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## 4.2 Absorption of photons

### 4.2.1 X-ray absorption edges, characteristic X-ray lines and fluorescence yields

For a given absorbing element, the general fall in X-ray absorption coefficient with increasing energy of incident photon is interrupted by a sharp rise when the energy is equal to the binding energy of an electron shell (K, L, M, etc.) in the absorber; this energy is the least at which a vacancy can be created in the particular shell and is referred to as the 'edge' or 'critical excitation' energy. Characteristic X-ray lines are generated when an 'initial' vacancy in an inner shell, created by X-ray or electron excitation, is filled by transfer of an electron from another shell, thus leaving a 'final' vacancy in that shell; the energy of the line is equal to the difference in binding energies of the shells with the 'initial' and 'final' vacancies. Depending on atomic number, the X-ray spectra from the elements can include lines from the K, L, M, N and O series corresponding to excitation of the K, L, M, N or O levels; the table lists the energies—in keV—of the principal lines of the common K, L and M series along with the corresponding edge, or excitation, energy. Lines are identified both by the common labels—e.g.  $K\alpha_1$ ,  $K\alpha_2$ , etc.—and the term labels giving in order the shells with the 'initial' and 'final' vacancies—e.g.  $KL_{III}$ ,  $KL_{II}$ , etc. With the exception of the elements 92–103 the table has been prepared by calculation of line energies from the compilation of smoothed edge energies given by Dewey, Mapes and Reynolds, which in turn drew extensively on the compilation by Bearden; the edge data for elements 92–103 are taken directly from Bearden. The energies of the softer radiations may be affected by the chemical state of the elements concerned; generally the shifts do not exceed a few electron volts. The wavelength  $\lambda$ , in pm, can be derived from the tabulated energy  $E$ , in keV, by the relationship  $\lambda = 1239.81/E$ .

Approximate K and L line intensities are given at the head of the columns in the table, relative to the line in the series which is normally the strongest. Where a range of values is indicated, the first number represents the value for lowest Z, the second number that for the highest Z, in the section of the table to which it refers. The values given are based on the compilation of experimental relative intensities of Salem, Panossian and Krause and the intensities calculated by Scofield (Salem *et al.*, pp. 121–37). The values are intended only as a rough guide and the original references should be consulted for details. The accompanying figure gives a plot of the relative intensities for the commonly encountered  $K\beta$  line.

In addition to the lines given in the table, satellite, or non-diagram, lines also occur; these are generally only of significance in the case of the K-satellites or the lighter elements Al, Mg, Si, etc. where their intensities may be a few per cent of that of the  $K\alpha$  line (see Clark or Sandström).

The transition of an electron to fill, for example, a vacancy in the K-shell may be accompanied by either the emission of an X-ray photon or the transfer of energy to another electron which is then emitted (an Auger electron); the probability that a vacancy in a given shell will result in emission of an X-ray is the fluorescence yield of that shell.

The accompanying figures give plots of the fluorescence yield  $\omega_K$  for the K shell and an effective yield  $\gamma_{LII}$  for the  $L_{II}$  shell versus Z; the effective yield for the  $L_{III}$  is similar to that for the  $L_{II}$ . The K and L plots are based on the extensive survey by Krause, the validity of which is discussed in papers by Mitchell and Barfoot, and Singh *et al.* which consider additional experimental data including  $L_I$  yields. A few values for the average M shell fluorescence yield taken from *The Handbook of Spectroscopy* (ed. J. W. Robinson) are also given in the figure.

#### References

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## X-ray adsorption edges and characteristic X-ray line energies (keV)

| Atomic number and element | K-series |                     |                   |                  |                   |                  | L-series            |                                |                                |                               |                      |                               |                               |                       |                              |                              |                               | M-series                     |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
|---------------------------|----------|---------------------|-------------------|------------------|-------------------|------------------|---------------------|--------------------------------|--------------------------------|-------------------------------|----------------------|-------------------------------|-------------------------------|-----------------------|------------------------------|------------------------------|-------------------------------|------------------------------|---------------------------------|-----------------------|---------------------------------|----------------------|---------------------------------|---------------------|---------------------------------|--------------------------------|--|
|                           | K edge   | KN <sub>III</sub>   | KM <sub>III</sub> | KM <sub>II</sub> | KL <sub>III</sub> | KL <sub>II</sub> | L <sub>I</sub> edge | L <sub>IN</sub> <sub>III</sub> | L <sub>IM</sub> <sub>III</sub> | L <sub>IM</sub> <sub>II</sub> | L <sub>II</sub> edge | L <sub>IN</sub> <sub>IV</sub> | L <sub>IM</sub> <sub>IV</sub> | L <sub>III</sub> edge | L <sub>IN</sub> <sub>V</sub> | L <sub>IM</sub> <sub>V</sub> | L <sub>IM</sub> <sub>IV</sub> | L <sub>IM</sub> <sub>I</sub> | M <sub>II</sub> N <sub>IV</sub> | M <sub>III</sub> edge | M <sub>III</sub> N <sub>V</sub> | M <sub>IV</sub> edge | M <sub>IV</sub> N <sub>VI</sub> | M <sub>V</sub> edge | M <sub>V</sub> N <sub>VII</sub> | M <sub>V</sub> N <sub>VI</sub> |  |
|                           |          | Kβ <sub>2</sub>     | Kβ <sub>1</sub>   | Kβ <sub>3</sub>  | Kα <sub>1</sub>   | Kα <sub>2</sub>  |                     | Lγ <sub>3</sub>                | Lβ <sub>3</sub>                | Lβ <sub>4</sub>               |                      | Lγ <sub>1</sub>               | Lβ <sub>1</sub>               |                       | Lβ <sub>2</sub>              | Lα <sub>1</sub>              | Lα <sub>2</sub>               | L <sub>I</sub>               |                                 |                       | Mγ                              |                      | Mβ                              |                     | Mα <sub>1</sub>                 | Mα <sub>2</sub>                |  |
| Intensity                 | —        | 2–5                 | ~20               | ~10              | 100               | 50–53            | —                   | ~5                             | 50–35                          | 20                            | —                    | ~5                            | ~50                           | —                     | ~5                           | ~90                          | 10                            | 20–5                         |                                 | —                     |                                 | —                    |                                 | —                   |                                 |                                |  |
| 4 Be                      | 0.115    |                     |                   |                  | 0.109             |                  |                     |                                |                                |                               |                      |                               |                               | 0.006                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 5 B                       | 0.188    |                     |                   |                  | 0.183             |                  |                     |                                |                                |                               |                      |                               |                               | 0.005                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 6 C                       | 0.282    |                     |                   |                  | 0.277             |                  |                     |                                |                                |                               |                      |                               |                               | 0.005                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 7 N                       | 0.397    |                     |                   |                  | 0.393             |                  |                     |                                |                                |                               |                      |                               |                               | 0.004                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 8 O                       | 0.533    |                     |                   |                  | 0.525             |                  |                     |                                |                                |                               |                      |                               |                               | 0.008                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 9 F                       | 0.692    |                     |                   |                  | 0.677             |                  |                     |                                |                                |                               |                      |                               |                               | 0.015                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 10 Ne                     | 0.874    |                     | 0.858             |                  | 0.848             |                  |                     |                                |                                |                               |                      |                               |                               | 0.026                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 11 Na                     | 1.080    |                     | 1.071             |                  | 1.041             |                  |                     |                                |                                |                               |                      |                               |                               | 0.039                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 12 Mg                     | 1.309    |                     | 1.302             |                  | 1.253             | 0.062            |                     |                                |                                |                               |                      |                               |                               | 0.056                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 13 Al                     | 1.562    |                     | 1.557             |                  | 1.487             | 1.486            | 0.087               |                                |                                | 0.076                         |                      |                               |                               | 0.075                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 14 Si                     | 1.840    |                     | 1.836             |                  | 1.740             | 1.739            | 0.118               |                                |                                | 0.101                         |                      |                               |                               | 0.100                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 15 P                      | 2.143    |                     | 2.139             |                  | 2.014             | 2.013            | 0.153               |                                |                                | 0.130                         |                      |                               |                               | 0.129                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 16 S                      | 2.471    |                     | 2.464             |                  | 2.308             | 2.307            | 0.193               |                                |                                | 0.164                         |                      |                               |                               | 0.163                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 17 Cl                     | 2.824    |                     | 2.816             |                  | 2.622             | 2.620            | 0.237               |                                |                                | 0.204                         |                      |                               |                               | 0.202                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 18 Ar                     | 3.203    |                     | 3.190             |                  | 2.958             | 2.956            | 0.286               |                                |                                | 0.247                         |                      |                               |                               | 0.245                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 19 K                      | 3.607    |                     | 3.590             |                  | 3.314             | 3.311            | 0.340               |                                |                                | 0.296                         |                      |                               |                               | 0.293                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 20 Ca                     | 4.034    |                     | 4.013             |                  | 3.692             | 3.688            | 0.403               |                                |                                | 0.346                         |                      |                               |                               | 0.342                 |                              |                              |                               |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 21 Sc                     | 4.486    |                     | 4.461             |                  | 4.090             | 4.086            | 0.462               |                                |                                | 0.400                         | 0.400                | 0.396                         |                               | 0.395                 |                              |                              | 0.348                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 22 Ti                     | 4.965    |                     | 4.932             |                  | 4.511             | 4.505            | 0.529               |                                |                                | 0.460                         | 0.458                | 0.454                         |                               | 0.452                 |                              |                              | 0.395                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 23 V                      | 5.463    |                     | 5.427             |                  | 4.952             | 4.944            | 0.626               |                                | 0.585                          | 0.519                         | 0.519                | 0.511                         |                               | 0.511                 |                              |                              | 0.446                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 24 Cr                     | 5.987    |                     | 5.947             |                  | 5.415             | 5.405            | 0.694               |                                | 0.654                          | 0.582                         | 0.583                | 0.572                         |                               | 0.573                 |                              |                              | 0.500                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 25 Mn                     | 6.537    |                     | 6.490             |                  | 5.899             | 5.888            | 0.768               |                                | 0.721                          | 0.649                         | 0.649                | 0.638                         |                               | 0.637                 |                              |                              | 0.556                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 26 Fe                     | 7.112    |                     | 7.058             |                  | 6.404             | 6.391            | 0.846               |                                | 0.792                          | 0.721                         | 0.719                | 0.708                         |                               | 0.705                 |                              |                              | 0.615                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 27 Co                     | 7.712    |                     | 7.649             |                  | 6.930             | 6.915            | 0.929               |                                | 0.870                          | 0.797                         | 0.791                | 0.782                         |                               | 0.776                 |                              |                              | 0.678                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 28 Ni                     | 8.339    |                     | 8.265             |                  | 7.478             | 7.461            | 1.016               |                                | 0.941                          | 0.878                         | 0.869                | 0.861                         |                               | 0.852                 |                              |                              | 0.743                         |                              |                                 |                       |                                 |                      |                                 |                     |                                 |                                |  |
| 29 Cu                     | 8.993    |                     | 8.905             | 8.903            | 8.048             | 8.028            | 1.109               |                                | 1.023                          | 1.019                         | 0.965                | 0.950                         | 0.945                         |                       | 0.930                        |                              | 0.811                         |                              |                                 |                       | 0.015                           |                      |                                 |                     |                                 |                                |  |
| 30 Zn                     | 9.673    | 9.658 <sup>1</sup>  | 9.572             | 9.567            | 8.639             | 8.616            | 1.208               |                                | 1.107                          | 1.102                         | 1.057                | 1.035                         | 1.034                         |                       | 1.012                        |                              | 0.884                         |                              |                                 |                       | 0.022                           |                      |                                 |                     |                                 |                                |  |
| 31 Ga                     | 10.386   | 10.366 <sup>1</sup> | 10.271            | 10.261           | 9.252             | 9.231            | 1.316               |                                | 1.197                          | 1.191                         | 1.155                | 1.125                         | 1.134                         |                       | 1.098                        |                              | 0.957                         |                              |                                 | 0.115                 |                                 | 0.030                |                                 |                     |                                 |                                |  |
| 32 Ge                     | 11.115   | 11.101 <sup>1</sup> | 10.983            | 10.978           | 9.887             | 9.856            | 1.426               |                                | 1.294                          | 1.289                         | 1.259                | 1.218                         | 1.228                         |                       | 1.188                        |                              | 1.036                         |                              |                                 | 0.132                 |                                 | 0.041                |                                 |                     |                                 |                                |  |
| 33 As                     | 11.877   | 11.864 <sup>1</sup> | 11.727            | 11.721           | 10.544            | 10.509           | 1.536               |                                | 1.386                          | 1.380                         | 1.368                | 1.316                         | 1.333                         |                       | 1.282                        |                              | 1.120                         |                              |                                 | 0.150                 |                                 | 0.052                |                                 |                     |                                 |                                |  |
| 34 Se                     | 12.666   | 12.652 <sup>1</sup> | 12.496            | 12.489           | 11.222            | 11.181           | 1.662               |                                | 1.492                          | 1.485                         | 1.485                | 1.419                         | 1.444                         |                       | 1.379                        |                              | 1.204                         |                              |                                 | 0.170                 |                                 | 0.066                |                                 |                     |                                 |                                |  |
| 35 Br                     | 13.483   | 13.470 <sup>1</sup> | 13.292            | 13.285           | 11.924            | 11.878           | 1.791               |                                | 1.600                          | 1.593                         | 1.605                | 1.523                         | 1.559                         |                       | 1.480                        |                              | 1.294                         |                              |                                 | 0.191                 |                                 | 0.082                |                                 |                     |                                 |                                |  |
| 36 Kr                     | 14.330   | 14.315 <sup>1</sup> | 14.113            | 14.105           | 12.650            | 12.598           | 1.923               |                                | 1.706                          | 1.698                         | 1.732                | 1.637                         | 1.680                         |                       | 1.586                        |                              | 1.386                         |                              |                                 | 0.217                 |                                 | 0.095                |                                 |                     |                                 |                                |  |



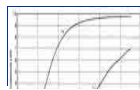
|                  |         |         |         |         |         |         |        |        |        |        |        |        |        |        |        |        |        |        |       |       |       |       |       |       |       |       |
|------------------|---------|---------|---------|---------|---------|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| 76 Os            | 73.869  | 73.404  | 71.416  | 71.077  | 63.001  | 61.487  | 12.968 | 12.503 | 10.515 | 10.176 | 12.382 | 12.092 | 10.349 | 10.868 | 10.592 | 8.905  | 8.835  | 7.822  |       | 2.453 | 2.177 | 2.033 | 1.988 | 1.963 | 1.921 | 1.918 |
| 77 Ir            | 76.111  | 75.620  | 73.560  | 73.203  | 64.896  | 63.287  | 13.416 | 12.925 | 10.865 | 10.508 | 12.824 | 12.514 | 10.705 | 11.215 | 10.919 | 9.175  | 9.096  | 8.046  |       | 2.551 | 2.255 | 2.119 | 2.062 | 2.040 | 1.988 | 1.983 |
| 78 Pt            | 78.400  | 77.883  | 75.751  | 75.364  | 66.832  | 65.123  | 13.880 | 13.363 | 11.231 | 10.844 | 13.277 | 12.944 | 11.073 | 11.568 | 11.251 | 9.439  | 9.364  | 8.271  |       | 2.649 | 2.332 | 2.204 | 2.134 | 2.129 | 2.065 | 2.059 |
| 79 Au            | 80.729  | 80.182  | 77.985  | 77.580  | 68.804  | 66.990  | 14.353 | 13.806 | 11.609 | 11.204 | 13.739 | 13.383 | 11.432 | 11.925 | 11.585 | 9.705  | 9.618  | 8.494  |       | 2.744 | 2.404 | 2.307 | 2.220 | 2.220 | 2.142 | 2.133 |
| 80 Hg            | 83.109  | 82.532  | 80.261  | 79.822  | 70.819  | 68.894  | 14.835 | 14.258 | 11.987 | 11.548 | 14.215 | 13.834 | 11.823 | 12.290 | 11.927 | 9.999  | 9.898  | 8.722  |       | 2.848 | 2.485 | 2.392 | 2.285 | 2.291 | 2.195 | 2.184 |
| 81 Tl            | 83.532  | 84.924  | 82.575  | 82.384  | 72.872  | 70.832  | 15.344 | 14.736 | 13.387 | 12.196 | 14.700 | 14.293 | 12.217 | 12.660 | 12.272 | 10.271 | 10.117 | 8.953  | 3.012 | 2.957 | 2.569 | 2.483 | 2.360 | 2.389 | 2.270 | 2.266 |
| 82 Pb            | 88.008  | 87.367  | 84.936  | 84.450  | 74.969  | 72.804  | 15.863 | 15.222 | 12.791 | 12.305 | 15.204 | 14.769 | 12.618 | 13.039 | 12.625 | 10.555 | 10.453 | 9.185  | 3.125 | 3.072 | 2.658 | 2.586 | 2.442 | 2.484 | 2.345 | 2.340 |
| 83 Bi            | 90.540  | 89.866  | 87.354  | 86.831  | 77.118  | 74.815  | 16.391 | 15.717 | 13.205 | 12.682 | 15.725 | 15.261 | 13.031 | 13.422 | 12.981 | 10.836 | 10.728 | 9.421  | 3.234 | 3.186 | 2.745 | 2.694 | 2.534 | 2.586 | 2.422 | 2.426 |
| 84 Po            | 93.113  | 92.403  | 89.801  | 89.250  | 79.301  | 76.863  | 16.940 | 16.230 | 13.628 | 13.077 | 16.250 | 15.756 | 13.452 | 13.812 | 13.342 | 11.131 | 11.014 | 9.664  | 3.354 | 3.312 | 2.842 | 2.798 | 2.620 | 2.681 | 2.501 | 2.503 |
| 85 At            | 95.730  | 94.983  | 92.302  | 91.722  | 81.523  | 78.943  | 17.495 | 16.748 | 14.067 | 13.487 | 16.787 | 16.262 | 13.882 | 14.207 | 13.708 | 11.427 | 11.302 | 9.858  | 3.475 | 3.428 | 2.929 | 2.905 | 2.707 | 2.780 | 2.581 | 2.582 |
| 86 Rn            | 98.402  | 97.617  | 94.866  | 94.246  | 83.793  | 81.065  | 18.047 | 17.262 | 14.511 | 13.891 | 17.337 | 16.777 | 14.323 | 14.609 | 14.079 | 11.727 | 11.595 | 10.085 | 3.593 | 3.536 | 3.006 | 3.014 | 2.794 | 2.882 | 2.663 | 2.662 |
| 87 Fr            | 101.131 | 100.306 | 97.477  | 96.807  | 86.114  | 83.231  | 18.630 | 17.805 | 14.976 | 14.306 | 17.900 | 17.307 | 14.775 | 15.017 | 14.456 | 12.031 | 11.892 | 10.340 | 3.724 | 3.654 | 3.093 | 3.125 | 2.881 | 2.986 | 2.746 | 2.742 |
| 88 Ra            | 103.909 | 103.039 | 100.130 | 99.432  | 88.476  | 85.434  | 19.222 | 18.352 | 15.443 | 14.745 | 18.475 | 17.848 | 15.238 | 15.433 | 14.839 | 12.340 | 12.196 | 10.622 | 3.853 | 3.779 | 3.185 | 3.237 | 2.967 | 3.093 | 2.829 | 2.823 |
| 89 Ac            | 106.738 | 105.837 | 102.846 | 102.101 | 90.884  | 87.675  | 19.823 | 18.922 | 15.931 | 15.186 | 19.063 | 18.402 | 15.711 | 15.854 | 15.227 | 12.652 | 12.502 | 10.835 | 3.981 | 3.892 | 3.265 | 3.352 | 3.054 | 3.202 | 2.913 | 2.904 |
| 90 Th            | 109.641 | 108.690 | 105.611 | 104.831 | 93.358  | 89.952  | 20.449 | 19.498 | 16.419 | 15.639 | 16.689 | 18.993 | 16.215 | 16.283 | 15.622 | 12.970 | 12.809 | 11.119 | 4.118 | 4.030 | 3.369 | 3.474 | 3.145 | 3.313 | 2.996 | 2.984 |
| 91 Pa            | 112.599 | 111.606 | 108.435 | 107.606 | 95.883  | 92.287  | 21.088 | 20.095 | 16.924 | 16.095 | 20.312 | 19.581 | 16.715 | 16.716 | 16.022 | 13.300 | 13.119 | 11.366 | 4.261 | 4.164 | 3.470 | 3.597 | 3.251 | 3.416 | 3.083 | 3.070 |
| 92 U             | 115.606 | 114.561 | 111.303 | 110.424 | 98.440  | 94.659  | 21.757 | 20.712 | 17.454 | 16.575 | 20.947 | 20.167 | 17.219 | 17.166 | 16.429 | 13.614 | 13.438 | 11.619 | 4.401 | 4.303 | 3.566 | 3.728 | 3.337 | 3.552 | 3.171 | 3.161 |
| 93 Np            | 118.678 | 117.591 | 114.243 | 113.312 | 101.068 | 97.077  | 22.427 | 21.340 | 17.992 | 17.061 | 21.601 | 20.785 | 17.751 | 17.610 | 16.840 | 13.944 | 13.760 | 11.890 | 4.543 | 4.435 | 3.665 | 3.850 | 3.435 | 3.666 | 3.262 | 3.251 |
| 94 Pu            | 121.818 | 120.703 | 117.261 | 116.277 | 103.761 | 99.552  | 23.097 | 21.982 | 18.540 | 17.556 | 22.266 | 21.417 | 18.293 | 18.057 | 17.256 | 14.279 | 14.084 | 12.124 | 4.699 | 4.557 | 3.756 | 3.973 | 3.527 | 3.778 | 3.346 | 3.332 |
| 95 Am            | 125.027 | 123.891 | 120.360 | 119.317 | 106.523 | 102.083 | 23.773 | 22.637 | 19.106 | 18.063 | 22.944 | 22.065 | 18.852 | 18.504 | 17.676 | 14.617 | 14.412 | 12.384 |       | 4.667 | 3.839 | 4.092 | 0.0   | 3.887 | 0.0   | 0.0   |
| <i>Intensity</i> | —       | ~15     | ~20     | ~10     | 100     | ~65     | —      | ~5     | ~20    | 20     | —      | ~25    | ~100   | —      | ~20    | ~90    | 10     | 20-5   |       | —     |       |       | —     |       |       |       |
| 96 Cm            | 128.220 | 127.066 | 123.423 | 122.325 | 109.290 | 104.441 | 24.460 | 23.306 | 19.663 | 18.565 | 23.779 |        | 19.552 | 18.930 |        | 14.959 | 14.703 |        |       | 4.797 |       |       |       | 3.971 |       |       |
| 97 Bk            | 131.590 | 130.355 | 126.663 | 125.443 | 112.138 | 107.205 | 25.275 | 24.040 | 20.348 | 19.128 | 24.385 |        | 20.019 | 19.452 |        | 15.320 | 15.086 |        |       | 4.927 |       |       |       | 4.132 |       |       |
| 98 Cf            | 135.960 | 134.681 | 130.851 | 129.601 | 116.030 | 110.710 | 26.110 | 24.831 | 21.001 | 19.751 | 25.250 |        | 20.763 | 19.930 |        | 15.677 | 15.443 |        |       | 5.109 |       |       |       | 4.253 |       |       |
| 99 Es            | 139.490 | 138.169 | 134.238 | 132.916 | 119.080 | 113.470 | 26.900 | 25.579 | 21.648 | 20.326 | 26.020 |        | 21.390 | 20.410 |        | 16.036 | 15.780 |        |       | 5.252 |       |       |       | 4.374 |       |       |
| 100 Fm           | 143.090 | 141.724 | 137.693 | 136.347 | 122.190 | 116.280 | 27.700 | 26.334 | 22.303 | 20.957 | 26.810 |        | 22.044 | 20.900 |        | 16.402 | 16.134 |        |       | 5.397 |       |       |       | 4.498 |       |       |
| 101 Md           | 146.780 | 145.370 | 141.234 | 139.761 | 125.390 | 119.170 | 28.530 | 27.120 | 22.984 | 21.511 | 27.610 |        | 22.707 | 21.390 |        | 16.768 | 16.487 |        |       | 5.546 |       |       |       | 4.622 |       |       |
| 102 No           | 150.540 | 149.092 | 144.852 | 143.295 | 128.660 | 122.100 | 29.380 | 27.932 | 23.692 | 22.135 | 28.440 |        | 23.403 | 21.880 |        | 17.139 | 16.843 |        |       | 5.688 |       |       |       | 4.741 |       |       |
| 103 Lw           | 154.380 | 152.900 | 148.670 | 146.920 | 132.020 | 125.100 | 30.240 | 28.760 | 24.530 | 22.780 | 29.280 |        | 24.130 | 22.360 |        | 17.500 | 17.210 |        |       | 5.710 |       |       |       | 4.860 |       |       |

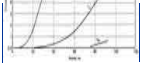
Unresolved lines:

1— $\text{KN}_{\text{II,III}} (\text{K}\beta_2)$ ; 2— $\text{L}_1\text{N}_{\text{II,III}} (\text{L}\gamma_{2,3})$ 

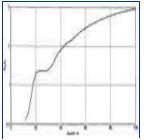
Depending on the resolving power of the dispersing system used (e.g. crystal spectrometer, solid state energy dispersive detector) line pairs shown separately in the table may not be resolved and the effective energy of the doublet will be close to the mean value weighted by the relative intensity of the components.

(Click the Images to view Larger Images)

Variations of the fluorescence yields  $\omega_K$  and  $\omega_M$  for the K-shell and M-shell respectively and



**of the effective  
fluorescence yield  $\gamma_{LII}$  for the  $L_{II}$  shell with atomic number.**



Variations of  $K_{\beta} / K_{\alpha}$  with atomic number

D.M. Poole

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