

APPENDIX B

X-Ray Critical-Absorption and Emission Energies in keV

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Increased use of energy-proportional detectors for x rays has created a need for a table of energy values of K and L absorption and emission series.

The table presented here includes all elements. Most values were obtained by a conversion to keV of tabulated experimental wavelength values (1-3); some are from previous energy-value compilations (4,5). Where a choice existed, the value chosen was the one derived from later work. Certain values were determined by interpolation, using Moseley's law. (All this is annotated in footnotes.)

The conversion equations relating energy and wavelength used are (6)

$$E(\text{keV}) = (12.39644 \pm 0.00017)/\lambda(\text{\AA}) \\ = 12.39644/1.002020 \lambda(\text{kX unit})$$

In computing values the number of places retained sufficed to maintain the uncertainty in the original source value. The values in the table have been listed uniformly to 1 eV. However, chemical form may shift absorption edges as much as 10-20 eV (4,5).

To discover computational errors a fit was made to Moseley's law. In general the values were consistent, however there were a few irregularities due to the deviation of some input values (1). These were retained in the body of the table but a set of values calculated to fit better are footnoted.

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X-Ray Critical-Absorption and Emission Energies in keV

Atomic Number	Element	K series					L series							
		K _{ab}	Kβ ₂	Kβ ₁	Kα ₁	Kα ₂	L _{Iab}	L _{IIab}	L _{IIIab}	Lγ ₁	Lβ ₁	Lβ ₂	Lα ₁	Lα ₂
1	Hydrogen	0.0136†												
2	Helium	0.0246‡												
3	Lithium	0.055				0.052								
4	Beryllium	0.116‡				0.110								
5	Boron	0.192†				0.185								
6	Carbon	0.283				0.282								
7	Nitrogen	0.399				0.392								
8	Oxygen	0.531				0.523								
9	Fluorine	0.687†				0.677								
10	Neon	0.874*				0.851‡	0.048†	0.022†	0.022†					
11	Sodium	1.08*		1.067		1.041	0.055‡	0.034‡	0.034‡					
12	Magnesium	1.303		1.297		1.254	0.063	0.050	0.049					
13	Aluminum	1.559		1.553	1.497	1.486	0.087	0.073**	0.072**					
14	Silicon	1.838		1.832	1.740	1.739	0.118*	0.099**	0.098**					
15	Phosphorus	2.142		2.136	2.015‡	2.014‡	0.153*	0.129‡	0.128‡					
16	Sulphur	2.470		2.464	2.308	2.306	0.193*	0.164**	0.163**					
17	Chlorine	2.819‡		2.815	2.622	2.621	0.238*	0.203‡	0.202‡					
18	Argon	3.203		3.192‡	2.957	2.955	0.287*	0.247**	0.245**					
19	Potassium	3.607		3.589	3.313	3.310	0.341*	0.297**	0.294**					
20	Calcium	4.038		4.012	3.691	3.688	0.399*	0.352	0.349		0.344		0.341	
21	Scandium	4.496		4.460	4.090	4.085	0.462*	0.411**	0.406**		0.399		0.395	
22	Titanium	4.964		-4.931	4.510	4.504	0.530*	0.460**	0.454**		0.458		0.452	
23	Vanadium	5.463		-5.427	4.952	4.944	0.604*	0.519**	0.512**		0.519		0.510	
24	Chromium	5.988		-5.946	5.414	5.405	0.679*	0.583**	0.574**		0.581		0.571	
25	Manganese	6.537		6.490	5.898	5.887	0.762*	0.650**	0.639**		0.647		0.636	
26	Iron	7.111		7.057	6.403	6.390	0.849*	0.721**	0.708**		0.717		0.704	
27	Cobalt	7.709		7.649	6.930	6.915	0.929*	0.794**	0.779**		0.790		0.775	
28	Nickel	8.331	8.328	8.204	7.477	7.460	1.015*	0.871**	0.853**		0.866		0.849	
29	Copper	8.980	8.976	8.904	8.047	8.027	1.100*	0.953	0.933		0.948		0.928	
30	Zinc	9.660	9.657	9.571	8.638	8.616	1.200*	1.045	1.022		1.032		1.009	
31	Gallium	10.368	10.365	10.263	9.351	9.334	1.30*	1.134**	1.117**		1.122		1.096	
32	Germanium	11.103	11.100	10.981	9.885	9.854	1.42*	1.248**	1.217**		1.216		1.186	
33	Arsenic	11.863	11.863	11.725	10.543	10.507	1.529	1.359	1.323		1.317		1.282	
34	Selenium	12.652	12.651	12.495	11.221	11.181	1.652	1.473	1.434		1.419		1.379	
35	Bromine	13.475	13.465	13.290	11.923	11.877	1.794‡	1.599**	1.552**		1.526		1.480	
36	Krypton	14.323	14.313	14.112	12.648	12.597	1.931‡	1.727**	1.675**		1.638‡		1.587**	
37	Rubidium	15.201	15.184	14.960	13.394	13.335	2.067	1.866	1.806		1.752	1.694	1.692	
38	Strontium	16.106	16.083	15.834	14.164	14.097	2.221	2.008	1.941		1.872	1.806	1.805	
39	Yttrium	17.037	17.011	16.736	14.957	14.882	2.369	2.154	2.079		1.996	1.922	1.920	
40	Zirconium	17.998	17.969	17.666	15.774	15.690	2.547	2.305	2.220	2.302	2.219	2.124	2.042	2.040

Atomic Number	Element	K series					L series							
		K _{ab}	Kβ ₁	Kβ ₂	Kα ₁	Kα ₂	L _{Iab}	L _{IIab}	L _{IIIab}	Lγ ₁	Lβ ₂	Lβ ₁	Lα ₁	Lα ₂
41	Niobium	18.987	18.951	18.621	16.614	16.520	2.706	2.467**	2.374	2.462	2.367	2.257	2.166	2.163
42	Molybdenum	20.002	19.964	19.607	17.478	17.373	2.884	2.627	2.523	2.623	2.518	2.395	2.293	2.290
43	Technetium	21.054	21.012	20.585	18.410	18.328	3.054	2.795	2.677	2.792	2.674	2.538	2.424	2.420
44	Ruthenium	22.118	22.072	21.655	19.278	19.149	3.236	2.966	2.837	2.964	2.836	2.683	2.558	2.554
45	Rhodium	23.224	23.169	22.721	20.214	20.072	3.419	3.145	3.002	3.144	3.001	2.834	2.696	2.692
46	Palladium	24.347	24.297	23.816	21.175	21.018	3.617	3.329	3.172	3.328	3.172	2.990	2.838	2.833
47	Silver	25.517	25.454	24.942	22.162	21.988	3.810	3.528	3.352	3.519	3.348	3.151	2.984	2.978
48	Cadmium	26.712	26.641	26.093	23.172	22.982	4.019	3.727	3.538	3.716	3.528	3.316	3.133	3.127
49	Indium	27.928	27.859	27.274	24.207	24.000	4.237	3.939	3.729	3.920	3.713	3.487	3.287	3.279
50	Tin	29.190	29.106	28.483	25.270	25.042	4.464	4.157	3.928	4.131	3.904	3.662	3.444	3.436
51	Antimony	30.486	30.387	29.723	26.357	26.109	4.697	4.381	4.132	4.347	4.100	3.843	3.605	3.595
52	Tellurium	31.809	31.698	30.993	27.471	27.200	4.938	4.613	4.341	4.570	4.301	4.029	3.769	3.758
53	Iodine	33.164	33.016	32.292	28.610	28.315	5.190	4.856	4.559	4.800	4.507	4.220	3.937	3.926
54	Xenon	34.579	34.446	33.644	29.802	29.485	5.452	5.104	4.782	5.036	4.720	4.422	4.111	4.098
55	Cesium	35.959	35.819	34.984	30.970	30.623	5.720	5.358	5.011	5.280	4.936	4.620	4.286	4.272
56	Barium	37.410	37.255	36.376	32.191	31.815	5.995	5.623	5.247	5.531	5.156	4.828	4.467	4.451
57	Lanthanum	38.931	38.728	37.799	33.440	33.033	6.283	5.894	5.489	5.789	5.384	5.043	4.651	4.635
58	Cerium	40.449	40.231	39.255	34.717	34.276	6.561	6.165	5.729	6.052	5.613	5.262	4.840	4.823
59	Praseodymium	41.998	41.772	40.746	36.023	35.548	6.846	6.443	5.968	6.322	5.850	5.489	5.034	5.014
60	Neodymium	43.571	43.298	42.269	37.359	36.845	7.144	6.727	6.215	6.602	6.090	5.722	5.230	5.208
61	Promethium	45.207	44.955	43.945	38.649	38.160	7.448	7.018	6.466	6.891	6.336	5.956	5.431	5.408
62	Samarium	46.846	46.553	45.400	40.124	39.523	7.754	7.281	6.721	7.180	6.587	6.206	5.636	5.609
63	Europium	48.515	48.241	47.027	41.529	40.877	8.069	7.624	6.983	7.478	6.842	6.456	5.848	5.816
64	Gadolinium	50.229	49.961	48.718	42.983	42.280	8.393	7.940	7.252	7.788	7.102	6.714	6.059	6.027
65	Terbium	51.998	51.737	50.391	44.470	43.737	8.724	8.258	7.519	8.104	7.368	6.979	6.275	6.241
66	Dysprosium	53.789	53.491	52.178	45.985	45.193	9.083	8.621	7.850	8.418	7.638	7.249	6.495	6.457
67	Holmium	55.615	55.292	53.934	47.528	46.686	9.411	8.920	8.074	8.748	7.912	7.528	6.720	6.680
68	Erbium	57.483	57.088	55.690	49.099	48.205	9.776	9.263	8.364	9.089	8.188	7.810	6.948	6.904
69	Thulium	59.335	58.969	57.576	50.730	49.762	10.144	9.628	8.652	9.424	8.472	8.103	7.181	7.135
70	Ytterbium	61.303	60.959	59.352	52.360	51.326	10.486	9.977	8.943	9.779	8.758	8.401	7.414	7.367
71	Lutecium	63.304	62.946	61.282	54.063	52.959	10.867	10.345	9.241	10.142	9.048	8.708	7.654	7.604
72	Hafnium	65.313	64.936	63.209	55.757	54.579	11.264	10.734	9.556	10.514	9.346	9.021	7.898	7.843
73	Tantalum	67.400	66.999	65.210	57.524	56.270	11.676	11.130	9.876	10.892	9.649	9.341	8.145	8.087
74	Tungsten	69.508	69.090	67.233	59.310	57.973	12.090	11.535	10.198	11.283	9.959	9.670	8.396	8.333
75	Rhenium	71.662	71.220	69.298	61.131	59.707	12.522	11.955	10.531	11.684	10.273	10.008	8.651	8.584
76	Osmium	73.860	73.393	71.404	62.991	61.477	12.965	12.383	10.869	12.094	10.596	10.354	8.910	8.840
77	Iridium	76.097	75.605	73.549	64.886	63.278	13.413	12.819	11.211	12.509	10.918	10.706	9.173	9.098
78	Platinum	78.379	77.866	75.736	66.820	65.111	13.873	13.268	11.569	12.939	11.249	11.069	9.441	9.360
79	Gold	80.713	80.165	77.968	68.794	66.980	14.353	13.733	11.919	13.379	11.582	11.439	9.711	9.625
80	Mercury	83.106	82.526	80.258	70.821	68.894	14.841	14.212	12.285	13.828	11.923	11.823	9.987	9.896
81	Thallium	85.517	84.904	82.558	72.860	70.820	15.346	14.697	12.657	14.288	12.268	12.210	10.266	10.170
82	Lead	88.001	87.343	84.922	74.957	72.794	15.870	15.207	13.044	14.762	12.620	12.611	10.549	10.448
83	Bismuth	90.521	89.833	87.335	77.097	74.805	16.393	15.716	13.424	15.244	12.977	13.021	10.836	10.729
84	Polonium	93.112	92.386	89.809	79.296	76.868	16.935	16.244	13.817	15.740	13.338	13.441	11.128	11.014
85	Astatine	95.740	94.976	92.319	81.525	78.956	17.490	16.784	14.215	16.248	13.705	13.873	11.424	11.304
86	Radon	98.418	97.616	94.877	83.800	81.080	18.058	17.337	14.618	16.768	14.077	14.316	11.724	11.597
87	Francium	101.147	100.305	97.483	86.119	83.243	18.638	17.904	15.028	17.301	14.459	14.770	12.029	11.894
88	Radium	103.927	103.048	100.136	88.485	85.446	19.233	18.481	15.442	17.845	14.839	15.233	12.338	12.194
89	Actinium	106.759	105.838	102.846	90.894	87.681	19.842	19.078	15.865	18.405	15.227	15.712	12.650	12.499
90	Thorium	109.630	108.671	105.592	93.334	89.942	20.460	19.688	16.296	18.977	15.620	16.200	12.966	12.808
91	Protactinium	112.581	111.575	108.408	95.851	92.271	21.102	20.311	16.731	19.559	16.022	16.700	13.291	13.120
92	Uranium	115.591	114.549	111.289	98.428	94.648	21.753	20.943	17.163	20.163	16.425	17.218	13.613	13.438
93	Neptunium	118.619	117.533	114.181	101.005	97.023	22.417	21.596	17.614	20.774	16.837	17.740	13.945	13.758
94	Plutonium	121.720	120.592	117.146	103.653	99.457	23.097	22.262	18.066	21.401	17.254	18.278	14.279	14.082
95	Americium	124.876	123.706	120.163	106.351	101.932	23.793	22.944	18.525	22.042	17.677	18.829	14.618	14.411
96	Curium	128.088	126.875	123.235	109.098	104.448	24.503	23.640	18.990	22.699	18.106	19.393	14.961	14.743
97	Berkelium	131.357	130.101	126.362	111.896	107.023	25.230	24.352	19.461	23.370	18.540	19.971	15.309	15.079
98	Californium	134.683	133.383	129.544	114.745	109.603	25.971	25.080	19.938	24.056	18.980	20.562	15.661	15.420
99		138.067	136.724	132.781	117.646	112.244	26.729	25.824	20.422	24.758	19.426	21.166	16.018	15.764
100		141.510	140.122	136.075	120.598	114.926	27.503	26.584	20.912	25.475	19.879	21.785	16.379	16.113

For $Z \leq 69$, values without symbols are derived from (1). Values prefixed with a - sign are $K\beta_{1,2}$.
 For $Z \geq 70$, absorption-edge values are from (3) in the case of $Z = 70-83, 88, 90$, and 92 ; remaining absorption edges to $Z = 100$ are obtained from these by least-squares quadratic fitting. All emission values for $Z \geq 70$ are derived from the preceding absorption edges, and others based on (4), using the transition relations $K\alpha_1 = K_{ab} - L_{III}$, $K\alpha_2 = K_{ab} - L_{II}$, $K\beta_1 = K_{ab} - M_{III}$, etc.
 * Obtained from R. D. Hill, E. L. Church, J. W. Mihelich (5). † Derived from Compton and Allison (2). ‡ Derived from C. E. Moore (3).
 § Values derived from Cauchois and Hulubei (1) which deviate from the Moseley law. Better-fitting values are: $Z = 17$, $K_{ab} = 2.826$; $Z = 43$, $K\alpha_1 = 18.370$, $K\alpha_2 = 18.250$, $K\beta_1 = 20.612$; $Z = 54$, $K\alpha_1 = 29.779$, $K\alpha_2 = 29.463$, $K\beta_1 = 34.398$; $Z = 80$, $K\beta_1 = 43.349$; $Z = 61$, $K\alpha_1 = 38.726$, $K\alpha_2 = 38.180$, $K\beta_1 = 43.811$; $Z = 62$, $K\beta_1 = 46.581$, $L_{II} = 7.312$; $Z = 66$, $L_{II} = 8.591$, $L_{III} = 7.790$; $Z = 69$, $K_{ab} = 59.382$, $K\beta_1 = 57.487$.
 § Calculated by method of least squares. ** Calculated by transition relations.