126
Fe^{4+}	6	72.5	La^{3+}	6	117.2		8	132
Fe^{6+}	4	39		7	124		9	138
Fr^{1+}	6	194		8	130		12	153
Ga^{3+}	4	61		9	135.6	Nb^{3+}	6	86
	5	69		10	141	Nb^{4+}	6	82
	6	76		12	150		8	93
Gd^{3+}	6	107.8	Li^{1+}	4	73	Nb^{5+}	4	62
	7	114		6	90		6	78
	8	119.3		8	106		7	83
	9	124.7	Lu^{3+}	6	100.1		8	88
Ge^{2+}	6	87		8	111.7	Nd^{2+}	8	143
Ge^{4+}	4	53		9	117.2		9	149
	6	67	Mg^{2+}	4	71	Nd^{3+}	6	112.3
H^{1+}	1	−24		5	80		8	124.9
	2	−4		6	86		9	130.3
Hf^{4+}	4	72		8	103		12	141
	6	85	Mn^{2+}	4 HS	80	Ni^{2+}	4	69
	7	90		5 HS	89		4 SQ	63
	8	97		6 LS	81		5	77
Hg^{1+}	3	111		HS	97		6	83
	6	133		7 HS	104	Ni^{3+}	6 LS	70
Hg^{2+}	2	83		8	110		HS	74
	4	110	Mn^{3+}	5	72	Ni^{4+}	6 LS	62
	6	116		6 LS	72	No^{2+}	6	124
	8	128		HS	78.5	Np^{2+}	6	124
Ho^{3+}	6	104.1	Mn^{4+}	4	53	Np^{3+}	6	115
	8	115.5		6	67	Np^{4+}	6	101
	9	121.2	Mn^{5+}	4	47		8	112
	10	126	Mn^{6+}	4	39.5	Np^{5+}	6	89
I^{1-}	6	206	Mn^{7+}	4	39	Np^{6+}	6	86
I^{5+}	3 PY	58		6	60	Np^{7+}	6	85
	6	109	Mo^{3+}	6	83	O^{2-}	2	121
I^{7+}	4	56	Mo^{4+}	6	79		3	122
	6	67	Mo^{5+}	4	60		4	124

Continued

Table 4.4 (*Continued*)

Effective ionic radii of the elements[a]

Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm
	6	126		9	131.9	Se^{6+}	4	42
	8	128	Pt^{4+}	6	99		6	56
OH^{1-}	2	118		8	110	Si^{4+}	4	40
	3	120	Pt^{2+}	4 SQ	74		6	54
	4	121		6	94	Sm^{2+}	7	136
	6	123	Pt^{4+}	6	76.5		8	141
Os^{4+}	6	77	Pt^{5+}	6	71		9	146
Os^{5+}	6	71.5	Pu^{3+}	6	114	Sm^{3+}	6	109.8
Os^{6+}	5	63	Pu^{4+}	6	100		7	116
	6	68.5		8	110		8	121.9
Os^{7+}	6	66.5	Pu^{5+}	6	88		9	127.2
Os^{8+}	4	53	Pu^{6+}	6	85		12	138
P^{3-}	6	200[d]	Ra^{2+}	8	162	Sn^{4+}	4	69
P^{3+}	6	58		12	184		5	76
P^{5+}	4	31	Rb^{1-}	—	317[c]		6	83
	5	43	Rb^{1+}	6	166		7	89
	6	52		7	170		8	95
Pa^{3+}	6	118		8	175	Sr^{2+}	6	132
Pa^{4+}	6	104		9	177		7	135
	8	115		10	180		8	140
Pa^{5+}	6	92		11	183		9	145
	8	105		12	186		10	150
	9	109		14	197		12	158
Pb^{2+}	4 PY	112	Re^{4+}	6	77	Ta^{3+}	6	86
	6	133	Re^{5+}	6	72	Ta^{4+}	6	82
	7	137	Re^{6+}	6	69	Ta^{5+}	6	78
	8	143	Re^{7+}	4	52		7	83
	9	149		6	67		8	88
	10	154	Rh^{3+}	6	80.5	Tb^{3+}	6	106.3
	11	159	Rh^{4+}	6	74		7	112
	12	163	Rh^{5+}	6	69		8	118
Pb^{4+}	4	79	Ru^{3+}	6	82		9	123.5
	5	87	Ru^{4+}	6	76	Tb^{4+}	6	90
	6	91.5	Ru^{5+}	6	70.5		8	102
	8	108	Ru^{7+}	4	52	Tc^{4+}	6	78.5
Pd^{1+}	2	73	Ru^{8+}	4	50	Tc^{5+}	6	74
Pd^{2+}	4 SQ	78	S^{2-}	6	170	Tc^{7+}	4	51
	6	100	S^{4+}	6	51		6	70
Pd^{3+}	6	90	S^{6+}	4	26	Te^{2-}	6	207
Pd^{4+}	6	75.5		6	43	Te^{4+}	3	66
Pm^{3+}	6	111	Sb^{3+}	4 PY	90		4	80
	8	123.3		5	94		6	111
	9	128.4		6	90	Te^{6+}	4	57
Po^{4+}	6	108	Sb^{5+}	6	74		6	70
	8	122	Sc^{3+}	6	88.5	Th^{4+}	6	108
Po^{6+}	6	81		8	101		8	119
Pr^{3+}	6	113	Se^{2-}	6	184		9	123
	8	126.6	Se^{4+}	6	64		10	127

Continued

Table 4.4 (*Continued*)

Effective ionic radii of the elements[a]

Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm	Ion	Coordination number[b]	pm
	11	132		9	119		6	62
	12	135		12	131	Y^{3+}	6	104
Ti^{2+}	6	100	U^{5+}	6	90		7	110
Ti^{3+}	6	81		7	98		8	115.9
Ti^{4+}	4	56	U^{6+}	2	59		9	121.5
	5	65		4	66	Yb^{2+}	6	116
	6	74.5		6	87		7	122
	8	88		7	95		8	128
Tl^{1+}	6	164		8	100	Yb^{3+}	6	100.8
	8	173	V^{2+}	6	93		7	106.5
	12	184	V^{3+}	6	78		8	112.5
Tl^{3+}	4	89	V^{4+}	5	67		9	118.2
	6	102.5		6	72	Zn^{2+}	4	74
	8	112		8	86		5	82
Tm^{2+}	6	117	V^{5+}	4	49.5		6	88
	7	123		5	60		8	104
Tm^{3+}	6	102		6	68	Zr^{4+}	4	73
	8	113.4	W^{4+}	6	80		5	80
	9	119.2	W^{5+}	6	76		6	86
U^{3+}	6	116.5	W^{6+}	4	56		7	92
U^{4+}	6	103		5	65		8	98
	7	109		6	74		9	103
	8	114	Xe^{8+}	4	54			

[a] Values of crystal radii from Shannon, R. D. *Acta Crystallogr.* **1976**, *A32*, 751–767.

[b] SQ = square planer; PY = pyramidal; HS = high spin; LS = low spin.

[c] Huang, R. H.; Ward, D. L.; Dye, J. L. *J. Am. Chem. Soc.* **1989**, *111*, 5707–5708.

[d] Modified from Pauling, L. *Nature of the Chemical Bond*, 3rd ed.; Cornell University: Ithaca, NY, 1960. These values are only approximate.

even in simple ions—often becomes much worse. For example, one set of data indicates that the radius of the ammonium ion is consistently 175 pm, but a different set indicates that it is the same size as Rb^+, 166 ppm.[22] This is not a serious discrepancy, but it is a disturbing one since its source is not obvious.

Yatsimirskii[23] has provided an ingenious method for estimating the radii of polyatomic ions. A Born–Haber calculation utilizing the enthalpy of formation and related data can provide an estimate of the lattice energy. It is then possible to find what value of the radius of the ion in question is consistent with this lattice energy. These values are thus termed *thermochemical radii*. The most recent set of such values is given in Table 4.5. In many cases the fact that the ions (such as CO_3^{2-}, CNS^-, CH_3COO^-) are markedly nonspherical limits the use of these radii. Obviously they

[22] Shannon, R. D. *Acta Crystallogr.* **1976**, *A32*, 751.

[23] Yatsimirskii, K. B. *Izv. Akad. Nauk SSSR, Otdel, Khim. Nauk* **1947**, 453; **1948**, 398. See also Mingos, D. M. P.; Rolf, A. L. *Inorg. Chem.* **1991**, *30*, 3769–3771, where the shape of the ion is taken into consideration as well as its size (see Problem 4.42).