

## 6. Atomic and Nuclear Properties of Materials

**Table 6.1:** Abridged from <https://pdg.lbl.gov/current/AtomicNuclearProperties> by D.E. Groom (2023). 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. $dE/dx _{\min}$<br>$X_0$ { MeV<br>{g cm <sup>-2</sup> } g <sup>-1</sup> cm <sup>2</sup> } | Density<br>{g cm <sup>-3</sup> }<br>{g ℓ <sup>-1</sup> } | Melting point<br>(K)                            | Boiling 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 SF5                                                                 |     |                 | 0.44522               | 84.0                                                      | 133.4                                                      | 10.07 1.406                                                                                        | 4.080                                                    |                                                 |                      | 1.6727                      |
| 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</sub> ≈23CH <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> ) |                      |                             |
| Epoxy (Epotek-301-1)                                                           |     |                 | 0.53409               | 58.1                                                      | 83.0                                                       | 41.22 1.925                                                                                        | 1.190                                                    |                                                 |                      |                             |
| G10                                                                            |     |                 | 0.51166               | 56.8                                                      | 78.4                                                       | 32.17 1.762                                                                                        | 1.800                                                    |                                                 |                      |                             |