Table 14.6. *K* Series X-Ray Wavelengths and Energies[a]

Element	$K\alpha_1$		*K* edge	
	λ (Å)	*E*(keV)	λ(Å)	*E* (keV)
4 Be	114.00	0.109	110.0	0.111
5 B	67.6	0.183	64.57	0.192
6 C	44.7	0.277	43.68	0.284
7 N	31.6	0.392	30.9	0.400
8 O	23.62	0.525	23.32	0.532
9 F	18.32	0.677	18.05	0.687
10 Ne	14.61	0.849	14.30	0.867
11 Na	11.91	1.041	11.57	1.072
12 Mg	9.89	1.254	9.512	1.303
13 Al	8.339	1.487	7.948	1.560
14 Si	7.125	1.740	6.738	1.84
15 P	6.157	2.014	5.784	2.144
16 S	5.372	2.308	5.019	2.470
17 Cl	4.728	2.622	4.397	2.820
18 Ar	4.192	2.958	3.871	3.203
19 K	3.741	3.314	3.437	3.608
20 Ca	3.358	3.692	3.070	4.038
21 Sc	3.031	4.091	2.762	4.489
22 Ti	2.749	4.511	2.497	4.965
23 V	2.504	4.952	2.269	5.464
24 Cr	2.290	5.415	2.070	5.989
25 Mn	2.102	5.899	1.896	6.538
26 Fe	1.936	6.404	1.743	7.111
27 Co	1.789	6.930	1.608	7.710
28 Ni	1.658	7.478	1.483	8.332
29 Cu	1.541	8.048	1.381	8.980
30 Zn	1.435	8.639	1.283	9.661
31 Ga	1.340	9.252	1.196	10.37
32 Ge	1.254	9.886	1.17	11.10
33 As	1.176	10.544	1.045	11.87
34 Se	1.109	11.181	0.9797	12.65
35 Br	1.040	11.924	0.9204	13.47
36 Kr	0.980	12.649	0.8655	14.32
37 Rb	0.926	13.395	0.8155	15.20
38 Sr	0.875	14.165	0.7697	16.11
39 Y	0.8288	14.958	0.7277	17.04
40 Zr	0.7859	15.775	0.6888	17.999
41 Nb	0.7462	16.615	0.6530	18.99
42 Mo	0.7093	17.479	0.6198	20.00
43 Te	0.6750	18.367	0.5891	21.05
44 Ru	0.6431	19.279	0.5605	22.12
45 Rh	0.6133	20.21	0.534	23.22
46 Pd	0.5854	21.18	0.5092	24.34
47 Ag	0.5594	22.16	0.4859	25.52
48 Cd	0.5350	23.17	0.4641	26.72
49 In	0.5121	24.21	0.4437	27.94
50 Sn	0.4906	25.27	0.4247	29.19
51 Sb	0.4704	26.36	0.4067	30.49
52 Te	0.4513	27.47	0.3897	31.81
53 I	0.43333	28.61	0.3738	33.17
54 Xe	0.4163	29.78	0.3584	34.59

Table 14.6. (*Continued*)

Element	$K\alpha_1$		*K* edge	
	λ (Å)	*E*(keV)	λ(Å)	*E* (keV)
55 Cu	0.4003	30.97	0.3445	35.99
56 Ba	0.3851	32.19	0.3310	37.45
57 La	0.3707	33.44	0.3184	38.93
58 Ce	0.3571	34.72	0.3065	40.45
59 Pr	0.3441	36.03	0.2952	42.00
60 Nd	0.3318	37.36	0.2845	43.57
61 Pm	0.3202	38.72	0.2743	45.20
62 Sm	0.3090	40.12	0.2646	46.85
63 Eu	0.2984	41.54	0.2555	48.52
64 Gd	0.2884	42.996	0.2468	50.23
65 Tb	0.2787	44.48	0.2384	52.00
66 Dy	0.2695	45.998	0.2305	53.79
67 Ho	0.2608	47.55	0.2229	55.62
68 Er	0.2524	49.13	0.2157	57.49
69 Tm	0.2443	50.74	0.2088	59.38
70 Yb	0.2367	52.39	0.2022	61.30
71 Lu	0.2293	54.07	0.1959	63.31
72 Hf	0.2270	54.61	0.1898	65.31
73 Ta	0.2155	57.53	0.1839	67.40
74 W	0.2090	59.32	0.1784	69.51
75 Re	0.2028	61.14	0.1730	71.66
76 Os	0.1968	63.00	0.1679	73.86
77 Ir	0.1910	64.90	0.1629	76.10
78 Pt	0.1855	66.83	0.1582	78.38
79 Au	0.1851	66.99	0.1536	80.72
80 Hg	0.1751	70.82	0.1492	83.11
81 Tl	0.1701	72.87	0.1450	85.53
82 Pb	0.1654	74.97	0.1409	88.00
83 Bi	0.1608	77.11	0.1369	90.53
84 Po	0.1546	79.29	0.1331	93.12
85 At	0.1521	81.52	0.1294	95.74
86 Rn	0.1480	83.78	0.1260	98.42
87 Fr	0.1440	86.10	0.1226	101.15
88 Ra	0.1401	88.47	0.1193	103.93
89 Ac	0.1364	90.88	0.1161	106.76
90 Th	0.1328	93.35	0.1131	109.65
91 Pa	0.1293	95.87	0.1101	112.58
92 U	0.1259	98.44	0.1072	115.62

[a] Bearden (1964).

Table 14.7. *L* Series X-Ray Wavelengths and Energies[a]

	$L\alpha_1$		L_3 edge			$L\alpha_1$		L_3 edge	
Element	λ (Å)	E (keV)	λ (Å)	E (keV)	Element	λ (Å)	E (keV)	λ (Å)	E (keV)
20 Ca	36.33	0.341	35.49	0.349	57 La	2.666	4.651	2.261	5.484
21 Se	31.35	0.395	30.54	0.406	58 Ce	2.562	4.840	2.166	5.723
22 Ti	27.42	0.452	27.3	0.454	59 Pr	2.463	5.034	2.079	5.963
23 V	24.25	0.511	24.2	0.512	60 Nd	2.370	5.230	1.997	6.209
24 Cr	21.64	0.573	20.7	0.598	61 Pm	2.282	5.433	1.919	6.461
25 Mn	19.45	0.637	19.4	0.639	62 Sm	2.200	5.636	1.846	6.717
26 Fe	17.59	0.705	17.53	0.707	63 Eu	2.121	5.846	1.776	6.981
27 Co	15.97	0.776	15.92	0.779	64 Gd	2.047	6.057	1.712	7.243
28 Ni	14.56	0.852	14.52	0.854	65 Tb	1.977	6.273	1.650	7.515
29 Cu	13.34	0.930	13.29	0.933	66 Dy	1.909	6.495	1.592	7.790
30 Zn	12.25	1.012	12.31	1.022	67 Ho	1.845	6.720	1.537	8.068
31 Ga	11.29	1.098	11.10	1.117	68 Er	1.784	6.949	1.484	8.358
32 Ge	10.44	1.188	10.19	1.217	69 Tm	1.727	7.180	1.433	8.650
33 As	9.671	1.282	9.37	1.324	70 Yb	1.672	7.416	1.386	8.944
34 Se	8.99	1.379	8.65	1.434	71 Lu	1.620	7.656	1.341	9.249
35 Br	8.375	1.480	7.984	1.553	72 Hf	1.57	7.899	1.297	9.558
36 Kr	7.817	1.586	7.392	1.677	73 Ta	1.522	8.146	1.255	9.877
37 Rb	7.318	1.694	6.862	1.807	74 W	1.476	8.398	1.216	10.20
38 Sr	6.863	1.807	6.387	1.941	75 Re	1.433	8.653	1.177	10.53
39 Y	6.449	1.923	5.962	2.079	76 Os	1.391	8.912	1.141	10.87
40 Zr	6.071	2.042	5.579	2.223	77 Ir	1.351	9.175	1.106	11.21
41 Nb	5.724	2.166	5.230	2.371	78 Pt	1.313	9.442	1.072	11.56
42 Mo	5.407	2.293	4.913	2.523	79 Au	1.276	9.713	1.040	11.92
43 Tc	5.115	2.424	4.630	2.678	80 Hg	1.241	9.989	1.009	12.29
44 Ru	4.846	2.559	4.369	2.838	81 Tl	1.207	10.27	0.979	12.66
45 Rh	4.597	2.697	4.130	3.002	82 Pb	1.175	10.55	0.951	13.04
46 Pd	4.368	2.839	3.907	3.173	83 Bi	1.144	10.84	0.923	13.43
47 Ag	4.154	2.984	3.699	3.351	84 Po	1.114	11.13	0.897	13.82
48 Cd	3.956	3.134	3.505	3.538	85 At	1.085	11.43	0.872	14.22
49 In	3.772	3.287	3.324	3.730	86 Rn	1.057	11.73	0.848	14.62
50 Sn	3.600	3.414	3.156	3.929	87 Fr	1.030	12.03	0.825	15.03
51 Sb	3.439	3.605	3.000	4.132	88 Ra	1.005	12.34	0.803	15.44
52 Te	3.289	3.769	2.856	4.342	89 Ac	0.9799	12.65	0.781	15.87
53 1	3.149	3.938	2.720	4.559	90 Th	0.956	12.97	0.761	16.30
54 Xe	3.017	4.110	2.593	4.782	91 Pa	0.933	13.29	0.741	16.73
55 Cs	2.892	4.287	2.474	5.011	92 U	0.911	13.61	0.722	17.17
56 Ba	2.776	4.466	2.363	5.247					

[a] Bearden (1964).

Table 14.8. *M* Series X-Ray Wavelengths and Energies[a]

	$M\alpha_1$		M_5 edge	
Element	λ (Å)	E (keV)	λ (Å)	E (keV)
57 La	14.88	0.833	14.90	0.832
58 Ce	14.04	0.883	14.04	0.883
59 Pr	13.34	0.929	13.32	0.931
60 Nd	12.68	0.978	12.68	0.978
61 Pm	12.00	1.033	12.07	1.027
62 Sm	11.47	1.081	11.48	1.080
63 Eu	10.96	1.131	10.97	1.130
64 Gd	10.46	1.185	10.46	1.185
65 Tb	10.00	1.240	9.99	1.241
66 Dy	9.59	1.293	9.57	1.295
67 Ho	9.20	1.348	9.177	1.351
68 Er	8.82	1.406	8.799	1.409
69 Tm	8.48	1.462	8.451	1.467
70 Yb	8.149	1.521	8.11	1.528
71 Lu	7.840	1.581	7.81	1.588
72 Hf	7.539	1.645	7.46	1.661
73 Ta	7.252	1.710	7.11	1.743
74 W	6.983	1.775	6.83	1.814
75 Re	6.729	1.843	6.56	1.89
76 Os	6.490	1.910	6.30	1.967
77 Ir	6.262	1.980	6.05	2.048
78 Pt	6.047	2.051	5.81	2.133
79 Au	5.840	2.123	5.58	2.220
80 Hg	5.645	2.196	5.36	2.313
81 Tl	5.460	2.271	5.153	2.406
82 Pb	5.286	2.346	4.955	2.502
83 Bi	5.118	2.423	4.764	2.603
90 Th	4.138	2.996	3.729	3.325
91 Pa	4.022	3.082	3.602	3.442
92 U	3.910	3.171	3.497	3.545

[a] Bearden (1964).

most morphological, high-resolution problems. For high-resolution STEM studies, heavy metals such as tantalum and tungsten, which have a low specific mobility, appear to be the best choice. For high-resolution SEM, where one can be sure to be collecting only the primary secondary electrons, then platinum, chromium, or niobium is the material of choice. Where this is not the case, the noble metals and their alloys should be used. In all instances, a film thickness of 1–2 nm appears to give the best result. In situations where one wishes to achieve high-resolution spatial decoration, Peters (1984b) recommends fast evaporation of a small amount of metal with high specific surface mobility. The crystallites round up as a result of vertical growth and give the best contrast with the smallest amount of metal. Increased spatial resolution can be obtained with metals with lower mobilities, i.e., platinum, rhodium, and tungsten.

3. For medium-resolution SEM (spatial resolutions 3–5 nm), low-voltage plasma–magnetron sputter coating with either gold–palladium or platinum gives the best result. Alternatively, ion-beam or Penning sputtering with W or Pt gives an equally good coating layer. The final film thickness should be in the range 3–8 nm.

4. For routine scanning microscopy on coated specimens (spatial resolutions greater than 8–12 nm), a plasma–magnetron sputter coater using Au–Pd working at a relatively high deposition rate gives good, even films. However, care must be taken with thermolabile samples. The final film thickness should be in the range 8–12 nm.

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Data Base

Table 14.1. Atomic Number, Atomic Weight, and Density of Elements

Element		Atomic number	Atomic weight	Density (g/cm^3)
H	Hydrogen	1	1.008	—
He	Helium	2	4.003	—
Li	Lithium	3	6.941	0.534
Be	Beryllium	4	9.012	1.848
B	Boron	5	10.81	2.5
C	Carbon	6	12.01	2.34 (amorphous C) 2.25 (graphite)
N	Nitrogen	7	14.01	—
O	Oxygen	8	16.00	—
F	Fluorine	9	19.00	—
Ne	Neon	10	20.18	—
Na	Sodium	11	22.99	0.97
Mg	Magnesium	12	24.31	1.74
Al	Aluminum	13	26.98	2.7
Si	Silicon	14	28.09	2.34
P	Phosphorus	15	30.97	2.20 (red)
S	Sulfur	16	32.06	2.07
Cl	Chlorine	17	35.45	—
Ar	Argon	18	39.95	—
K	Potassium	19	39.10	0.86
Ca	Calcium	20	40.08	1.54
Sc	Scandium	21	44.96	2.99
Ti	Titanium	22	47.90	4.5
V	Vanadium	23	50.94	6.1
Cr	Chromium	24	52.00	7.1
Mn	Manganese	25	54.94	7.4
Fe	Iron	26	55.85	7.87
Co	Cobalt	27	58.93	8.9
Ni	Nickel	28	58.71	8.9
Cu	Copper	29	63.55	8.96
Zn	Zinc	30	65.37	7.14
Ga	Gallium	31	69.72	5.91
Ge	Germanium	32	72.59	5.32
As	Arsenic	33	74.92	5.72
Se	Selenium	34	78.96	4.79

(*continued*)

Table 14.1. (*Continued*)

Element		Atomic number	Atomic weight	Density (g/cm³)
Br	Bromine	35	79.90	3.12
Kr	Krypton	36	83.80	—
Rb	Rubidium	37	85.47	1.53
Sr	Strontium	38	87.62	2.6
Y	Yttrium	39	88.91	4.472
Zr	Zirconium	40	91.22	6.49
Nb	Niobium	41	92.91	8.6
Mo	Molybdenum	42	95.94	10.2
Tc	Technetium	43	98.91	11.46
Ru	Ruthenium	44	101.1	12.2
Rh	Rhodium	45	102.9	12.4
Pd	Palladium	46	106.4	12.00
Ag	Silver	47	107.9	10.5
Cd	Cadmium	48	112.4	8.64
In	Indium	49	114.8	7.3
Sn	Tin	50	118.7	7.3
Sb	Antimony	51	121.8	6.68
Te	Tellurium	52	127.6	6.24
I	Iodine	53	126.9	4.94
Xe	Xenon	54	131.3	—
Cs	Cesium	55	132.9	1.87
Ba	Barium	56	137.3	3.5
La	Lanthanum	57	138.9	6.189
Ce	Cerium	58	140.1	6.75
Pr	Praseodymium	59	140.9	6.769
Nd	Neodymium	60	144.2	7.00
Pm	Promethium	61	[145]	—
Sm	Samarium	62	150.4	7.49
Eu	Europium	63	152	5.245
Gd	Gadolinium	64	157.3	7.86
Tb	Terbium	65	158.9	8.25
Dy	Dysprosium	66	160.5	8.55
Ho	Holmium	67	164.9	8.79
Er	Erbium	68	167.3	9.15
Tm	Thulium	69	168.9	9.31
Yb	Ytterbium	70	173.0	6.959
Lu	Lutetium	71	175.0	9.849
Hf	Hafnium	72	178.5	13.1
Ta	Tantalum	73	180.9	16.6
W	Tungsten	74	183.9	19.3
Re	Rhenium	75	186.2	21.0
Os	Osmium	76	190.2	22.5
Ir	Iridium	77	192.2	22.4
Pt	Platinum	78	195.1	21.45
Au	Gold	79	197.0	19.3
Hg	Mercury	80	200.6	13.55
Tl	Thallium	81	204.4	11.85
Pb	Lead	82	207.2	11.34
Bi	Bismuth	83	209.0	9.8
Po	Polonium	84	[210]	[9.24]
At	Astatine	85	[210]	—
Rn	Radon	86	[222]	—
Fr	Francium	87	[223]	—
Ra	Radium	88	226.0	5.0
Ac	Actinium	89	[227]	—
Th	Thorium	90	232.0	11.5
Pa	Protactinium	91	231.0	15.4
U	Uranium	92	238.0	19.05(α), 18.9(β)

Table 14.2. Common Oxides of the Elements

Symbol, atomic no.	Oxide	Wt. fraction of element	Wt. fraction of oxygen	Symbol, atomic no.	Oxide	Wt. fraction of element	Wt. fraction of oxygen
Na 11	Na_2O	0.7419	0.2581	Cd 48	CdO	0.8754	0.1246
Mg 12	MgO	0.60317	0.3968	In 49	In_2O_3	0.8271	0.1729
Al 13	Al_2O_3	0.5292	0.4708	Sn 50	SnO	0.8812	0.1188
Si 14	SiO_2	0.4675	0.5326		SnO_2	0.7876	0.2124
	SiO	0.6371	0.3629	Sb 51	SbO_2	0.7918	0.2081
P 15	P_2O_5	0.4363	0.5636		Sb_2O_3	0.8353	0.1647
K 19	K_2O	0.8301	0.1699	Te 52	TeO_2	0.7995	0.2005
Ca 20	CaO	0.7147	0.2853	Ba 56	BaO	0.8110	0.1889
Sc 21	Sc_2O_3	0.6519	0.3481	La 57	La_2O_3	0.8973	0.1027
Ti 22	TiO_2	0.5995	0.4005	Ce 58	CeO_2	0.8141	0.1859
	TiO	0.7496	0.2504	Pr 59	PrO_2	0.8149	0.1851
	Ti_2O_3	0.6519	0.3481	Nd 60	Nd_2O_3	0.8573	0.1427
V 23	V_2O_3	0.6797	0.3203	Sm 62	Sm_2O_3	0.8623	0.1377
	V_2O_5	0.5601	0.4399	Eu 63	Eu_2O_3	0.8636	0.1364
Cr 24	Cr_2O_3	0.6842	0.3158	Gd 64	Gd_2O_3	0.8676	0.1364
	CrO_3	0.5199	0.4800	Tb 65	Tb_4O_7	0.8688	0.1312
Mn 25	Mn_3O_4	0.7203	0.2797	Dy 66	Dy_2O_3	0.8598	0.1402
	MnO_2	0.6319	0.3681	Ho 67	Ho_2O_3	0.8730	0.1270
Fe 26	Fe_2O_3	0.6994	0.3006	Er 68	Er_2O_3	0.8745	0.1255
	FeO	0.7773	0.2227	Tm 69	Tm_2O_3	0.8756	0.1244
Co 27	CoO	0.7865	0.2135	Yb 70	Yb_2O_3	0.8782	0.1218
Ni 28	NiO	0.7858	0.2142	Lu 71	Lu_2O_3	0.8794	0.1206
Cu 29	CuO	0.7988	0.2012	Hf 72	HfO_2	0.8479	0.1520
	Cu_2O	0.8882	0.1118	Ta 73	Ta_2O_5	0.8829	0.1171
Zn 30	ZnO	0.8034	0.1966	W 74	WO_3	0.7930	0.2070
Ga 31	Ga_2O_3	0.7439	0.2561	Re 75	Re_2O_7	0.7688	0.2312
Ge 32	GeO_2	0.8194	0.1806		ReO_3	0.7950	0.2050
As 33	As_2O_5	0.6519	0.3481	Os 76	OsO_4	0.7482	0.2518
	As_2O_3	0.7574	0.2426	Ir 77	IrO_2	0.8573	0.1427
Se 34	SeO_2	0.7116	0.2884		Ir_2O_3	0.8886	0.1114
Rb 37	Rb_2O	0.9144	0.0856	Pt 78	PtO_2	0.8591	0.1409
Sr 38	SrO	0.8456	0.1544	Hg 80	HgO	0.9261	0.0739
Zr 40	ZrO_2	0.7403	0.2597	Tl 81	Tl_2O_3	0.8949	0.1051
Nb 41	Nb_2O_5	0.3495	0.6505	Pb 82	PbO_2	0.8662	0.1338
Mo 42	MoO_3	0.6665	0.3335		PbO	0.9283	0.0717
Ru 44	RuO_4	0.6124	0.3876	Bi 83	Bi_2O_3	0.8970	0.1030
	RuO_2	0.7595	0.2405	U 92	UO_2	0.8815	0.1185
Rh 45	Rh_2O_3	0.8109	0.1819		U_3O_8	0.8480	0.1520
Pd 46	PdO	0.8693	0.1307				
Ag 47	Ag_2O	0.9309	0.0690				
	AgO	0.8708	0.1292				