

## 6. Atomic and Nuclear Properties of Materials

**Table 6.1** Abridged from [pdg.lbl.gov/AtomicNuclearProperties](http://pdg.lbl.gov/AtomicNuclearProperties) by D.E. Groom (2017). See web pages for more detail about entries in this table and for several hundred others. Parentheses in the  $dE/dx$  and density columns indicate gases at 20° C and 1 atm. Boiling points are at 1 atm. Refractive indices  $n$  are evaluated at the sodium D line blend (589.2 nm); values  $\gg 1$  in brackets indicate  $(n - 1) \times 10^6$  for gases at 0° C and 1 atm.

| Material   | $Z$ | $A$             | $\langle Z/A \rangle$ | Nucl.coll.<br>length $\lambda_T$<br>{g cm <sup>-2</sup> } | Nucl.inter.<br>length $\lambda_I$<br>{g cm <sup>-2</sup> } | Rad.len.<br>$X_0$<br>{g cm <sup>-2</sup> } | $dE/dx _{\min}$<br>{ MeV<br>g <sup>-1</sup> cm <sup>2</sup> } | Density<br>{g cm <sup>-3</sup> }<br>({g ℓ <sup>-1</sup> }) | Melting<br>point<br>(K)                         | Boiling<br>point<br>(K) | Refract.<br>index<br>@ Na D |
|--|-----|-----------------|-----------------------|---|--|--|---|--|---|-------------------------|-----------------------------|
| H <sub>2</sub>   | 1   | 1.008(7)        | 0.99212               | 42.8  | 52.0   | 63.05                                      | (4.103)   | 0.071(0.084)   | 13.81   | 20.28                   | 1.11[132.]                  |
| D <sub>2</sub>   | 1   | 2.014101764(8)  | 0.49650               | 51.3  | 71.8   | 125.97                                     | (2.053)   | 0.169(0.168)   | 18.7  | 23.65                   | 1.11[138.]                  |
| He   | 2   | 4.002602(2)     | 0.49967               | 51.8  | 71.0   | 94.32                                      | (1.937)   | 0.125(0.166)   |   | 4.220                   | 1.02[35.0]                  |
| Li   | 3   | 6.94(2)         | 0.43221               | 52.2  | 71.3   | 82.78                                      | 1.639   | 0.534  | 453.6   | 1615.                   |                             |
| Be   | 4   | 9.0121831(5)    | 0.44384               | 55.3  | 77.8   | 65.19                                      | 1.595   | 1.848  | 1560.   | 2744.                   |                             |
| C diamond  | 6   | 12.0107(8)      | 0.49955               | 59.2  | 85.8   | 42.70                                      | 1.725   | 3.520  |   |                         | 2.419                       |
| C graphite   | 6   | 12.0107(8)      | 0.49955               | 59.2  | 85.8   | 42.70                                      | 1.742   | 2.210  | Sublimes at 4098. K                             |                         |                             |
| N <sub>2</sub>   | 7   | 14.007(2)       | 0.49976               | 61.1  | 89.7   | 37.99                                      | (1.825)   | 0.807(1.165)   | 63.15   | 77.29                   | 1.20[298.]                  |
| O <sub>2</sub>   | 8   | 15.999(3)       | 0.50002               | 61.3  | 90.2   | 34.24                                      | (1.801)   | 1.141(1.332)   | 54.36   | 90.20                   | 1.22[271.]                  |
| F <sub>2</sub>   | 9   | 18.998403163(6) | 0.47372               | 65.0  | 97.4   | 32.93                                      | (1.676)   | 1.507(1.580)   | 53.53   | 85.03                   | [195.]                      |
| Ne   | 10  | 20.1797(6)      | 0.49555               | 65.7  | 99.0   | 28.93                                      | (1.724)   | 1.204(0.839)   | 24.56   | 27.07                   | 1.09[67.1]                  |
| Al   | 13  | 26.9815385(7)   | 0.48181               | 69.7  | 107.2  | 24.01                                      | 1.615   | 2.699  | 933.5   | 2792.                   |                             |
| Si   | 14  | 28.0855(3)      | 0.49848               | 70.2  | 108.4  | 21.82                                      | 1.664   | 2.329  | 1687.   | 3538.                   | 3.95                        |
| Cl <sub>2</sub>  | 17  | 35.453(2)       | 0.47951               | 73.8  | 115.7  | 19.28                                      | (1.630)   | 1.574(2.980)   | 171.6   | 239.1                   | [773.]                      |
| Ar   | 18  | 39.948(1)       | 0.45059               | 75.7  | 119.7  | 19.55                                      | (1.519)   | 1.396(1.662)   | 83.81   | 87.26                   | 1.23[281.]                  |
| Ti   | 22  | 47.867(1)       | 0.45961               | 78.8  | 126.2  | 16.16                                      | 1.477   | 4.540  | 1941.   | 3560.                   |                             |
| Fe   | 26  | 55.845(2)       | 0.46557               | 81.7  | 132.1  | 13.84                                      | 1.451   | 7.874  | 1811.   | 3134.                   |                             |
| Cu   | 29  | 63.546(3)       | 0.45636               | 84.2  | 137.3  | 12.86                                      | 1.403   | 8.960  | 1358.   | 2835.                   |                             |
| Ge   | 32  | 72.630(1)       | 0.44053               | 86.9  | 143.0  | 12.25                                      | 1.370   | 5.323  | 1211.   | 3106.                   |                             |
| Sn   | 50  | 118.710(7)      | 0.42119               | 98.2  | 166.7  | 8.82                                       | 1.263   | 7.310  | 505.1   | 2875.                   |                             |
| Xe   | 54  | 131.293(6)      | 0.41129               | 100.8   | 172.1  | 8.48                                       | (1.255)   | 2.953(5.483)   | 161.4   | 165.1                   | 1.39[701.]                  |
| W  | 74  | 183.84(1)       | 0.40252               | 110.4   | 191.9  | 6.76                                       | 1.145   | 19.300   | 3695.   | 5828.                   |                             |
| Pt   | 78  | 195.084(9)      | 0.39983               | 112.2   | 195.7  | 6.54                                       | 1.128   | 21.450   | 2042.   | 4098.                   |                             |
| Au   | 79  | 196.966569(5)   | 0.40108               | 112.5   | 196.3  | 6.46                                       | 1.134   | 19.320   | 1337.   | 3129.                   |                             |
| Pb   | 82  | 207.2(1)        | 0.39575               | 114.1   | 199.6  | 6.37                                       | 1.122   | 11.350   | 600.6   | 2022.                   |                             |
| U  | 92  | [238.02891(3)]  | 0.38651               | 118.6   | 209.0  | 6.00                                       | 1.081   | 18.950   | 1408.   | 4404.                   |                             |
| Air (dry, 1 atm)   |     |                 | 0.49919               | 61.3  | 90.1   | 36.62                                      | (1.815)   | (1.205)  |   | 78.80                   | [289]                       |
| Shielding concrete   |     |                 | 0.50274               | 65.1  | 97.5   | 26.57                                      | 1.711   | 2.300  |   |                         |                             |
| Borosilicate glass (Pyrex)   |     |                 | 0.49707               | 64.6  | 96.5   | 28.17                                      | 1.696   | 2.230  |   |                         |                             |
| Lead glass   |     |                 | 0.42101               | 95.9  | 158.0  | 7.87                                       | 1.255   | 6.220  |   |                         |                             |
| Standard rock  |     |                 | 0.50000               | 66.8  | 101.3  | 26.54                                      | 1.688   | 2.650  |   |                         |                             |
| Methane (CH <sub>4</sub> )   |     |                 | 0.62334               | 54.0  | 73.8   | 46.47                                      | (2.417)   | (0.667)  | 90.68   | 111.7                   | [444.]                      |
| Ethane (C <sub>2</sub> H <sub>6</sub> )  |     |                 | 0.59861               | 55.0  | 75.9   | 45.66                                      | (2.304)   | (1.263)  | 90.36   | 184.5                   |                             |
| Propane (C <sub>3</sub> H <sub>8</sub> )                                       |     |                 | 0.58962               | 55.3  | 76.7   | 45.37                                      | (2.262)   | 0.493(1.868)   | 85.52   | 231.0                   |                             |
| Butane (C <sub>4</sub> H <sub>10</sub> )                                       |     |                 | 0.59497               | 55.5  | 77.1   | 45.23                                      | (2.278)   | (2.489)  | 134.9   | 272.6                   |                             |
| Octane (C <sub>8</sub> H <sub>18</sub> )                                       |     |                 | 0.57778               | 55.8  | 77.8   | 45.00                                      | 2.123   | 0.703  | 214.4   | 398.8                   |                             |
| Paraffin (CH <sub>3</sub> (CH <sub>2</sub> ) <sub>n≈23</sub> CH <sub>3</sub> ) |     |                 | 0.57275               | 56.0  | 78.3   | 44.85                                      | 2.088   | 0.930  |   |                         |                             |
| Nylon (type 6, 6/6)  |     |                 | 0.54790               | 57.5  | 81.6   | 41.92                                      | 1.973   | 1.18   |   |                         |                             |
| Polycarbonate (Lexan)  |     |                 | 0.52697               | 58.3  | 83.6   | 41.50                                      | 1.886   | 1.20   |   |                         |                             |
| Polyethylene ([CH <sub>2</sub> CH <sub>2</sub> ] <sub>n</sub> )                |     |                 | 0.57034               | 56.1  | 78.5   | 44.77                                      | 2.079   | 0.89   |   |                         |                             |
| Polyethylene terephthalate (Mylar)   |     |                 | 0.52037               | 58.9  | 84.9   | 39.95                                      | 1.848   | 1.40   |   |                         |                             |
| Polyimide film (Kapton)  |     |                 | 0.51264               | 59.2  | 85.5   | 40.58                                      | 1.820   | 1.42   |   |                         |                             |
| Polymethylmethacrylate (acrylic)   |     |                 | 0.53937               | 58.1  | 82.8   | 40.55                                      | 1.929   | 1.19   |   |                         | 1.49                        |
| Polypropylene  |     |                 | 0.55998               | 56.1  | 78.5   | 44.77                                      | 2.041   | 0.90   |   |                         |                             |
| Polystyrene ([C <sub>6</sub> H <sub>5</sub> CHCH <sub>2</sub> ] <sub>n</sub> ) |     |                 | 0.53768               | 57.5  | 81.7   | 43.79                                      | 1.936   | 1.06   |   |                         | 1.59                        |
| Polytetrafluoroethylene (Teflon)   |     |                 | 0.47992               | 63.5  | 94.4   | 34.84                                      | 1.671   | 2.20   |   |                         |                             |
| Polyvinyltoluene   |     |                 | 0.54141               | 57.3  | 81.3   | 43.90                                      | 1.956   | 1.03   |   |                         | 1.58                        |
| Aluminum oxide (sapphire)  |     |                 | 0.49038               | 65.5  | 98.4   | 27.94                                      | 1.647   | 3.970  | 2327.   | 3273.                   | 1.77                        |
| Barium fluoride (BaF <sub>2</sub> )  |     |                 | 0.42207               | 90.8  | 149.0  | 9.91                                       | 1.303   | 4.893  | 1641.   | 2533.                   | 1.47                        |
| Bismuth germanate (BGO)  |     |                 | 0.42065               | 96.2  | 159.1  | 7.97                                       | 1.251   | 7.130  | 1317.   |                         | 2.15                        |
| Carbon dioxide gas (CO <sub>2</sub> )  |     |                 | 0.49989               | 60.7  | 88.9   | 36.20                                      | 1.819   | (1.842)  |   |                         | [449.]                      |
| Solid carbon dioxide (dry ice)   |     |                 | 0.49989               | 60.7  | 88.9   | 36.20                                      | 1.787   | 1.563  | Sublimes at 194.7 K                             |                         |                             |
| Cesium iodide (CsI)  |     |                 | 0.41569               | 100.6   | 171.5  | 8.39                                       | 1.243   | 4.510  | 894.2   | 1553.                   | 1.79                        |
| Lithium fluoride (LiF)   |     |                 | 0.46262               | 61.0  | 88.7   | 39.26                                      | 1.614   | 2.635  | 1121.   | 1946.                   | 1.39                        |
| Lithium hydride (LiH)  |     |                 | 0.50321               | 50.8  | 68.1   | 79.62                                      | 1.897   | 0.820  | 965.  |                         |                             |
| Lead tungstate (PbWO <sub>4</sub> )  |     |                 | 0.41315               | 100.6   | 168.3  | 7.39                                       | 1.229   | 8.300  | 1403.   |                         | 2.20                        |
| Silicon dioxide (SiO <sub>2</sub> , fused quartz)                              |     |                 | 0.49930               | 65.2  | 97.8   | 27.05                                      | 1.699   | 2.200  | 1986.   | 3223.                   | 1.46                        |
| Sodium chloride (NaCl)   |     |                 | 0.47910               | 71.2  | 110.1  | 21.91                                      | 1.847   | 2.170  | 1075.   | 1738.                   | 1.54                        |
| Sodium iodide (NaI)  |     |                 | 0.42697               | 93.1  | 154.6  | 9.49                                       | 1.305   | 3.667  | 933.2   | 1577.                   | 1.77                        |
| Water (H <sub>2</sub> O)   |     |                 | 0.55509               | 58.5  | 83.3   | 36.08                                      | 1.992   | 1.000  | 273.1   | 373.1                   | 1.33                        |
| Silica aerogel   |     |                 | 0.50093               | 65.0  | 97.3   | 27.25                                      | 1.740   | 0.200  | (0.03 H <sub>2</sub> O, 0.97 SiO <sub>2</sub> ) |                         |                             |

| Material       | Dielectric constant ( $\kappa = \epsilon/\epsilon_0$ )<br>( ) is $(\kappa-1)\times 10^6$<br>for gas | Young's modulus<br>[ $10^6$ psi] | Coeff. of thermal expansion<br>[ $10^{-6}$ cm/cm- $^{\circ}$ C] | Specific heat<br>[cal/g- $^{\circ}$ C] | Electrical resistivity<br>[ $\mu\Omega$ cm(@ $^{\circ}$ C)] | Thermal conductivity<br>[cal/cm- $^{\circ}$ C-sec] |
|----------------|---|----------------------------------|---|--|---|--|
| H <sub>2</sub> | (253.9)   | —                                | —   | —                                      | —   | —  |
| He             | (64)  | —                                | —   | —                                      | —   | —  |
| Li             | —   | —                                | 56  | 0.86                                   | 8.55(0 $^{\circ}$ )   | 0.17   |
| Be             | —   | 37                               | 12.4  | 0.436                                  | 5.885(0 $^{\circ}$ )  | 0.38   |
| C              | —   | 0.7                              | 0.6-4.3   | 0.165                                  | 1375(0 $^{\circ}$ )   | 0.057  |
| N <sub>2</sub> | (548.5)   | —                                | —   | —                                      | —   | —  |
| O <sub>2</sub> | (495)   | —                                | —   | —                                      | —   | —  |
| Ne             | (127)   | —                                | —   | —                                      | —   | —  |
| Al             | —   | 10                               | 23.9  | 0.215                                  | 2.65(20 $^{\circ}$ )  | 0.53   |
| Si             | 11.9  | 16                               | 2.8-7.3   | 0.162                                  | —   | 0.20   |
| Ar             | (517)   | —                                | —   | —                                      | —   | —  |
| Ti             | —   | 16.8                             | 8.5   | 0.126                                  | 50(0 $^{\circ}$ )   | —  |
| Fe             | —   | 28.5                             | 11.7  | 0.11                                   | 9.71(20 $^{\circ}$ )  | 0.18   |
| Cu             | —   | 16                               | 16.5  | 0.092                                  | 1.67(20 $^{\circ}$ )  | 0.94   |
| Ge             | 16.0  | —                                | 5.75  | 0.073                                  | —   | 0.14   |
| Sn             | —   | 6                                | 20  | 0.052                                  | 11.5(20 $^{\circ}$ )  | 0.16   |
| Xe             | —   | —                                | —   | —                                      | —   | —  |
| W              | —   | 50                               | 4.4   | 0.032                                  | 5.5(20 $^{\circ}$ )   | 0.48   |
| Pt             | —   | 21                               | 8.9   | 0.032                                  | 9.83(0 $^{\circ}$ )   | 0.17   |
| Pb             | —   | 2.6                              | 29.3  | 0.038                                  | 20.65(20 $^{\circ}$ )                                       | 0.083  |
| U              | —   | —                                | 36.1  | 0.028                                  | 29(20 $^{\circ}$ )  | 0.064  |