

# APPENDIX A

## Atomic Masses

| Atomic Number, Z | Name      | Atomic Mass Number, A | Symbol              | Atomic Mass (u) | Percent Abundance or Decay Mode | Half-life, t <sub>1/2</sub> |
|------------------|-----------|-----------------------|---------------------|-----------------|---------------------------------|-----------------------------|
| 0                | neutron   | 1                     | <i>n</i>            | 1.008 665       | $\beta^-$                       | 10.37 min                   |
| 1                | Hydrogen  | 1                     | <sup>1</sup> H      | 1.007 825       | 99.985%                         |                             |
|                  | Deuterium | 2                     | <sup>2</sup> H or D | 2.014 102       | 0.015%                          |                             |
|                  | Tritium   | 3                     | <sup>3</sup> H or T | 3.016 050       | $\beta^-$                       | 12.33 y                     |
| 2                | Helium    | 3                     | <sup>3</sup> He     | 3.016 030       | $1.38 \times 10^{-4}\%$         |                             |
|                  |           | 4                     | <sup>4</sup> He     | 4.002 603       | ≈100%                           |                             |
| 3                | Lithium   | 6                     | <sup>6</sup> Li     | 6.015 121       | 7.5%                            |                             |
|                  |           | 7                     | <sup>7</sup> Li     | 7.016 003       | 92.5%                           |                             |
| 4                | Beryllium | 7                     | <sup>7</sup> Be     | 7.016 928       | EC                              | 53.29 d                     |
|                  |           | 9                     | <sup>9</sup> Be     | 9.012 182       | 100%                            |                             |
| 5                | Boron     | 10                    | <sup>10</sup> B     | 10.012 937      | 19.9%                           |                             |
|                  |           | 11                    | <sup>11</sup> B     | 11.009 305      | 80.1%                           |                             |
| 6                | Carbon    | 11                    | <sup>11</sup> C     | 11.011 432      | EC, $\beta^+$                   |                             |
|                  |           | 12                    | <sup>12</sup> C     | 12.000 000      | 98.90%                          |                             |
|                  |           | 13                    | <sup>13</sup> C     | 13.003 355      | 1.10%                           |                             |
|                  |           | 14                    | <sup>14</sup> C     | 14.003 241      | $\beta^-$                       | 5730 y                      |
| 7                | Nitrogen  | 13                    | <sup>13</sup> N     | 13.005 738      | $\beta^+$                       | 9.96 min                    |
|                  |           | 14                    | <sup>14</sup> N     | 14.003 074      | 99.63%                          |                             |
|                  |           | 15                    | <sup>15</sup> N     | 15.000 108      | 0.37%                           |                             |
| 8                | Oxygen    | 15                    | <sup>15</sup> O     | 15.003 065      | EC, $\beta^+$                   | 122 s                       |

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|------------------|------------|-----------------------|------------------|-----------------|---------------------------------|------------------------------|
|                  |            | 16                    | $^{16}\text{O}$  | 15.994 915      | 99.76%                          |                              |
|                  |            | 18                    | $^{18}\text{O}$  | 17.999 160      | 0.200%                          |                              |
| 9                | Fluorine   | 18                    | $^{18}\text{F}$  | 18.000 937      | EC, $\beta^+$                   | 1.83 h                       |
|                  |            | 19                    | $^{19}\text{F}$  | 18.998 403      | 100%                            |                              |
| 10               | Neon       | 20                    | $^{20}\text{Ne}$ | 19.992 435      | 90.51%                          |                              |
|                  |            | 22                    | $^{22}\text{Ne}$ | 21.991 383      | 9.22%                           |                              |
| 11               | Sodium     | 22                    | $^{22}\text{Na}$ | 21.994 434      | $\beta^+$                       | 2.602 y                      |
|                  |            | 23                    | $^{23}\text{Na}$ | 22.989 767      | 100%                            |                              |
|                  |            | 24                    | $^{24}\text{Na}$ | 23.990 961      | $\beta^-$                       | 14.96 h                      |
| 12               | Magnesium  | 24                    | $^{24}\text{Mg}$ | 23.985 042      | 78.99%                          |                              |
| 13               | Aluminum   | 27                    | $^{27}\text{Al}$ | 26.981 539      | 100%                            |                              |
| 14               | Silicon    | 28                    | $^{28}\text{Si}$ | 27.976 927      | 92.23%                          | 2.62h                        |
|                  |            | 31                    | $^{31}\text{Si}$ | 30.975 362      | $\beta^-$                       |                              |
| 15               | Phosphorus | 31                    | $^{31}\text{P}$  | 30.973 762      | 100%                            |                              |
|                  |            | 32                    | $^{32}\text{P}$  | 31.973 907      | $\beta^-$                       | 14.28 d                      |
| 16               | Sulfur     | 32                    | $^{32}\text{S}$  | 31.972 070      | 95.02%                          |                              |
|                  |            | 35                    | $^{35}\text{S}$  | 34.969 031      | $\beta^-$                       | 87.4 d                       |
| 17               | Chlorine   | 35                    | $^{35}\text{Cl}$ | 34.968 852      | 75.77%                          |                              |
|                  |            | 37                    | $^{37}\text{Cl}$ | 36.965 903      | 24.23%                          |                              |
| 18               | Argon      | 40                    | $^{40}\text{Ar}$ | 39.962 384      | 99.60%                          |                              |
| 19               | Potassium  | 39                    | $^{39}\text{K}$  | 38.963 707      | 93.26%                          |                              |
|                  |            | 40                    | $^{40}\text{K}$  | 39.963 999      | 0.0117%, EC, $\beta^-$          | $1.28 \times 10^9 \text{ y}$ |
| 20               | Calcium    | 40                    | $^{40}\text{Ca}$ | 39.962 591      | 96.94%                          |                              |
| 21               | Scandium   | 45                    | $^{45}\text{Sc}$ | 44.955 910      | 100%                            |                              |

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| Atomic Number, Z | Name      | Atomic Mass Number, A | Symbol           | Atomic Mass (u) | Percent Abundance or Decay Mode | Half-life, $t_{1/2}$ |
|------------------|-----------|-----------------------|------------------|-----------------|---------------------------------|----------------------|
| 22               | Titanium  | 48                    | $^{48}\text{Ti}$ | 47.947 947      | 73.8%                           |                      |
| 23               | Vanadium  | 51                    | $^{51}\text{V}$  | 50.943 962      | 99.75%                          |                      |
| 24               | Chromium  | 52                    | $^{52}\text{Cr}$ | 51.940 509      | 83.79%                          |                      |
| 25               | Manganese | 55                    | $^{55}\text{Mn}$ | 54.938 047      | 100%                            |                      |
| 26               | Iron      | 56                    | $^{56}\text{Fe}$ | 55.934 939      | 91.72%                          |                      |
| 27               | Cobalt    | 59                    | $^{59}\text{Co}$ | 58.933 198      | 100%                            |                      |
|                  |           | 60                    | $^{60}\text{Co}$ | 59.933 819      | $\beta^-$                       | 5.271 y              |
| 28               | Nickel    | 58                    | $^{58}\text{Ni}$ | 57.935 346      | 68.27%                          |                      |
|                  |           | 60                    | $^{60}\text{Ni}$ | 59.930 788      | 26.10%                          |                      |
| 29               | Copper    | 63                    | $^{63}\text{Cu}$ | 62.939 598      | 69.17%                          |                      |
|                  |           | 65                    | $^{65}\text{Cu}$ | 64.927 793      | 30.83%                          |                      |
| 30               | Zinc      | 64                    | $^{64}\text{Zn}$ | 63.929 145      | 48.6%                           |                      |
|                  |           | 66                    | $^{66}\text{Zn}$ | 65.926 034      | 27.9%                           |                      |
| 31               | Gallium   | 69                    | $^{69}\text{Ga}$ | 68.925 580      | 60.1%                           |                      |
| 32               | Germanium | 72                    | $^{72}\text{Ge}$ | 71.922 079      | 27.4%                           |                      |
|                  |           | 74                    | $^{74}\text{Ge}$ | 73.921 177      | 36.5%                           |                      |
| 33               | Arsenic   | 75                    | $^{75}\text{As}$ | 74.921 594      | 100%                            |                      |
| 34               | Selenium  | 80                    | $^{80}\text{Se}$ | 79.916 520      | 49.7%                           |                      |
| 35               | Bromine   | 79                    | $^{79}\text{Br}$ | 78.918 336      | 50.69%                          |                      |
| 36               | Krypton   | 84                    | $^{84}\text{Kr}$ | 83.911 507      | 57.0%                           |                      |
| 37               | Rubidium  | 85                    | $^{85}\text{Rb}$ | 84.911 794      | 72.17%                          |                      |
| 38               | Strontium | 86                    | $^{86}\text{Sr}$ | 85.909 267      | 9.86%                           |                      |
|                  |           | 88                    | $^{88}\text{Sr}$ | 87.905 619      | 82.58%                          |                      |
|                  |           | 90                    | $^{90}\text{Sr}$ | 89.907 738      | $\beta^-$                       | 28.8 y               |

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| Atomic Number, Z | Name       | Atomic Mass Number, A | Symbol            | Atomic Mass (u) | Percent Abundance or Decay Mode | Half-life, $t_{1/2}$           |
|------------------|------------|-----------------------|-------------------|-----------------|---------------------------------|--------------------------------|
| 39               | Yttrium    | 89                    | $^{89}\text{Y}$   | 88.905 849      | 100%                            |                                |
|                  |            | 90                    | $^{90}\text{Y}$   | 89.907 152      | $\beta^-$                       | 64.1 h                         |
| 40               | Zirconium  | 90                    | $^{90}\text{Zr}$  | 89.904 703      | 51.45%                          |                                |
| 41               | Niobium    | 93                    | $^{93}\text{Nb}$  | 92.906 377      | 100%                            |                                |
| 42               | Molybdenum | 98                    | $^{98}\text{Mo}$  | 97.905 406      | 24.13%                          |                                |
| 43               | Technetium | 98                    | $^{98}\text{Tc}$  | 97.907 215      | $\beta^-$                       | $4.2 \times 10^6 \text{ y}$    |
| 44               | Ruthenium  | 102                   | $^{102}\text{Ru}$ | 101.904 348     | 31.6%                           |                                |
| 45               | Rhodium    | 103                   | $^{103}\text{Rh}$ | 102.905 500     | 100%                            |                                |
| 46               | Palladium  | 106                   | $^{106}\text{Pd}$ | 105.903 478     | 27.33%                          |                                |
| 47               | Silver     | 107                   | $^{107}\text{Ag}$ | 106.905 092     | 51.84%                          |                                |
|                  |            | 109                   | $^{109}\text{Ag}$ | 108.904 757     | 48.16%                          |                                |
| 48               | Cadmium    | 114                   | $^{114}\text{Cd}$ | 113.903 357     | 28.73%                          |                                |
| 49               | Indium     | 115                   | $^{115}\text{In}$ | 114.903 880     | 95.7%, $\beta^-$                | $4.4 \times 10^{14} \text{ y}$ |
| 50               | Tin        | 120                   | $^{120}\text{Sn}$ | 119.902 200     | 32.59%                          |                                |
| 51               | Antimony   | 121                   | $^{121}\text{Sb}$ | 120.903 821     | 57.3%                           |                                |
| 52               | Tellurium  | 130                   | $^{130}\text{Te}$ | 129.906 229     | 33.8%, $\beta^-$                | $2.5 \times 10^{21} \text{ y}$ |
| 53               | Iodine     | 127                   | $^{127}\text{I}$  | 126.904 473     | 100%                            |                                |
|                  |            | 131                   | $^{131}\text{I}$  | 130.906 114     | $\beta^-$                       | 8.040 d                        |

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|------------------|--------------|-----------------------|-------------------|-----------------|---------------------------------|----------------------|
| 54               | Xenon        | 132                   | $^{132}\text{Xe}$ | 131.904 144     | 26.9%                           |                      |
|                  |              | 136                   | $^{136}\text{Xe}$ | 135.907 214     | 8.9%                            |                      |
| 55               | Cesium       | 133                   | $^{133}\text{Cs}$ | 132.905 429     | 100%                            |                      |
|                  |              | 134                   | $^{134}\text{Cs}$ | 133.906 696     | EC, $\beta^-$                   | 2.06 y               |
| 56               | Barium       | 137                   | $^{137}\text{Ba}$ | 136.905 812     | 11.23%                          |                      |
|                  |              | 138                   | $^{138}\text{Ba}$ | 137.905 232     | 71.70%                          |                      |
| 57               | Lanthanum    | 139                   | $^{139}\text{La}$ | 138.906 346     | 99.91%                          |                      |
| 58               | Cerium       | 140                   | $^{140}\text{Ce}$ | 139.905 433     | 88.48%                          |                      |
| 59               | Praseodymium | 141                   | $^{141}\text{Pr}$ | 140.907 647     | 100%                            |                      |
| 60               | Neodymium    | 142                   | $^{142}\text{Nd}$ | 141.907 719     | 27.13%                          |                      |
| 61               | Promethium   | 145                   | $^{145}\text{Pm}$ | 144.912 743     | EC, $\alpha$                    | 17.7 y               |
| 62               | Samarium     | 152                   | $^{152}\text{Sm}$ | 151.919 729     | 26.7%                           |                      |
| 63               | Europium     | 153                   | $^{153}\text{Eu}$ | 152.921 225     | 52.2%                           |                      |
| 64               | Gadolinium   | 158                   | $^{158}\text{Gd}$ | 157.924 099     | 24.84%                          |                      |
| 65               | Terbium      | 159                   | $^{159}\text{Tb}$ | 158.925 342     | 100%                            |                      |
| 66               | Dysprosium   | 164                   | $^{164}\text{Dy}$ | 163.929 171     | 28.2%                           |                      |
| 67               | Holmium      | 165                   | $^{165}\text{Ho}$ | 164.930 319     | 100%                            |                      |

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|------------------|-----------|-----------------------|-------------------|-----------------|---------------------------------|--------------------------------|
| 68               | Erbium    | 166                   | $^{166}\text{Er}$ | 165.930 290     | 33.6%                           |                                |
| 69               | Thulium   | 169                   | $^{169}\text{Tm}$ | 168.934 212     | 100%                            |                                |
| 70               | Ytterbium | 174                   | $^{174}\text{Yb}$ | 173.938 859     | 31.8%                           |                                |
| 71               | Lutecium  | 175                   | $^{175}\text{Lu}$ | 174.940 770     | 97.41%                          |                                |
| 72               | Hafnium   | 180                   | $^{180}\text{Hf}$ | 179.946 545     | 35.10%                          |                                |
| 73               | Tantalum  | 181                   | $^{181}\text{Ta}$ | 180.947 992     | 99.98%                          |                                |
| 74               | Tungsten  | 184                   | $^{184}\text{W}$  | 183.950 928     | 30.67%                          |                                |
| 75               | Rhenium   | 187                   | $^{187}\text{Re}$ | 186.955 744     | 62.6%, $\beta^-$                | $4.6 \times 10^{10} \text{ y}$ |
| 76               | Osmium    | 191                   | $^{191}\text{Os}$ | 190.960 920     | $\beta^-$                       | 15.4 d                         |
|                  |           | 192                   | $^{192}\text{Os}$ | 191.961 467     | 41.0%                           |                                |
| 77               | Iridium   | 191                   | $^{191}\text{Ir}$ | 190.960 584     | 37.3%                           |                                |
|                  |           | 193                   | $^{193}\text{Ir}$ | 192.962 917     | 62.7%                           |                                |
| 78               | Platinum  | 195                   | $^{195}\text{Pt}$ | 194.964 766     | 33.8%                           |                                |
| 79               | Gold      | 197                   | $^{197}\text{Au}$ | 196.966 543     | 100%                            |                                |
|                  |           | 198                   | $^{198}\text{Au}$ | 197.968 217     | $\beta^-$                       | 2.696 d                        |
| 80               | Mercury   | 199                   | $^{199}\text{Hg}$ | 198.968 253     | 16.87%                          |                                |

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| Atomic Number, Z | Name     | Atomic Mass Number, A | Symbol            | Atomic Mass (u) | Percent Abundance or Decay Mode | Half-life, $t_{1/2}$ |
|------------------|----------|-----------------------|-------------------|-----------------|---------------------------------|----------------------|
|                  |          | 202                   | $^{202}\text{Hg}$ | 201.970 617     | 29.86%                          |                      |
| 81               | Thallium | 205                   | $^{205}\text{Tl}$ | 204.974 401     | 70.48%                          |                      |
| 82               | Lead     | 206                   | $^{206}\text{Pb}$ | 205.974 440     | 24.1%                           |                      |
|                  |          | 207                   | $^{207}\text{Pb}$ | 206.975 872     | 22.1%                           |                      |
|                  |          | 208                   | $^{208}\text{Pb}$ | 207.976 627     | 52.4%                           |                      |
|                  |          | 210                   | $^{210}\text{Pb}$ | 209.984 163     | $\alpha, \beta^-$               | 22.3 y               |
|                  |          | 211                   | $^{211}\text{Pb}$ | 210.988 735     | $\beta^-$                       | 36.1 min             |
|                  |          | 212                   | $^{212}\text{Pb}$ | 211.991 871     | $\beta^-$                       | 10.64 h              |
| 83               | Bismuth  | 209                   | $^{209}\text{Bi}$ | 208.980 374     | 100%                            |                      |
|                  |          | 211                   | $^{211}\text{Bi}$ | 210.987 255     | $\alpha, \beta^-$               | 2.14 min             |
| 84               | Polonium | 210                   | $^{210}\text{Po}$ | 209.982 848     | $\alpha$                        | 138.38 d             |
| 85               | Astatine | 218                   | $^{218}\text{At}$ | 218.008 684     | $\alpha, \beta^-$               | 1.6 s                |
| 86               | Radon    | 222                   | $^{222}\text{Rn}$ | 222.017 570     | $\alpha$                        | 3.82 d               |
| 87               | Francium | 223                   | $^{223}\text{Fr}$ | 223.019 733     | $\alpha, \beta^-$               | 21.8 min             |
| 88               | Radium   | 226                   | $^{226}\text{Ra}$ | 226.025 402     | $\alpha$                        | $1.60 \times 10^3$ y |
| 89               | Actinium | 227                   | $^{227}\text{Ac}$ | 227.027 750     | $\alpha, \beta^-$               | 21.8 y               |

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|------------------|--------------|-----------------------|-------------------|-----------------|---------------------------------|-------------------------|
| 90               | Thorium      | 228                   | $^{228}\text{Th}$ | 228.028 715     | $\alpha$                        | 1.91 y                  |
|                  |              | 232                   | $^{232}\text{Th}$ | 232.038 054     | 100%, $\alpha$                  | $1.41 \times 10^{10}$ y |
| 91               | Protactinium | 231                   | $^{231}\text{Pa}$ | 231.035 880     | $\alpha$                        | $3.28 \times 10^4$ y    |
| 92               | Uranium      | 233                   | $^{233}\text{U}$  | 233.039 628     | $\alpha$                        | $1.59 \times 10^3$ y    |
|                  |              | 235                   | $^{235}\text{U}$  | 235.043 924     | 0.720%, $\alpha$                | $7.04 \times 10^8$ y    |
|                  |              | 236                   | $^{236}\text{U}$  | 236.045 562     | $\alpha$                        | $2.34 \times 10^7$ y    |
|                  |              | 238                   | $^{238}\text{U}$  | 238.050 784     | 99.2745%, $\alpha$              | $4.47 \times 10^9$ y    |
|                  |              | 239                   | $^{239}\text{U}$  | 239.054 289     | $\beta^-$                       | 23.5 min                |
| 93               | Neptunium    | 239                   | $^{239}\text{Np}$ | 239.052 933     | $\beta^-$                       | 2.355 d                 |
| 94               | Plutonium    | 239                   | $^{239}\text{Pu}$ | 239.052 157     | $\alpha$                        | $2.41 \times 10^4$ y    |
| 95               | Americium    | 243                   | $^{243}\text{Am}$ | 243.061 375     | $\alpha$ , fission              | $7.37 \times 10^3$ y    |
| 96               | Curium       | 245                   | $^{245}\text{Cm}$ | 245.065 483     | $\alpha$                        | $8.50 \times 10^3$ y    |
| 97               | Berkelium    | 247                   | $^{247}\text{Bk}$ | 247.070 300     | $\alpha$                        | $1.38 \times 10^3$ y    |
| 98               | Californium  | 249                   | $^{249}\text{Cf}$ | 249.074 844     | $\alpha$                        | 351 y                   |
| 99               | Einsteinium  | 254                   | $^{254}\text{Es}$ | 254.088 019     | $\alpha$ , $\beta^-$            | 276 d                   |
| 100              | Fermium      | 253                   | $^{253}\text{Fm}$ | 253.085 173     | EC, $\alpha$                    | 3.00 d                  |

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|------------------|---------------|-----------------------|-------------------|-----------------|---------------------------------|----------------------|
| 101              | Mendelevium   | 255                   | $^{255}\text{Md}$ | 255.091 081     | EC, $\alpha$                    | 27 min               |
| 102              | Nobelium      | 255                   | $^{255}\text{No}$ | 255.093 260     | EC, $\alpha$                    | 3.1 min              |
| 103              | Lawrencium    | 257                   | $^{257}\text{Lr}$ | 257.099 480     | EC, $\alpha$                    | 0.646 s              |
| 104              | Rutherfordium | 261                   | $^{261}\text{Rf}$ | 261.108 690     | $\alpha$                        | 1.08 min             |
| 105              | Dubnium       | 262                   | $^{262}\text{Db}$ | 262.113 760     | $\alpha$ , fission              | 34 s                 |
| 106              | Seaborgium    | 263                   | $^{263}\text{Sg}$ | 263.11 86       | $\alpha$ , fission              | 0.8 s                |
| 107              | Bohrium       | 262                   | $^{262}\text{Bh}$ | 262.123 1       | $\alpha$                        | 0.102 s              |
| 108              | Hassium       | 264                   | $^{264}\text{Hs}$ | 264.128 5       | $\alpha$                        | 0.08 ms              |
| 109              | Meitnerium    | 266                   | $^{266}\text{Mt}$ | 266.137 8       | $\alpha$                        | 3.4 ms               |

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