# Theory of Subatomic and Atomic Masses and Half-Lives

by
Ronald W. Satz, Ph.D.*
Transpower Corporation

## Abstract

This paper presents the derivation of the equations for the properties of mass and half-life of subatoms and atoms according to the Reciprocal System of theory developed by D. B. Larson. For atomic mass the factors include the atomic number Z and isotope charge number G (= A - 2·Z, where A = mass number), together with a modified inter-regional ratio to account for the mass defect and secondary mass. Average lifetimes of radioactive atoms and half-lives of radioactive substances are calculated as a function of the quantity of secondary mass converted to energy and the energy supplied by the entrained magnetically-charged neutrinos.

**keywords:** subatomic mass, atomic mass, neutrinos, isotopic charges, mass defect, secondary mass, radioactivity, half-lives, average lifetime, Reciprocal System

*The author is president of Transpower Corporation, a commercial and custom software manufacturing company and engineering/physics consultancy. Mailing address: P. O. Box 7132, Penndel, PA 19047. He is a full member of ASME, SAE, INFORMS, ISUS, and SIAM.

## Nomenclature

A = atomic mass number (integer)

A = activity of radioactive substance at time t, disintegrations/sec

$A_0$ = activity of radioactive substance at time t = 0, disintegrations/sec

C = mass of normal electric charge (subscript has units)

$C_1...C_5$ = best-fit constants used in conventional theory for binding energy and atomic mass

c = mass of electric charge of electron and positron (subscript has units)

c = speed of light (units depend on context)

$conv_{amu\_to\_u}$ = conversion factor between amu ($O^{16}$ -based) and u ($C^{12}$ -based)

$conv_{u\_to\_MeV}$ = conversion factor from u to MeV

$delta\_m_s$ = change in secondary mass from parent atom to daughter atom and alpha particle, u

E = secondary mass of electric rotational displacement for atoms (subscript has units)

$E_B$ = binding energy in conventional atomic/nuclear theory, MeV

e = secondary mass of electric rotational displacement of subatoms (subscript has units)

G = number of gravitational charges (integer); also referred to as isotopic charge number

p = primary rotational mass (subscript has units)

$I_R$ = inter-regional ratio for atoms (between time region and time-space region) (dimensionless)

$I_{R\_1}$ = inter-regional ratio for subatoms (between time region and time-space region) (dimensionless)

$I_{R\_2}$ = modified inter-regional ratio for the mass of atoms with Z > 1 (dimensionless)

$M_A$ = actual mass of atom of mass number A, u

m = secondary mass of magnetic rotational displacement (subscript has units)

$m_{defect}$ = mass defect, u

$m_{e\_pot\_u}$ = potential mass of uncharged electron or positron, u

$m_{e\_neg\_u}$ = mass of charged electron, u

$m_{e\_pos\_u}$ = mass of charged positron, u

$m_H$ = mass of isotope 1 of hydrogen used in conventional theory

$m_{H1\_u}$ = mass of isotope 1 of hydrogen, u

$m_{H2\_u}$ = mass of isotope 2 of hydrogen (deuterium), u

$m_{neutrino\_pot\_u}$ = potential mass of neutrino, u

$m_{neutron\_pot\_u}$ = potential mass of neutron, u

$m_{neutron\_u}$ = mass of (compound) neutron, u

$m_{neutron}$ = mass of neutron used in conventional theory, u

$m_{p\_u}$= mass of uncharged proton, u

$m_{p\_pos\_u}$ = mass of charged proton, u

$m_s$ = total secondary mass of an element, u

N = number of neutrons supposedly in the nucleus of conventional theory (dimensionless)

N = number of radioactive atoms in substance at time t

$N_0$ = number of radioactive atoms in substance at time t = 0

p = primary mass (subscript has units)

$Q_{obs}$ = observed total decay energy of radioactive atom, MeV

$Q_s$ = energy equivalent of delta_$m_s$, MeV

$Q_u$ = natural unit of energy applicable to alpha-radioactivity, MeV

$Q_\alpha$ = energy of emitted alpha particle, MeV (Q, with no subscript, means total decay energy)

$t_u$ = natural unit of time, stated in sec

$t_{.5}$ = half-life of radioactive substance, sec

x = energy from each neutrino supplied to alpha particle, MeV

Z = atomic number (dimensionless)

$\lambda$ = radioactive decay constant, $sec^{-1}$

$\tau$ = average lifetime of radioactive atom, sec

Note: A black square in the upper right of an equation means that the equation is disabled from running in *Mathcad*. This is done because not all variables in the equation have, as yet, been given numerical values at that point in the program.

## 1. Subatomic and Atomic Masses

Larson, in Ref. [1], 2nd ed., pp. 162-167, derives the equations for subatomic mass and the atomic mass of $H^1$ and $H^{2,}$ which we will now briefly recapitulate (see Ref. [1] for the details).

The natural unit of primary mass in the Reciprocal System is conformant with the older $O^{16}$ physical scale (based on the "amu"). Thus:

$$p_{amu} := 1 \quad \text{amu} \tag{1}$$

It is therefore quite unfortunate that the scientific community has switched to the $C^{12}$ scale, based on "u". The conversion factor between amu and u is

$$conv_{amu\_to\_u} := 0.9996822 \tag{2}$$

One unit of (magnetic) primary mass is then

$$p_u := 1.0000000 \cdot conv_{amu\_to\_u} \qquad p_u = 0.9996822 \quad \text{u} \tag{3}$$

To obtain a unit of inertial or gravitational mass, a unit of secondary mass must be added to p. This unit of secondary mass is reduced by the inter-regional ratio (the derivation of which is given on p. 162 of Ref. 1, 2nd ed.) :

$$I_R := 156.4444 \tag{4}$$

$$m_u := \frac{1}{I_R} \cdot conv_{amu\_to\_u} \qquad m_u = 0.006390016 \quad u \tag{5}$$

But this is just the magnetic component of the secondary mass; there is also an electric component. Note: the terms "magnetic" and "electric" used here do not imply magnetic or electric charges; rather they are terms for 2-dimensional and 1-dimensional rotational displacement, respectively. The two types of the electric component are as follows.

$$E_u := \frac{1}{9} \cdot \frac{1}{128} \cdot conv_{amu\_to\_u} \qquad E_u = 0.00086778 \quad u \qquad \text{(3 dimensions)} \tag{6}$$

$$e_u := \frac{2}{3} \cdot E_u \qquad e_u = 0.00057852 \quad u \qquad \text{(2 dimensions)} \tag{7}$$

$E_u$ applies to $H^2$ and above, $e_u$ applies to subatoms and $H^1$ (which is really an "intermediate" particle).

The mass of a normal electric charge depends on the inter-regional ratio given above and also on the subatomic inter-regional ratio:

$$I_{R\_1} := 142.2222 \tag{8}$$

$$C_u := \frac{1}{I_R} \cdot \frac{1}{I_{R\_1}} \cdot conv_{amu\_to\_u} \qquad C_u = 0.00004493 \quad u \tag{9}$$

The mass of an electron or positron charge is this value times 2/3:

$$c_u := \frac{2}{3} \cdot C_u \qquad c_u = 0.000029953 \quad u \tag{10}$$

With this information, the masses of the subatoms and $H^1$ and $H^2$ are calculated as follows. Note: the subscript "pot" means "potential mass only." The end column gives the observed values from the *CRC Handbook of Chemistry and Physics*.

| | Definition | Value | Unit | Obs. (Ref. [5], 1-2 to 1-4, 11-57) | |
|---|---|---|---|---|---|
| massless electron: | $m_{e\_pot\_u} := e_u$ | $m_{e\_pot\_u} = 0.00057852$ | u | | (11) |
| charged electron: | $m_{e\_neg\_u} := e_u - c_u$ | $m_{e\_neg\_u} = 0.000548567$ | u | .000548579 | (12) |
| massless positron: | $m_{e\_pot\_u} := e_u$ | $m_{e\_pot\_u} = 0.00057852$ | u | | (13) |
| charged positron: | $m_{e\_pos\_u} := e_u - c_u$ | $m_{e\_pos\_u} = 0.000548567$ | u | .000548579 | (14) |
| massless neutrino: | $m_{neutrino\_pot\_u} := e_u$ | $m_{neutrino\_pot\_u} = 0.00057852$ | u | | (15) |
| massless neutron: | $m_{neutron\_pot\_u} := p_u + m_u + e_u$ | $m_{neutron\_pot\_u} = 1.006650736$ | u | | (16) |
| proton: | $m_{p\_u} := p_u + m_u + 2 \cdot e_u$ | $m_{p\_u} = 1.007229255$ | u | | (17) |
| charged proton: | $m_{p\_pos\_u} := p_u + m_u + 2 \cdot e_u + C_u$ | $m_{p\_pos\_u} = 1.007274185$ | u | 1.007276466 | (18) |
| hydrogen ($H^1$): | $m_{H1\_u} := p_u + m_u + 3 \cdot e_u$ | $m_{H1\_u} = 1.007807775$ | u | 1.007825032 | (19) |
| compound neutron: | $m_{neutron\_u} := p_u + m_u + 3 \cdot e_u + E_u$ | $m_{neutron\_u} = 1.008675555$ | u | 1.008664916 | (20) |
| deuterium ($H^2$ or D): | $m_{H2\_u} := 2 \cdot m_{p\_u} - \left(E_u - e_u\right)$ | $m_{H2\_u} = 2.014169251$ | u | 2.014101778 | (21) |

Larson did not go beyond this in Ref. 1, 2nd. ed., although he did in Ref. 1, 1st ed, pp. 109-111. However, the 1st ed. used a different value for the natural unit of mass, since abandoned, and so from here on out we are on our own.

Before proceeding to the the calculation of the mass of the isotopes of higher elements, let's review the conventional theory on this topic.

Unlike the Reciprocal System, conventional theory says that atoms are comprised of protons, neutrons, and electrons. But the sum of the masses of the supposed individual protons, neutrons, and electrons of an atom is *less* than the measured mass. This difference is termed the "mass defect" and, when multiplied by 931.5 MeV/$c^2$, the result is said to be the "binding energy" of the "nucleus." Ref. [2], p.1629, gives the equation as

$$E_B := \left(Z \cdot M_H + N \cdot m_{neutron} - M_A\right) \cdot c^2$$

where the symbols have their usual meaning. But even after 100 years of the nuclear theory of the atom, there is still no precise theoretical method to calculate the "mass defect" and hence there is no precise theoretical method to calculate the masses of all isotopes--there are only various *empirical* equations, such as this one from Gamow and Bohr (Ref. [2], p. 1633):

$$E_B := C_1 \cdot A - C_2 \cdot A^{\frac{2}{3}} - C_3 \cdot \frac{Z \cdot (Z-1)}{A^{\frac{1}{3}}} - C_4 \cdot \frac{(A - 2 \cdot Z)^2}{A} + C_5 \cdot A^{\frac{-4}{3}}$$

The best fit constants are supposedly

$C_1 := 15.75$ $C_2 := 17.80$ $C_3 := 0.7100$ $C_4 := 23.69$ $C_5 := 39$ (+/-) all in MeV

The calculated atomic mass is then supposed to be

$$M_A := Z \cdot M_H + N \cdot m_{neutron} - \frac{E_B}{c^2}$$

Of course, in the Reciprocal System, there are no constituent individual particles in the atom and thus there is no "binding energy." Rather there are discrete rotations around the three orthogonal axes of the two perpendicular photons inside the atom. Therefore our mass calculation will be very, very different from the above derivation.

The first *real* element in the Reciprocal System is the $H^2$ isotope, rather than the $H^1$ isotope. This can be seen by displaying the rotational displacements (see Ref. [3] for more details):

| | | |
|---|---|---|
| | 2 - 1 | proton-like rotation |
| | \ | |
| $H^1$: | (1) | |
| | / | |
| | 1 - 1 | m-neutrino-like rotation |

| | | |
|---|---|---|
| | 2 - 1 | proton-like rotation |
| | \ | |
| $H^2$: | (1) | |
| | / | |
| | 2 - 1 | proton-like rotation |

In the Reciprocal System, the mass number, A, is comprised of two components: the atomic number, Z, and the isotopic charge number, G. This latter is the number of magnetically charged neutrinos contained within an isotope--the magnetic charges induce corresponding gravitational charges in the isotope, thereby increasing the observed mass. (See Chapter 24 of Ref. [4] for the details.) Note: the neutrinos are not constituents, per se, of the atoms; the quantity depends on the average ambient neutrino flux and may be different in different parts of the universe.

$$A := (2 \cdot Z + G) \qquad G := A - 2 \cdot Z \qquad (22a)$$

This equation for mass number is perfectly correct for the $O^{16}$ physical scale but must be modified for the $C^{12}$ scale to calculate the corresponding mass in u. The *primary* atomic mass is then

$$M_A := (2\cdot Z + G)\cdot conv_{amu\_to\_u} \quad u \tag{22b}$$

For the reason stated above, instead of $2\cdot Z$ in Eq. (22b) we need $m_{H2\_u}$, which is a bit more than $2\cdot u$ or $2\cdot Z$ and incorporates $conv_{amu\_to\_u}$. With G multiplied by $conv_{amu\_to\_u}$ we now have

$$M_A := Z\cdot m_{H2\_u} + G\cdot conv_{amu\_to\_u} \quad u \tag{22c}$$

But there is still the "mass defect" to subtract. We measure mass from the time-space region (the "gas" region), rather than from the time region, and as pointed out in Ref. [4], p. 59 the gas constant, R, is 2/3 of the corresponding natural unit. Therefore, the inter-regional ratio to apply is 2/3 of the *usual* inter-regional ratio, $I_R$.

$$I_{R\_2} := \frac{2}{3}\cdot I_R \qquad I_{R\_2} = 104.296266667 \tag{23}$$

Also, the effect is opposite between the normal rotational mass and the vibrational (isotopic) mass. Therefore

$$m_{defect} := \frac{1}{I_{R\_2}}\cdot\left(Z\cdot m_{H2\_u} - G\cdot conv_{amu\_to\_u}\right) \quad u \qquad Z \geq 10 \tag{24a}$$

Below atomic number 10 there is a 1/3 reduction in the mass defect due to the atom's one inactive dimension against the space-time progression, similar to what is found for the inter-atomic distance relationships (Ref. [1], 1st ed., pp. 44-45).

$$m_{defect} := \frac{1}{I_{R\_2}}\cdot\left(Z\cdot m_{H2\_u} - G\cdot conv_{amu\_to\_u}\right)\cdot\frac{2}{3} \quad u \qquad 1 < Z < 10 \tag{24b}$$

Then

$$M_A := Z\cdot m_{H2\_u} + G\cdot conv_{amu\_to\_u} - m_{defect} \quad u \tag{25a}$$

After some algebra, we get the final equations:

$$M_A := 1.994857253 \cdot Z + 1.009267224 \cdot G \quad u \qquad Z \geq 10 \tag{25b}$$

$$M_A := 2.001294586 \cdot Z + 1.006072216 \cdot G \quad u \qquad 1 < Z < 10 \tag{25c}$$

As defined, the mass defect is not the quite the same as the *secondary mass*. In radioactive decay, the primary mass of the radioactive substance is conserved in the decay product(s), but the secondary mass is not--it is converted into energy. The definition of secondary mass is

$$m_S := M_A - A \cdot conv_{amu\_to\_u} \tag{26a}$$

After a little algebra, we get the reduced equations:

$$m_S := .004507147 \cdot Z - .009585024 \cdot G \quad u \qquad Z \geq 10 \tag{26b}$$

$$m_S := .001930186 \cdot Z - .006390016 \cdot G \quad u \qquad 1 < Z < 10 \tag{26c}$$

Table I (from *Excel*) provides the calculations and observations for the most important isotopes of the elements. As can be seen, the calculations are usually within .001 or .0001 of those observed. The Reciprocal System mass equation is purely linear, as one would expect, unlike the empirical equation provided by conventional theory, which is very nonlinear. As is well known, the secondary mass is initially positive (up to Ne), then turns negative, and finally turns positive (at around Yb),

| Element | Z | A | nat_abund_% | G | Z x m_H2_u+_G x .9996822 | mass_defect_calc | M_A_calc_u | m_obs_u | M_A_calc_u/m_obs_u |
|---|---|---|---|---|---|---|---|---|---|
| D | 1 | 2 | 0.0115 | 0 | 2.014169 | 0.000000 | 2.014169 | 2.014102 | 1.0000 |
| He | 2 | 4 | 99.999866 | 0 | 4.028339 | 0.038624 | 4.002589 | 4.002603 | 1.0000 |
| Li | 3 | 6 | 7.59 | 0 | 6.042508 | 0.057936 | 6.003884 | 6.015123 | 0.9981 |
| | 3 | 7 | 92.41 | 1 | 7.042190 | 0.048356 | 7.009953 | 7.016005 | 0.9991 |
| Be | 4 | 9 | 100 | 1 | 9.056359 | 0.067668 | 9.011247 | 9.012182 | 0.9999 |
| B | 5 | 10 | 19.9 | 0 | 10.070846 | 0.096560 | 10.006473 | 10.012937 | 0.9994 |
| | 5 | 11 | 80.1 | 1 | 11.070528 | 0.086980 | 11.012542 | 11.009305 | 1.0003 |
| C | 6 | 12 | 98.93 | 0 | 12.085016 | 0.115872 | 12.007768 | 12.000000 | 1.0006 |
| | 6 | 13 | 1.07 | 1 | 13.084698 | 0.106292 | 13.013837 | 13.003355 | 1.0008 |
| N | 7 | 14 | 99.636 | 0 | 14.099185 | 0.135184 | 14.009062 | 14.003074 | 1.0004 |
| | 7 | 15 | 0.364 | 1 | 15.098867 | 0.125604 | 15.015131 | 15.000109 | 1.0010 |
| O | 8 | 16 | 99.757 | 0 | 16.113354 | 0.154496 | 16.010357 | 15.994915 | 1.0010 |
| | 8 | 17 | 0.038 | 1 | 17.113036 | 0.144916 | 17.016426 | 16.999132 | 1.0010 |
| | 8 | 18 | 0.205 | 2 | 18.112718 | 0.135336 | 18.022495 | 17.999161 | 1.0013 |
| F | 9 | 19 | 100 | 1 | 19.127205 | 0.164228 | 19.017720 | 18.998403 | 1.0010 |
| Ne | 10 | 20 | 90.48 | 0 | 20.141693 | 0.193120 | 19.948573 | 19.992440 | 0.9978 |
| | 10 | 21 | 0.27 | 1 | 21.141375 | 0.183540 | 20.957840 | 20.993847 | 0.9983 |
| | 10 | 22 | 9.25 | 2 | 22.141057 | 0.173960 | 21.967107 | 21.991385 | 0.9989 |
| Na | 11 | 23 | 100 | 1 | 23.155544 | 0.202852 | 22.952697 | 22.989769 | 0.9984 |
| Mg | 12 | 24 | 78.99 | 0 | 24.170031 | 0.231744 | 23.938287 | 23.985942 | 0.9980 |
| | 12 | 25 | 10 | 1 | 25.169713 | 0.222164 | 24.947554 | 24.985837 | 0.9985 |
| | 12 | 26 | 11.01 | 2 | 26.169395 | 0.212583 | 25.956821 | 25.982593 | 0.9990 |
| Al | 13 | 27 | 100 | 1 | 27.183882 | 0.241476 | 26.942412 | 26.981539 | 0.9985 |
| Si | 14 | 28 | 92.223 | 0 | 28.198370 | 0.270368 | 27.928002 | 27.976927 | 0.9983 |
| | 14 | 29 | 4.685 | 1 | 29.198052 | 0.260788 | 28.937269 | 28.976495 | 0.9986 |
| | 14 | 30 | 3.092 | 2 | 30.197734 | 0.251207 | 29.946536 | 29.973770 | 0.9991 |
| P | 15 | 31 | 100 | 1 | 31.212221 | 0.280100 | 30.932126 | 30.973762 | 0.9987 |
| S | 16 | 32 | 94.99 | 0 | 32.226708 | 0.308992 | 31.917716 | 31.972071 | 0.9983 |
| | 16 | 33 | 0.75 | 1 | 33.226390 | 0.299412 | 32.926983 | 32.971459 | 0.9987 |
| | 16 | 34 | 4.25 | 2 | 34.226072 | 0.289831 | 33.936250 | 33.967867 | 0.9991 |
| | 16 | 36 | 0.01 | 4 | 36.225437 | 0.270671 | 35.954785 | 35.967081 | 0.9997 |
| Cl | 17 | 35 | 75.76 | 1 | 35.240559 | 0.318724 | 34.921841 | 34.968853 | 0.9987 |
| | 17 | 37 | 24.24 | 3 | 37.239924 | 0.299563 | 36.940375 | 36.965903 | 0.9993 |
| Ar | 18 | 36 | 0.3365 | 0 | 36.255047 | 0.347616 | 35.907431 | 35.967545 | 0.9983 |
| | 18 | 38 | 0.0632 | 2 | 38.254411 | 0.328455 | 37.925965 | 37.962732 | 0.9990 |
| | 18 | 40 | 99.6003 | 4 | 40.253775 | 0.309295 | 39.944499 | 39.962383 | 0.9996 |
| K | 19 | 39 | 93.2581 | 1 | 39.268898 | 0.357348 | 38.911555 | 38.963707 | 0.9987 |
| | 19 | 40 | 0.0117 | 2 | 40.268580 | 0.347767 | 39.920822 | 39.963999 | 0.9989 |
| | 19 | 41 | 6.7302 | 3 | 41.268262 | 0.338187 | 40.930089 | 40.961826 | 0.9992 |
| Ca | 20 | 40 | 96.941 | 0 | 40.283385 | 0.386240 | 39.897145 | 39.962591 | 0.9984 |
| | 20 | 42 | 0.647 | 2 | 42.282749 | 0.367079 | 41.915680 | 41.958618 | 0.9990 |
| | 20 | 43 | 0.135 | 3 | 43.282432 | 0.357499 | 42.924947 | 42.958767 | 0.9992 |
| | 20 | 44 | 2.086 | 4 | 44.282114 | 0.347919 | 43.934214 | 43.955482 | 0.9995 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 19 | 40 | 0.0117 | 2 | 40.268580 | 0.347767 | 39.920822 | 39.963999 | 0.9989 |
| | 19 | 41 | 6.7302 | 3 | 41.268262 | 0.338187 | 40.930089 | 40.961826 | 0.9992 |
| Ca | 20 | 40 | 96.941 | 0 | 40.283385 | 0.386240 | 39.897145 | 39.962591 | 0.9984 |
| | 20 | 42 | 0.647 | 2 | 42.282749 | 0.367079 | 41.915680 | 41.958618 | 0.9990 |
| | 20 | 43 | 0.135 | 3 | 43.282432 | 0.357499 | 42.924947 | 42.958767 | 0.9992 |
| | 20 | 44 | 2.086 | 4 | 44.282114 | 0.347919 | 43.934214 | 43.955482 | 0.9995 |
| | 20 | 46 | 0.004 | 6 | 46.281478 | 0.328759 | 45.952748 | 45.953693 | 1.0000 |
| | 20 | 48 | 0.187 | 8 | 48.280843 | 0.309598 | 47.971283 | 47.952534 | 1.0004 |
| Sc | 21 | 45 | 100 | 3 | 45.296601 | 0.376811 | 44.919804 | 44.955912 | 0.9992 |
| Ti | 22 | 46 | 8.25 | 2 | 46.311088 | 0.405703 | 45.905394 | 45.952632 | 0.9990 |
| | 22 | 47 | 7.44 | 3 | 47.310770 | 0.396123 | 46.914661 | 46.951763 | 0.9992 |
| | 22 | 48 | 73.72 | 4 | 48.310452 | 0.386543 | 47.923928 | 47.947946 | 0.9995 |
| | 22 | 49 | 5.41 | 5 | 49.310135 | 0.376963 | 48.933196 | 48.947870 | 0.9997 |
| | 22 | 50 | 5.18 | 6 | 50.309817 | 0.367383 | 49.942463 | 49.944791 | 1.0000 |
| V | 23 | 50 | 0.25 | 4 | 50.324622 | 0.405855 | 49.918786 | 49.947159 | 0.9994 |
| | 23 | 51 | 99.75 | 5 | 51.324304 | 0.396275 | 50.928053 | 50.943960 | 0.9997 |
| Cr | 24 | 50 | 4.345 | 2 | 50.339426 | 0.444327 | 49.895109 | 49.946044 | 0.9990 |
| | 24 | 52 | 83.789 | 4 | 52.338791 | 0.425167 | 51.913643 | 51.940508 | 0.9995 |
| | 24 | 53 | 9.501 | 5 | 53.338473 | 0.415587 | 52.922910 | 52.940649 | 0.9997 |
| | 24 | 54 | 2.365 | 6 | 54.338155 | 0.406007 | 53.932177 | 53.938880 | 0.9999 |
| Mn | 25 | 55 | 100 | 5 | 55.352642 | 0.434899 | 54.917767 | 54.938045 | 0.9996 |
| Fe | 26 | 54 | 5.845 | 2 | 54.367765 | 0.482951 | 53.884823 | 53.939611 | 0.9990 |
| | 26 | 56 | 91.754 | 4 | 56.367129 | 0.463791 | 55.903357 | 55.934938 | 0.9994 |
| | 26 | 57 | 2.119 | 5 | 57.366812 | 0.454211 | 56.912625 | 56.935394 | 0.9996 |
| | 26 | 58 | 0.282 | 6 | 58.366494 | 0.444631 | 57.921892 | 57.933276 | 0.9998 |
| Co | 27 | 59 | 100 | 5 | 59.380981 | 0.473523 | 58.907482 | 58.933195 | 0.9996 |
| Ni | 28 | 58 | 68.0769 | 2 | 58.396103 | 0.521575 | 57.874538 | 57.935343 | 0.9990 |
| | 28 | 60 | 26.2231 | 4 | 60.395468 | 0.502415 | 59.893072 | 59.930786 | 0.9994 |
| | 28 | 61 | 1.1399 | 5 | 61.395150 | 0.492835 | 60.902339 | 60.931056 | 0.9995 |
| | 28 | 62 | 3.6345 | 6 | 62.394832 | 0.483255 | 61.911606 | 61.928345 | 0.9997 |
| | 28 | 64 | 0.9256 | 8 | 64.394197 | 0.464094 | 63.930141 | 63.927966 | 1.0000 |
| Cu | 29 | 63 | 69.15 | 5 | 63.409319 | 0.512147 | 62.897196 | 62.929598 | 0.9995 |
| | 29 | 65 | 30.85 | 7 | 65.408684 | 0.492986 | 64.915731 | 64.927790 | 0.9998 |
| Zn | 30 | 64 | 48.268 | 4 | 64.423806 | 0.541039 | 63.882786 | 63.929142 | 0.9993 |
| | 30 | 66 | 27.975 | 6 | 66.423171 | 0.521879 | 65.901321 | 65.926033 | 0.9996 |
| | 30 | 67 | 4.1 | 7 | 67.422853 | 0.512298 | 66.910588 | 66.927127 | 0.9998 |
| | 30 | 68 | 19.024 | 8 | 68.422535 | 0.502718 | 67.919855 | 67.924844 | 0.9999 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 30 | 70 | 0.631 | 10 | 70.421900 | 0.483558 | 69.938390 | 69.925319 | 1.0002 |
| Ga | 31 | 69 | 60.108 | 7 | 69.437022 | 0.531610 | 68.905445 | 68.925574 | 0.9997 |
| | 31 | 71 | 39.892 | 9 | 71.436387 | 0.512450 | 70.923980 | 70.924701 | 1.0000 |
| Ge | 32 | 70 | 20.38 | 6 | 70.451509 | 0.560502 | 69.891035 | 69.924247 | 0.9995 |
| | 32 | 72 | 27.31 | 8 | 72.450874 | 0.541342 | 71.909570 | 71.922076 | 0.9998 |
| | 32 | 73 | 7.76 | 9 | 73.450556 | 0.531762 | 72.918837 | 72.923459 | 0.9999 |
| | 32 | 74 | 36.72 | 10 | 74.450238 | 0.522182 | 73.928104 | 73.921178 | 1.0001 |
| | 32 | 76 | 7.83 | 12 | 76.449602 | 0.503021 | 75.946639 | 75.921403 | 1.0003 |
| As | 33 | 75 | 100 | 9 | 75.464725 | 0.551074 | 74.913694 | 74.921597 | 0.9999 |
| Se | 34 | 74 | 0.89 | 6 | 74.479848 | 0.599126 | 73.880750 | 73.922476 | 0.9994 |
| | 34 | 76 | 9.37 | 8 | 76.479212 | 0.579966 | 75.899284 | 75.919214 | 0.9997 |
| | 34 | 77 | 7.63 | 9 | 77.478894 | 0.570386 | 76.908552 | 76.919914 | 0.9999 |
| | 34 | 78 | 23.77 | 10 | 78.478577 | 0.560806 | 77.917819 | 77.917309 | 1.0000 |
| | 34 | 80 | 49.61 | 12 | 80.477941 | 0.541645 | 79.936353 | 79.916521 | 1.0002 |
| | 34 | 82 | 8.73 | 14 | 82.477305 | 0.522485 | 81.954888 | 81.916699 | 1.0005 |
| Br | 35 | 79 | 50.69 | 9 | 79.493064 | 0.589698 | 78.903409 | 78.918337 | 0.9998 |
| | 35 | 81 | 49.31 | 11 | 81.492428 | 0.570537 | 80.921943 | 80.916291 | 1.0001 |
| Kr | 36 | 78 | 0.355 | 6 | 78.508186 | 0.637750 | 77.870464 | 77.920365 | 0.9994 |
| | 36 | 80 | 2.286 | 8 | 80.507551 | 0.618590 | 79.888999 | 79.916379 | 0.9997 |
| | 36 | 82 | 11.593 | 10 | 82.506915 | 0.599430 | 81.907533 | 81.913484 | 0.9999 |
| | 36 | 83 | 11.5 | 11 | 83.506597 | 0.589849 | 82.916801 | 82.914136 | 1.0000 |
| | 36 | 84 | 56.987 | 12 | 84.506279 | 0.580269 | 83.926068 | 83.911507 | 1.0002 |
| | 36 | 86 | 17.279 | 14 | 86.505644 | 0.561109 | 85.944602 | 85.910611 | 1.0004 |
| Rb | 37 | 85 | 72.17 | 11 | 85.520766 | 0.609161 | 84.911658 | 84.911790 | 1.0000 |
| | 37 | 87 | 27.83 | 13 | 87.520131 | 0.590001 | 86.930192 | 86.909181 | 1.0002 |
| Sr | 38 | 84 | 0.56 | 8 | 84.535889 | 0.657214 | 83.878713 | 83.913425 | 0.9996 |
| | 38 | 86 | 9.86 | 10 | 86.535254 | 0.638054 | 85.897248 | 85.909260 | 0.9999 |
| | 38 | 87 | 7 | 11 | 87.534936 | 0.628473 | 86.906515 | 86.908877 | 1.0000 |
| | 38 | 88 | 82.58 | 12 | 88.534618 | 0.618893 | 87.915782 | 87.905612 | 1.0001 |
| Y | 39 | 89 | 100 | 11 | 89.549105 | 0.647785 | 88.901372 | 88.905848 | 0.9999 |
| Zr | 40 | 90 | 51.45 | 10 | 90.563592 | 0.676678 | 89.886962 | 89.904704 | 0.9998 |
| | 40 | 91 | 11.22 | 11 | 91.563274 | 0.667097 | 90.896230 | 90.905646 | 0.9999 |
| | 40 | 92 | 17.15 | 12 | 92.562956 | 0.657517 | 91.905497 | 91.905041 | 1.0000 |
| | 40 | 94 | 17.38 | 14 | 94.562321 | 0.638357 | 93.924031 | 93.906315 | 1.0002 |
| | 40 | 96 | 2.8 | 16 | 96.561685 | 0.619196 | 95.942566 | 95.908273 | 1.0004 |
| Nb | 41 | 93 | 100 | 11 | 93.577443 | 0.686409 | 92.891087 | 92.906378 | 0.9998 |
| Mo | 42 | 92 | 14.77 | 8 | 92.592566 | 0.734462 | 91.858142 | 91.906811 | 0.9995 |
| | 42 | 94 | 9.23 | 10 | 94.591931 | 0.715302 | 93.876677 | 93.905088 | 0.9997 |
| | 42 | 95 | 15.9 | 11 | 95.591613 | 0.705721 | 94.885944 | 94.905842 | 0.9998 |
| | 42 | 96 | 16.68 | 12 | 96.591295 | 0.696141 | 95.895211 | 95.904680 | 0.9999 |
| | 42 | 97 | 9.56 | 13 | 97.590977 | 0.686561 | 96.904479 | 96.906022 | 1.0000 |
| | 42 | 98 | 24.19 | 14 | 98.590659 | 0.676981 | 97.913746 | 97.905408 | 1.0001 |
| | 42 | 100 | 9.67 | 16 | 100.590024 | 0.657820 | 99.932280 | 99.907480 | 1.0002 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 42 | 94 | 9.23 | 10 | 94.591931 | 0.715302 | 93.876677 | 93.905088 | 0.9997 |
| | 42 | 95 | 15.9 | 11 | 95.591613 | 0.705721 | 94.885944 | 94.905842 | 0.9998 |
| | 42 | 96 | 16.68 | 12 | 96.591295 | 0.696141 | 95.895211 | 95.904680 | 0.9999 |
| | 42 | 97 | 9.56 | 13 | 97.590977 | 0.686561 | 96.904479 | 96.906022 | 1.0000 |
| | 42 | 98 | 24.19 | 14 | 98.590659 | 0.676981 | 97.913746 | 97.905408 | 1.0001 |
| | 42 | 100 | 9.67 | 16 | 100.590024 | 0.657820 | 99.932280 | 99.907480 | 1.0002 |
| Tc | 43 | 97 | | 11 | 97.605782 | 0.725033 | 96.880801 | 96.906365 | 0.9997 |
| | 43 | 98 | | 12 | 98.605464 | 0.715453 | 97.890069 | 97.907216 | 0.9998 |
| | 43 | 99 | | 13 | 99.605146 | 0.705873 | 98.899336 | 98.906255 | 0.9999 |
| Ru | 44 | 96 | 5.54 | 8 | 96.620905 | 0.773086 | 95.847857 | 95.907600 | 0.9994 |
| | 44 | 98 | 1.87 | 10 | 98.620269 | 0.753926 | 97.866391 | 97.905290 | 0.9996 |
| | 44 | 99 | 12.76 | 11 | 99.619951 | 0.744345 | 98.875659 | 98.905939 | 0.9997 |
| | 44 | 100 | 12.6 | 12 | 100.619633 | 0.734765 | 99.884926 | 99.904220 | 0.9998 |
| | 44 | 101 | 17.06 | 13 | 101.619316 | 0.725185 | 100.894193 | 100.905582 | 0.9999 |
| | 44 | 102 | 31.551 | 14 | 102.618998 | 0.715605 | 101.903460 | 101.904349 | 1.0000 |
| | 44 | 104 | 18.62 | 16 | 104.618362 | 0.696444 | 103.921995 | 103.905433 | 1.0002 |
| Rh | 45 | 103 | 100 | 13 | 103.633485 | 0.744497 | 102.889050 | 102.905504 | 0.9998 |
| Pd | 46 | 102 | 1.02 | 10 | 102.648608 | 0.792550 | 101.856106 | 101.905609 | 0.9995 |
| | 46 | 104 | 11.14 | 12 | 104.647972 | 0.773389 | 103.874640 | 103.904036 | 0.9997 |
| | 46 | 105 | 22.33 | 13 | 105.647654 | 0.763809 | 104.883908 | 104.905085 | 0.9998 |
| | 46 | 106 | 27.33 | 14 | 106.647336 | 0.754229 | 105.893175 | 105.903486 | 0.9999 |
| | 46 | 108 | 26.46 | 16 | 108.646701 | 0.735068 | 107.911709 | 107.903893 | 1.0001 |
| | 46 | 110 | 11.72 | 18 | 110.646065 | 0.715908 | 109.930244 | 109.905153 | 1.0002 |
| Ag | 47 | 107 | 51.839 | 13 | 107.661823 | 0.783121 | 106.878765 | 106.905097 | 0.9998 |
| | 47 | 109 | 48.161 | 15 | 109.661188 | 0.763960 | 108.897299 | 108.904752 | 0.9999 |
| Cd | 48 | 106 | 1.25 | 10 | 106.676946 | 0.831174 | 105.845820 | 105.906460 | 0.9994 |
| | 48 | 108 | 0.89 | 12 | 108.676310 | 0.812013 | 107.864355 | 107.904180 | 0.9996 |
| | 48 | 110 | 12.49 | 14 | 110.675675 | 0.792853 | 109.882889 | 109.903002 | 0.9998 |
| | 48 | 111 | 12.8 | 15 | 111.675357 | 0.783272 | 110.892157 | 110.904178 | 0.9999 |
| | 48 | 112 | 24.13 | 16 | 112.675039 | 0.773692 | 111.901424 | 111.902758 | 1.0000 |
| | 48 | 113 | 12.22 | 17 | 113.674721 | 0.764112 | 112.910691 | 112.904402 | 1.0001 |
| | 48 | 114 | 28.73 | 18 | 114.674404 | 0.754532 | 113.919958 | 113.903359 | 1.0001 |
| | 48 | 116 | 7.49 | 20 | 116.673768 | 0.735371 | 115.938493 | 115.904756 | 1.0003 |
| In | 49 | 113 | 4.29 | 15 | 113.689526 | 0.802584 | 112.887014 | 112.904058 | 0.9998 |
| | 49 | 115 | 95.71 | 17 | 115.688891 | 0.783424 | 114.905548 | 114.903878 | 1.0000 |
| Sn | 50 | 112 | 0.97 | 12 | 112.704649 | 0.850637 | 111.854069 | 111.904818 | 0.9995 |
| | 50 | 114 | 0.66 | 14 | 114.704013 | 0.831477 | 113.872604 | 113.902779 | 0.9997 |
| | 50 | 115 | 0.34 | 15 | 115.703696 | 0.821896 | 114.881871 | 114.903342 | 0.9998 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 50 | 116 | 14.54 | 16 | 116.703378 | 0.812316 | 115.891138 | 115.901741 | 0.9999 |
| | 50 | 117 | 7.68 | 17 | 117.703060 | 0.802736 | 116.900405 | 116.902952 | 1.0000 |
| | 50 | 118 | 24.22 | 18 | 118.702742 | 0.793156 | 117.909673 | 117.901603 | 1.0001 |
| | 50 | 119 | 8.59 | 19 | 119.702424 | 0.783575 | 118.918940 | 118.903308 | 1.0001 |
| | 50 | 120 | 32.58 | 20 | 120.702107 | 0.773995 | 119.928207 | 119.902195 | 1.0002 |
| | 50 | 122 | 4.63 | 22 | 122.701471 | 0.754835 | 121.946742 | 121.903439 | 1.0004 |
| | 50 | 124 | 5.79 | 24 | 124.700835 | 0.735674 | 123.965276 | 123.905274 | 1.0005 |
| Sb | 51 | 121 | 57.21 | 19 | 121.716594 | 0.802887 | 120.913797 | 120.903816 | 1.0001 |
| | 51 | 123 | 42.79 | 21 | 123.715958 | 0.783727 | 122.932332 | 122.904214 | 1.0002 |
| Te | 52 | 120 | 0.09 | 16 | 120.731716 | 0.850940 | 119.880853 | 119.904020 | 0.9998 |
| | 52 | 122 | 2.55 | 18 | 122.731081 | 0.831780 | 121.899387 | 121.903044 | 1.0000 |
| | 52 | 123 | 0.89 | 19 | 123.730763 | 0.822199 | 122.908654 | 122.904270 | 1.0000 |
| | 52 | 124 | 4.74 | 20 | 124.730445 | 0.812619 | 123.917922 | 123.902818 | 1.0001 |
| | 52 | 125 | 7.07 | 21 | 125.730127 | 0.803039 | 124.927189 | 124.904431 | 1.0002 |
| | 52 | 126 | 18.84 | 22 | 126.729809 | 0.793459 | 125.936456 | 125.903312 | 1.0003 |
| | 52 | 128 | 31.74 | 24 | 128.729174 | 0.774298 | 127.954991 | 127.904463 | 1.0004 |
| | 52 | 130 | 34.08 | 26 | 130.728538 | 0.755138 | 129.973525 | 129.906224 | 1.0005 |
| I | 53 | 127 | 100 | 21 | 127.744297 | 0.822351 | 126.922046 | 126.904473 | 1.0001 |
| Xe | 54 | 124 | 0.0952 | 16 | 124.760055 | 0.889564 | 123.870567 | 123.905893 | 0.9997 |
| | 54 | 126 | 0.089 | 18 | 126.759419 | 0.870404 | 125.889102 | 125.904270 | 0.9999 |
| | 54 | 128 | 1.9102 | 20 | 128.758784 | 0.851243 | 127.907636 | 127.903531 | 1.0000 |
| | 54 | 129 | 26.4006 | 21 | 129.758466 | 0.841663 | 128.916903 | 128.904779 | 1.0001 |
| | 54 | 130 | 4.071 | 22 | 130.758148 | 0.832083 | 129.926171 | 129.903508 | 1.0002 |
| | 54 | 131 | 21.2324 | 23 | 131.757830 | 0.822502 | 130.935438 | 130.905082 | 1.0002 |
| | 54 | 132 | 26.9086 | 24 | 132.757512 | 0.812922 | 131.944705 | 131.904153 | 1.0003 |
| | 54 | 134 | 10.4357 | 26 | 134.756877 | 0.793762 | 133.963239 | 133.905394 | 1.0004 |
| | 54 | 136 | 8.8573 | 28 | 136.756241 | 0.774601 | 135.981774 | 135.907220 | 1.0005 |
| Cs | 55 | 133 | 100 | 23 | 133.771999 | 0.841814 | 132.930295 | 132.905452 | 1.0002 |
| Ba | 56 | 130 | 0.106 | 18 | 130.787758 | 0.909028 | 129.878816 | 129.906321 | 0.9998 |
| | 56 | 132 | 0.101 | 20 | 132.787122 | 0.889867 | 131.897351 | 131.905061 | 0.9999 |
| | 56 | 134 | 2.417 | 22 | 134.786486 | 0.870707 | 133.915885 | 133.904508 | 1.0001 |
| | 56 | 135 | 6.592 | 23 | 135.786169 | 0.861126 | 134.925152 | 134.905689 | 1.0001 |
| | 56 | 136 | 7.854 | 24 | 136.785851 | 0.851546 | 135.934420 | 135.904576 | 1.0002 |
| | 56 | 137 | 11.232 | 25 | 137.785533 | 0.841966 | 136.943687 | 136.905827 | 1.0003 |
| | 56 | 138 | 71.698 | 26 | 138.785215 | 0.832386 | 137.952954 | 137.905247 | 1.0003 |
| La | 57 | 138 | 0.0888 | 24 | 138.800020 | 0.870858 | 137.929277 | 137.907112 | 1.0002 |
| | 57 | 139 | 99.9112 | 25 | 139.799702 | 0.861278 | 138.938544 | 138.906353 | 1.0002 |
| Ce | 58 | 136 | 0.185 | 20 | 136.815461 | 0.928491 | 135.887065 | 135.907170 | 0.9999 |
| | 58 | 138 | 0.251 | 22 | 138.814825 | 0.909331 | 137.905600 | 137.905990 | 1.0000 |
| | 58 | 140 | 88.45 | 24 | 140.814189 | 0.890170 | 139.924134 | 139.905439 | 1.0001 |
| | 58 | 142 | 11.114 | 26 | 142.813554 | 0.871010 | 141.942668 | 141.909244 | 1.0002 |
| Pr | 59 | 141 | 100 | 23 | 141.828676 | 0.919062 | 140.909724 | 140.907653 | 1.0000 |
| Nd | 60 | 142 | 27.153 | 22 | 142.843163 | 0.947955 | 141.895314 | 141.907723 | 0.9999 |
| | 60 | 143 | 12.173 | 23 | 143.842846 | 0.938374 | 142.904581 | 142.909814 | 1.0000 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 58 | 138 | 0.251 | 22 | 138.814825 | 0.909331 | 137.905600 | 137.905990 | 1.0000 |
| | 58 | 140 | 88.45 | 24 | 140.814189 | 0.890170 | 139.924134 | 139.905439 | 1.0001 |
| | 58 | 142 | 11.114 | 26 | 142.813554 | 0.871010 | 141.942668 | 141.909244 | 1.0002 |
| Pr | 59 | 141 | 100 | 23 | 141.828676 | 0.919062 | 140.909724 | 140.907653 | 1.0000 |
| Nd | 60 | 142 | 27.153 | 22 | 142.843163 | 0.947955 | 141.895314 | 141.907723 | 0.9999 |
| | 60 | 143 | 12.173 | 23 | 143.842846 | 0.938374 | 142.904581 | 142.909814 | 1.0000 |
| | 60 | 144 | 23.798 | 24 | 144.842528 | 0.928794 | 143.913849 | 143.910087 | 1.0000 |
| | 60 | 145 | 8.293 | 25 | 145.842210 | 0.919214 | 144.923116 | 144.912574 | 1.0001 |
| | 60 | 146 | 17.189 | 26 | 146.841892 | 0.909634 | 145.932383 | 145.913117 | 1.0001 |
| | 60 | 148 | 5.756 | 28 | 148.841257 | 0.890473 | 147.950917 | 147.916893 | 1.0002 |
| | 60 | 150 | 5.638 | 30 | 150.840621 | 0.871313 | 149.969452 | 149.920891 | 1.0003 |
| Pm | 61 | 145 | | 23 | 145.857015 | 0.957686 | 144.899439 | 144.912749 | 0.9999 |
| | 61 | 146 | | 24 | 146.856697 | 0.948106 | 145.908706 | 145.914696 | 1.0000 |
| | 61 | 147 | | 25 | 147.856379 | 0.938526 | 146.917973 | 146.915139 | 1.0000 |
| Sm | 62 | 144 | 3.083 | 20 | 144.872138 | 1.005739 | 143.866494 | 143.911999 | 0.9997 |
| | 62 | 147 | 15.017 | 23 | 147.871184 | 0.976998 | 146.894296 | 146.914898 | 0.9999 |
| | 62 | 148 | 11.254 | 24 | 148.870866 | 0.967418 | 147.903563 | 147.914823 | 0.9999 |
| | 62 | 149 | 13.83 | 25 | 149.870549 | 0.957838 | 148.912830 | 148.917185 | 1.0000 |
| | 62 | 150 | 7.351 | 26 | 150.870231 | 0.948258 | 149.922098 | 149.917276 | 1.0000 |
| | 62 | 152 | 26.735 | 28 | 152.869595 | 0.929097 | 151.940632 | 151.919732 | 1.0001 |
| | 62 | 154 | 22.73 | 30 | 154.868960 | 0.909937 | 153.959166 | 153.922209 | 1.0002 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Eu | 63 | 151 | 47.81 | 25 | 151.884718 | 0.977150 | 150.907688 | 150.919850 | 0.9999 |
| | 63 | 153 | 52.19 | 27 | 153.884082 | 0.957989 | 152.926222 | 152.921230 | 1.0000 |
| Gd | 64 | 152 | 0.2 | 24 | 152.899205 | 1.006042 | 151.893278 | 151.919791 | 0.9998 |
| | 64 | 154 | 2.18 | 26 | 154.898569 | 0.986882 | 153.911812 | 153.920867 | 0.9999 |
| | 64 | 155 | 14.8 | 27 | 155.898251 | 0.977301 | 154.921079 | 154.922622 | 1.0000 |
| | 64 | 156 | 20.47 | 28 | 156.897934 | 0.967721 | 155.930346 | 155.922123 | 1.0001 |
| | 64 | 158 | 24.84 | 30 | 158.897298 | 0.948561 | 157.948881 | 157.924104 | 1.0002 |
| | 64 | 160 | 21.86 | 32 | 160.896662 | 0.929400 | 159.967415 | 159.927064 | 1.0003 |
| Tb | 65 | 159 | 100 | 29 | 159.911785 | 0.977453 | 158.934471 | 158.925347 | 1.0001 |
| Dy | 66 | 156 | 0.056 | 24 | 156.927543 | 1.044666 | 155.882992 | 155.924280 | 0.9997 |
| | 66 | 158 | 0.095 | 26 | 158.926908 | 1.025506 | 157.901527 | 157.924409 | 0.9999 |
| | 66 | 160 | 2.329 | 28 | 160.926272 | 1.006345 | 159.920061 | 159.925198 | 1.0000 |
| | 66 | 161 | 18.889 | 29 | 161.925954 | 0.996765 | 160.929328 | 160.926933 | 1.0000 |
| | 66 | 162 | 25.475 | 30 | 162.925637 | 0.987185 | 161.938595 | 161.926798 | 1.0001 |
| | 66 | 163 | 24.896 | 31 | 163.925319 | 0.977604 | 162.947863 | 162.928731 | 1.0001 |
| | 66 | 164 | 28.26 | 32 | 164.925001 | 0.968024 | 163.957130 | 163.929175 | 1.0002 |
| Ho | 67 | 165 | 100 | 31 | 165.939488 | 0.996916 | 164.942720 | 164.930322 | 1.0001 |
| Er | 68 | 162 | 0.139 | 26 | 162.955246 | 1.064130 | 161.891241 | 161.928778 | 0.9998 |
| | 68 | 164 | 1.601 | 28 | 164.954611 | 1.044969 | 163.909775 | 163.929200 | 0.9999 |
| | 68 | 166 | 33.503 | 30 | 166.953975 | 1.025809 | 165.928310 | 165.930293 | 1.0000 |
| | 68 | 167 | 22.869 | 31 | 167.953657 | 1.016228 | 166.937577 | 166.932048 | 1.0000 |
| | 68 | 168 | 26.978 | 32 | 168.953339 | 1.006648 | 167.946844 | 167.932370 | 1.0001 |
| | 68 | 170 | 14.91 | 34 | 170.952704 | 0.987488 | 169.965379 | 169.935464 | 1.0002 |
| Tm | 69 | 169 | 100 | 31 | 169.967827 | 1.035540 | 168.932434 | 168.934213 | 1.0000 |
| Yb | 70 | 168 | 0.13 | 28 | 168.982949 | 1.083593 | 167.899490 | 167.933897 | 0.9998 |
| | 70 | 170 | 3.04 | 30 | 170.982314 | 1.064433 | 169.918024 | 169.934762 | 0.9999 |
| | 70 | 171 | 14.28 | 31 | 171.981996 | 1.054852 | 170.927292 | 170.936626 | 0.9999 |
| | 70 | 172 | 21.83 | 32 | 172.981678 | 1.045272 | 171.936559 | 171.936382 | 1.0000 |
| | 70 | 173 | 16.13 | 33 | 173.981360 | 1.035692 | 172.945826 | 172.938211 | 1.0000 |
| | 70 | 174 | 31.83 | 34 | 174.981042 | 1.026112 | 173.955093 | 173.938862 | 1.0001 |
| | 70 | 176 | 12.76 | 36 | 176.980407 | 1.006951 | 175.973628 | 175.942572 | 1.0002 |
| Lu | 71 | 175 | 97.41 | 33 | 175.995529 | 1.055004 | 174.940683 | 174.940772 | 1.0000 |
| | 71 | 176 | 2.59 | 34 | 176.995212 | 1.045424 | 175.949951 | 175.942686 | 1.0000 |
| Hf | 72 | 174 | 0.16 | 30 | 175.010652 | 1.103057 | 173.907739 | 173.940046 | 0.9998 |
| | 72 | 176 | 5.26 | 32 | 177.010016 | 1.083896 | 175.926273 | 175.941409 | 0.9999 |
| | 72 | 177 | 18.6 | 33 | 178.009699 | 1.074316 | 176.935541 | 176.943221 | 1.0000 |
| | 72 | 178 | 27.28 | 34 | 179.009381 | 1.064736 | 177.944808 | 177.943699 | 1.0000 |
| | 72 | 179 | 13.62 | 35 | 180.009063 | 1.055155 | 178.954075 | 178.945816 | 1.0000 |
| | 72 | 180 | 35.08 | 36 | 181.008745 | 1.045575 | 179.963342 | 179.946550 | 1.0001 |
| Ta | 73 | 180 | 0.01 | 34 | 181.023550 | 1.084048 | 179.939665 | 179.947465 | 1.0000 |
| | 73 | 181 | 99.988 | 35 | 182.023232 | 1.074467 | 180.948932 | 180.947996 | 1.0000 |
| W | 74 | 180 | 0.12 | 32 | 181.038355 | 1.122520 | 179.915988 | 179.946704 | 0.9998 |
| | 74 | 182 | 26.5 | 34 | 183.037719 | 1.103360 | 181.934522 | 181.948204 | 0.9999 |
| | 74 | 183 | 14.31 | 35 | 184.037402 | 1.093779 | 182.943790 | 182.950223 | 1.0000 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 72 | 180 | 35.08 | 36 | 181.008745 | 1.045575 | 179.963342 | 179.946550 | 1.0001 |
| Ta | 73 | 180 | 0.01 | 34 | 181.023550 | 1.084048 | 179.939665 | 179.947465 | 1.0000 |
| | 73 | 181 | 99.988 | 35 | 182.023232 | 1.074467 | 180.948932 | 180.947996 | 1.0000 |
| W | 74 | 180 | 0.12 | 32 | 181.038355 | 1.122520 | 179.915988 | 179.946704 | 0.9998 |
| | 74 | 182 | 26.5 | 34 | 183.037719 | 1.103360 | 181.934522 | 181.948204 | 0.9999 |
| | 74 | 183 | 14.31 | 35 | 184.037402 | 1.093779 | 182.943790 | 182.950223 | 1.0000 |
| | 74 | 184 | 30.64 | 36 | 185.037084 | 1.084199 | 183.953057 | 183.950931 | 1.0000 |
| | 74 | 186 | 28.43 | 38 | 187.036448 | 1.065039 | 185.971591 | 185.954364 | 1.0001 |
| Re | 75 | 185 | 37.4 | 35 | 186.051571 | 1.113091 | 184.938647 | 184.952955 | 0.9999 |
| | 75 | 187 | 62.6 | 37 | 188.050935 | 1.093931 | 186.957181 | 186.955753 | 1.0000 |
| Os | 76 | 184 | 0.02 | 32 | 185.066693 | 1.161144 | 183.905702 | 183.952489 | 0.9997 |
| | 76 | 186 | 1.59 | 34 | 187.066058 | 1.141984 | 185.924237 | 185.953838 | 0.9998 |
| | 76 | 187 | 1.96 | 35 | 188.065740 | 1.132403 | 186.933504 | 186.955750 | 0.9999 |
| | 76 | 188 | 13.24 | 36 | 189.065422 | 1.122823 | 187.942771 | 187.955838 | 0.9999 |
| | 76 | 189 | 16.15 | 37 | 190.065104 | 1.113243 | 188.952039 | 188.958148 | 1.0000 |
| | 76 | 190 | 26.26 | 38 | 191.064787 | 1.103663 | 189.961306 | 189.958447 | 1.0000 |
| | 76 | 192 | 40.78 | 40 | 193.064151 | 1.084502 | 191.979840 | 191.961481 | 1.0001 |
| Ir | 77 | 191 | 37.3 | 37 | 192.079274 | 1.132555 | 190.946896 | 190.960594 | 0.9999 |
| | 77 | 193 | 62.7 | 39 | 194.078638 | 1.113394 | 192.965430 | 192.962926 | 1.0000 |
| Pt | 78 | 190 | 0.014 | 34 | 191.094396 | 1.180608 | 189.913951 | 189.959930 | 0.9998 |
| | 78 | 192 | 0.782 | 36 | 193.093761 | 1.161447 | 191.932486 | 191.961038 | 0.9999 |
| | 78 | 194 | 32.967 | 38 | 195.093125 | 1.142287 | 193.951020 | 193.962680 | 0.9999 |
| | 78 | 195 | 33.832 | 39 | 196.092807 | 1.132706 | 194.960287 | 194.964791 | 1.0000 |
| | 78 | 196 | 25.242 | 40 | 197.092490 | 1.123126 | 195.969555 | 195.964952 | 1.0000 |
| | 78 | 198 | 7.163 | 42 | 199.091854 | 1.103966 | 197.988089 | 197.967000 | 1.0001 |
| Au | 79 | 197 | 100 | 39 | 198.106977 | 1.152018 | 196.955145 | 196.966569 | 0.9999 |
| Hg | 80 | 196 | 0.15 | 36 | 197.122099 | 1.200071 | 195.922200 | 195.965833 | 0.9998 |
| | 80 | 198 | 9.97 | 38 | 199.121464 | 1.180911 | 197.940735 | 197.966769 | 0.9999 |
| | 80 | 199 | 16.87 | 39 | 200.121146 | 1.171330 | 198.950002 | 198.968280 | 0.9999 |
| | 80 | 200 | 23.101 | 40 | 201.120828 | 1.161750 | 199.959269 | 199.968326 | 1.0000 |
| | 80 | 201 | 13.18 | 41 | 202.120510 | 1.152170 | 200.968536 | 200.970302 | 1.0000 |
| | 80 | 202 | 29.86 | 42 | 203.120192 | 1.142590 | 201.977804 | 201.970643 | 1.0000 |
| | 80 | 204 | 6.87 | 44 | 205.119557 | 1.123429 | 203.996338 | 203.973494 | 1.0001 |
| Tl | 81 | 203 | 29.524 | 41 | 204.134680 | 1.171482 | 202.963394 | 202.972344 | 1.0000 |
| | 81 | 205 | 70.476 | 43 | 206.134044 | 1.152322 | 204.981928 | 204.974428 | 1.0000 |
| Pb | 82 | 204 | 1.4 | 40 | 205.149167 | 1.200374 | 203.948984 | 203.973044 | 0.9999 |
| | 82 | 206 | 24.1 | 42 | 207.148531 | 1.181214 | 205.967518 | 205.974465 | 1.0000 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 82 | 207 | 22.1 | 43 | 208.148213 | 1.171634 | 206.976785 | 206.975897 | 1.0000 |
| | 82 | 208 | 52.4 | 44 | 209.147895 | 1.162053 | 207.986053 | 207.976652 | 1.0000 |
| Bi | 83 | 209 | 100 | 43 | 210.162382 | 1.190946 | 208.971643 | 208.980399 | 1.0000 |
| Po | 84 | 208 | | 40 | 209.177505 | 1.238998 | 207.938698 | 207.981246 | 0.9998 |
| | 84 | 209 | | 41 | 210.177187 | 1.229418 | 208.947965 | 208.982430 | 0.9998 |
| At | 85 | 210 | | 40 | 211.191674 | 1.258310 | 209.933555 | 209.987150 | 0.9997 |
| Rn | 86 | 211 | | 39 | 212.206161 | 1.287202 | 210.919145 | 210.990600 | 0.9997 |
| Fr | 87 | 212 | | 38 | 213.220648 | 1.316095 | 211.904736 | 211.996200 | 0.9996 |
| | 87 | 222 | | 48 | 223.217470 | 1.220292 | 221.997408 | 222.017550 | 0.9999 |
| | 87 | 223 | | 49 | 224.217153 | 1.210712 | 223.006675 | 223.019736 | 0.9999 |
| Ra | 88 | 226 | | 50 | 227.231004 | 1.220444 | 226.010799 | 226.025410 | 0.9999 |
| | 88 | 228 | | 52 | 229.230368 | 1.201283 | 228.029334 | 228.031070 | 1.0000 |
| Ac | 89 | 227 | | 49 | 228.245491 | 1.249336 | 226.996389 | 227.027752 | 0.9999 |
| Th | 90 | 232 | | 52 | 233.258707 | 1.239907 | 232.019048 | 232.030550 | 1.0000 |
| Pa | 91 | 231 | | 49 | 232.273830 | 1.287960 | 230.986104 | 231.035884 | 0.9998 |
| | 91 | 233 | | 51 | 234.273194 | 1.268800 | 233.004638 | 233.040247 | 0.9998 |
| U | 92 | 234 | 0.0054 | 50 | 235.287681 | 1.297692 | 233.990228 | 234.040952 | 0.9998 |
| | 92 | 235 | 0.7204 | 51 | 236.287363 | 1.288112 | 234.999496 | 235.043930 | 0.9998 |
| | 92 | 238 | 99.2742 | 54 | 239.286410 | 1.259371 | 238.027297 | 238.050788 | 0.9999 |
| Np | 93 | 236 | | 50 | 237.301850 | 1.317004 | 235.985086 | 236.046570 | 0.9997 |
| | 93 | 237 | | 51 | 238.301533 | 1.307424 | 236.994353 | 237.048173 | 0.9998 |
| Pu | 94 | 238 | | 50 | 239.316020 | 1.336316 | 237.979943 | 238.049560 | 0.9997 |
| | 94 | 239 | | 51 | 240.315702 | 1.326736 | 238.989210 | 239.052163 | 0.9997 |
| | 94 | 240 | | 52 | 241.315384 | 1.317155 | 239.998477 | 240.053814 | 0.9998 |
| | 94 | 241 | | 53 | 242.315066 | 1.307575 | 241.007745 | 241.056852 | 0.9998 |
| | 94 | 242 | | 54 | 243.314748 | 1.297995 | 242.017012 | 242.058743 | 0.9998 |
| | 94 | 244 | | 56 | 245.314113 | 1.278834 | 244.035546 | 244.064204 | 0.9999 |
| Am | 95 | 241 | | 51 | 242.329871 | 1.346048 | 240.984067 | 241.056829 | 0.9997 |
| | 95 | 243 | | 53 | 244.329235 | 1.326887 | 243.002602 | 243.061381 | 0.9998 |
| Cm | 96 | 240 | | 48 | 241.344994 | 1.394100 | 239.951123 | 240.055530 | 0.9996 |
| | 96 | 242 | | 50 | 243.344358 | 1.374940 | 241.969657 | 242.058836 | 0.9996 |
| | 96 | 243 | | 51 | 244.344040 | 1.365360 | 242.978925 | 243.061389 | 0.9997 |
| | 96 | 244 | | 52 | 245.343722 | 1.355779 | 243.988192 | 244.062753 | 0.9997 |
| | 96 | 245 | | 53 | 246.343405 | 1.346199 | 244.997459 | 245.065491 | 0.9997 |
| | 96 | 246 | | 54 | 247.343087 | 1.336619 | 246.006726 | 246.067224 | 0.9998 |
| | 96 | 247 | | 55 | 248.342769 | 1.327039 | 247.015994 | 247.070354 | 0.9998 |
| | 96 | 248 | | 56 | 249.342451 | 1.317458 | 248.025261 | 248.072349 | 0.9998 |
| | 96 | 249 | | 57 | 250.342133 | 1.307878 | 249.034528 | 249.075930 | 0.9998 |
| | 96 | 250 | | 58 | 251.341816 | 1.298298 | 250.043795 | 250.078360 | 0.9999 |
| Bk | 97 | 247 | | 53 | 248.357574 | 1.365511 | 246.992316 | 247.070310 | 0.9997 |
| | 97 | 249 | | 55 | 250.356938 | 1.346351 | 249.010851 | 249.074987 | 0.9997 |
| Cf | 98 | 248 | | 52 | 249.372061 | 1.394403 | 247.977906 | 248.072190 | 0.9996 |
| | 98 | 249 | | 53 | 250.371743 | 1.384823 | 248.987174 | 249.074854 | 0.9996 |
| | 98 | 250 | | 54 | 251.371425 | 1.375243 | 249.996441 | 250.076406 | 0.9997 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 96 | 250 | | 58 | 251.341816 | 1.298298 | 250.043795 | 250.078360 | 0.9999 |
| Bk | 97 | 247 | | 53 | 248.357574 | 1.365511 | 246.992316 | 247.070310 | 0.9997 |
| | 97 | 249 | | 55 | 250.356938 | 1.346351 | 249.010851 | 249.074987 | 0.9997 |
| Cf | 98 | 248 | | 52 | 249.372061 | 1.394403 | 247.977906 | 248.072190 | 0.9996 |
| | 98 | 249 | | 53 | 250.371743 | 1.384823 | 248.987174 | 249.074854 | 0.9996 |
| | 98 | 250 | | 54 | 251.371425 | 1.375243 | 249.996441 | 250.076406 | 0.9997 |
| | 98 | 251 | | 55 | 252.371108 | 1.365663 | 251.005708 | 251.079587 | 0.9997 |
| | 98 | 253 | | 57 | 254.370472 | 1.346502 | 253.024243 | 253.085130 | 0.9998 |
| Es | 99 | 252 | | 54 | 253.385595 | 1.394555 | 251.991298 | 252.082980 | 0.9996 |
| | 99 | 254 | | 56 | 255.384959 | 1.375394 | 254.009833 | 254.088022 | 0.9997 |
| Fm | 100 | 252 | | 52 | 253.400400 | 1.433027 | 251.967621 | 252.082470 | 0.9995 |
| | 100 | 254 | | 54 | 255.399764 | 1.413867 | 253.986155 | 254.086854 | 0.9996 |
| | 100 | 257 | | 57 | 258.398811 | 1.385126 | 257.013957 | 257.095110 | 0.9997 |

Average: 0.9998

| Element | Z | A | nat_abund_% | G | ms_calc_u |
|---|---|---|---|---|---|
| D | 1 | 2 | 0.0115 | 0 | 0.00193019 |
| He | 2 | 4 | 99.999866 | 0 | 0.00386037 |
| Li | 3 | 6 | 7.59 | 0 | 0.00579056 |
| | 3 | 7 | 92.41 | 1 | -0.05810960 |
| Be | 4 | 9 | 100 | 1 | -0.05617942 |
| B | 5 | 10 | 19.9 | 0 | 0.00965093 |
| | 5 | 11 | 80.1 | 1 | -0.05424923 |
| C | 6 | 12 | 98.93 | 0 | 0.01158112 |
| | 6 | 13 | 1.07 | 1 | -0.05231904 |
| N | 7 | 14 | 99.636 | 0 | 0.01351130 |
| | 7 | 15 | 0.364 | 1 | -0.05038886 |
| O | 8 | 16 | 99.757 | 0 | 0.01544149 |
| | 8 | 17 | 0.038 | 1 | -0.04845867 |
| | 8 | 18 | 0.205 | 2 | -0.11235883 |
| F | 9 | 19 | 100 | 1 | -0.04652849 |
| Ne | 10 | 20 | 90.48 | 0 | 0.04507147 |
| | 10 | 21 | 0.27 | 1 | 0.03548645 |
| | 10 | 22 | 9.25 | 2 | 0.02590142 |
| Na | 11 | 23 | 100 | 1 | 0.03999359 |
| Mg | 12 | 24 | 78.99 | 0 | 0.05408576 |
| | 12 | 25 | 10 | 1 | 0.04450074 |
| | 12 | 26 | 11.01 | 2 | 0.03491572 |
| Al | 13 | 27 | 100 | 1 | 0.04900789 |
| Si | 14 | 28 | 92.223 | 0 | 0.06310006 |
| | 14 | 29 | 4.685 | 1 | 0.05351503 |
| | 14 | 30 | 3.092 | 2 | 0.04393001 |
| P | 15 | 31 | 100 | 1 | 0.05802218 |
| S | 16 | 32 | 94.99 | 0 | 0.07211435 |
| | 16 | 33 | 0.75 | 1 | 0.06252933 |
| | 16 | 34 | 4.25 | 2 | 0.05294430 |
| | 16 | 36 | 0.01 | 4 | 0.03377426 |
| Cl | 17 | 35 | 75.76 | 1 | 0.06703648 |
| | 17 | 37 | 24.24 | 3 | 0.04786643 |
| Ar | 18 | 36 | 0.3365 | 0 | 0.08112865 |
| | 18 | 38 | 0.0632 | 2 | 0.06195860 |
| | 18 | 40 | 99.6003 | 4 | 0.04278855 |
| K | 19 | 39 | 93.2581 | 1 | 0.07605077 |
| | 19 | 40 | 0.0117 | 2 | 0.06646575 |
| | 19 | 41 | 6.7302 | 3 | 0.05688072 |
| Ca | 20 | 40 | 96.941 | 0 | 0.09014294 |
| | 20 | 42 | 0.647 | 2 | 0.07097289 |

| | | | | | |
|---|---|---|---|---|---|
| | 18 | 40 | 99.6003 | 4 | 0.04278855 |
| K | 19 | 39 | 93.2581 | 1 | 0.07605077 |
| | 19 | 40 | 0.0117 | 2 | 0.06646575 |
| | 19 | 41 | 6.7302 | 3 | 0.05688072 |
| Ca | 20 | 40 | 96.941 | 0 | 0.09014294 |
| | 20 | 42 | 0.647 | 2 | 0.07097289 |
| | 20 | 43 | 0.135 | 3 | 0.06138787 |
| | 20 | 44 | 2.086 | 4 | 0.05180284 |
| | 20 | 46 | 0.004 | 6 | 0.03263280 |
| | 20 | 48 | 0.187 | 8 | 0.01346275 |
| Sc | 21 | 45 | 100 | 3 | 0.06589502 |
| Ti | 22 | 46 | 8.25 | 2 | 0.07998719 |
| | 22 | 47 | 7.44 | 3 | 0.07040216 |
| | 22 | 48 | 73.72 | 4 | 0.06081714 |
| | 22 | 49 | 5.41 | 5 | 0.05123211 |
| | 22 | 50 | 5.18 | 6 | 0.04164709 |
| V | 23 | 50 | 0.25 | 4 | 0.06532429 |
| | 23 | 51 | 99.75 | 5 | 0.05573926 |
| Cr | 24 | 50 | 4.345 | 2 | 0.08900148 |
| | 24 | 52 | 83.789 | 4 | 0.06983143 |
| | 24 | 53 | 9.501 | 5 | 0.06024641 |
| | 24 | 54 | 2.365 | 6 | 0.05066138 |
| Mn | 25 | 55 | 100 | 5 | 0.06475356 |
| Fe | 26 | 54 | 5.845 | 2 | 0.09801577 |
| | 26 | 56 | 91.754 | 4 | 0.07884573 |
| | 26 | 57 | 2.119 | 5 | 0.06926070 |
| | 26 | 58 | 0.282 | 6 | 0.05967568 |
| Co | 27 | 59 | 100 | 5 | 0.07376785 |
| Ni | 28 | 58 | 68.0769 | 2 | 0.10703007 |
| | 28 | 60 | 26.2231 | 4 | 0.08786002 |
| | 28 | 61 | 1.1399 | 5 | 0.07827500 |
| | 28 | 62 | 3.6345 | 6 | 0.06868997 |
| | 28 | 64 | 0.9256 | 8 | 0.04951992 |
| Cu | 29 | 63 | 69.15 | 5 | 0.08278214 |
| | 29 | 65 | 30.85 | 7 | 0.06361210 |
| Zn | 30 | 64 | 48.268 | 4 | 0.09687431 |
| | 30 | 66 | 27.975 | 6 | 0.07770427 |
| | 30 | 67 | 4.1 | 7 | 0.06811924 |
| | 30 | 68 | 19.024 | 8 | 0.05853422 |

| | | | | | |
|---|---|---|---|---|---|
| | 30 | 70 | 0.631 | 10 | 0.03936417 |
| Ga | 31 | 69 | 60.108 | 7 | 0.07262639 |
| | 31 | 71 | 39.892 | 9 | 0.05345634 |
| Ge | 32 | 70 | 20.38 | 6 | 0.08671856 |
| | 32 | 72 | 27.31 | 8 | 0.06754851 |
| | 32 | 73 | 7.76 | 9 | 0.05796349 |
| | 32 | 74 | 36.72 | 10 | 0.04837846 |
| | 32 | 76 | 7.83 | 12 | 0.02920842 |
| As | 33 | 75 | 100 | 9 | 0.06247064 |
| Se | 34 | 74 | 0.89 | 6 | 0.09573285 |
| | 34 | 76 | 9.37 | 8 | 0.07656281 |
| | 34 | 77 | 7.63 | 9 | 0.06697778 |
| | 34 | 78 | 23.77 | 10 | 0.05739276 |
| | 34 | 80 | 49.61 | 12 | 0.03822271 |
| | 34 | 82 | 8.73 | 14 | 0.01905266 |
| Br | 35 | 79 | 50.69 | 9 | 0.07148493 |
| | 35 | 81 | 49.31 | 11 | 0.05231488 |
| Kr | 36 | 78 | 0.355 | 6 | 0.10474715 |
| | 36 | 80 | 2.286 | 8 | 0.08557710 |
| | 36 | 82 | 11.593 | 10 | 0.06640705 |
| | 36 | 83 | 11.5 | 11 | 0.05682203 |
| | 36 | 84 | 56.987 | 12 | 0.04723700 |
| | 36 | 86 | 17.279 | 14 | 0.02806696 |
| Rb | 37 | 85 | 72.17 | 11 | 0.06132918 |
| | 37 | 87 | 27.83 | 13 | 0.04215913 |
| Sr | 38 | 84 | 0.56 | 8 | 0.09459139 |
| | 38 | 86 | 9.86 | 10 | 0.07542135 |
| | 38 | 87 | 7 | 11 | 0.06583632 |
| | 38 | 88 | 82.58 | 12 | 0.05625130 |
| Y | 39 | 89 | 100 | 11 | 0.07034347 |
| Zr | 40 | 90 | 51.45 | 10 | 0.08443564 |
| | 40 | 91 | 11.22 | 11 | 0.07485062 |
| | 40 | 92 | 17.15 | 12 | 0.06526559 |
| | 40 | 94 | 17.38 | 14 | 0.04609554 |
| | 40 | 96 | 2.8 | 16 | 0.02692550 |
| Nb | 41 | 93 | 100 | 11 | 0.07935776 |
| Mo | 42 | 92 | 14.77 | 8 | 0.11261998 |
| | 42 | 94 | 9.23 | 10 | 0.09344993 |
| | 42 | 95 | 15.9 | 11 | 0.08386491 |
| | 42 | 96 | 16.68 | 12 | 0.07427989 |
| | 42 | 97 | 9.56 | 13 | 0.06469486 |
| | 42 | 98 | 24.19 | 14 | 0.05510984 |

| | | | | | |
|---|---|---|---|---|---|
| Mo | 42 | 92 | 14.77 | 8 | 0.11261998 |
| | 42 | 94 | 9.23 | 10 | 0.09344993 |
| | 42 | 95 | 15.9 | 11 | 0.08386491 |
| | 42 | 96 | 16.68 | 12 | 0.07427989 |
| | 42 | 97 | 9.56 | 13 | 0.06469486 |
| | 42 | 98 | 24.19 | 14 | 0.05510984 |
| | 42 | 100 | 9.67 | 16 | 0.03593979 |
| Tc | 43 | 97 | | 11 | 0.08837206 |
| | 43 | 98 | | 12 | 0.07878703 |
| | 43 | 99 | | 13 | 0.06920201 |
| Ru | 44 | 96 | 5.54 | 8 | 0.12163428 |
| | 44 | 98 | 1.87 | 10 | 0.10246423 |
| | 44 | 99 | 12.76 | 11 | 0.09287920 |
| | 44 | 100 | 12.6 | 12 | 0.08329418 |
| | 44 | 101 | 17.06 | 13 | 0.07370916 |
| | 44 | 102 | 31.551 | 14 | 0.06412413 |
| | 44 | 104 | 18.62 | 16 | 0.04495408 |
| Rh | 45 | 103 | 100 | 13 | 0.07821630 |
| Pd | 46 | 102 | 1.02 | 10 | 0.11147852 |
| | 46 | 104 | 11.14 | 12 | 0.09230847 |
| | 46 | 105 | 22.33 | 13 | 0.08272345 |
| | 46 | 106 | 27.33 | 14 | 0.07313843 |
| | 46 | 108 | 26.46 | 16 | 0.05396838 |
| | 46 | 110 | 11.72 | 18 | 0.03479833 |
| Ag | 47 | 107 | 51.839 | 13 | 0.08723060 |
| | 47 | 109 | 48.161 | 15 | 0.06806055 |
| Cd | 48 | 106 | 1.25 | 10 | 0.12049282 |
| | 48 | 108 | 0.89 | 12 | 0.10132277 |
| | 48 | 110 | 12.49 | 14 | 0.08215272 |
| | 48 | 111 | 12.8 | 15 | 0.07256770 |
| | 48 | 112 | 24.13 | 16 | 0.06298267 |
| | 48 | 113 | 12.22 | 17 | 0.05339765 |
| | 48 | 114 | 28.73 | 18 | 0.04381262 |
| | 48 | 116 | 7.49 | 20 | 0.02464258 |
| In | 49 | 113 | 4.29 | 15 | 0.07707484 |
| | 49 | 115 | 95.71 | 17 | 0.05790480 |
| Sn | 50 | 112 | 0.97 | 12 | 0.11033706 |
| | 50 | 114 | 0.66 | 14 | 0.09116701 |
| | 50 | 115 | 0.34 | 15 | 0.08158199 |

| | | | | | |
|---|---|---|---|---|---|
| | 50 | 116 | 14.54 | 16 | 0.07199697 |
| | 50 | 117 | 7.68 | 17 | 0.06241194 |
| | 50 | 118 | 24.22 | 18 | 0.05282692 |
| | 50 | 119 | 8.59 | 19 | 0.04324189 |
| | 50 | 120 | 32.58 | 20 | 0.03365687 |
| | 50 | 122 | 4.63 | 22 | 0.01448682 |
| | 50 | 124 | 5.79 | 24 | -0.00468323 |
| Sb | 51 | 121 | 57.21 | 19 | 0.04774904 |
| | 51 | 123 | 42.79 | 21 | 0.02857899 |
| Te | 52 | 120 | 0.09 | 16 | 0.08101126 |
| | 52 | 122 | 2.55 | 18 | 0.06184121 |
| | 52 | 123 | 0.89 | 19 | 0.05225619 |
| | 52 | 124 | 4.74 | 20 | 0.04267116 |
| | 52 | 125 | 7.07 | 21 | 0.03308614 |
| | 52 | 126 | 18.84 | 22 | 0.02350112 |
| | 52 | 128 | 31.74 | 24 | 0.00433107 |
| | 52 | 130 | 34.08 | 26 | -0.01483898 |
| I | 53 | 127 | 100 | 21 | 0.03759329 |
| Xe | 54 | 124 | 0.0952 | 16 | 0.09002555 |
| | 54 | 126 | 0.089 | 18 | 0.07085551 |
| | 54 | 128 | 1.9102 | 20 | 0.05168546 |
| | 54 | 129 | 26.4006 | 21 | 0.04210043 |
| | 54 | 130 | 4.071 | 22 | 0.03251541 |
| | 54 | 131 | 21.2324 | 23 | 0.02293039 |
| | 54 | 132 | 26.9086 | 24 | 0.01334536 |
| | 54 | 134 | 10.4357 | 26 | -0.00582469 |
| | 54 | 136 | 8.8573 | 28 | -0.02499473 |
| Cs | 55 | 133 | 100 | 23 | 0.02743753 |
| Ba | 56 | 130 | 0.106 | 18 | 0.07986980 |
| | 56 | 132 | 0.101 | 20 | 0.06069975 |
| | 56 | 134 | 2.417 | 22 | 0.04152970 |
| | 56 | 135 | 6.592 | 23 | 0.03194468 |
| | 56 | 136 | 7.854 | 24 | 0.02235966 |
| | 56 | 137 | 11.232 | 25 | 0.01277463 |
| | 56 | 138 | 71.698 | 26 | 0.00318961 |
| La | 57 | 138 | 0.0888 | 24 | 0.02686680 |
| | 57 | 139 | 99.9112 | 25 | 0.01728178 |
| Ce | 58 | 136 | 0.185 | 20 | 0.06971405 |
| | 58 | 138 | 0.251 | 22 | 0.05054400 |
| | 58 | 140 | 88.45 | 24 | 0.03137395 |
| | 58 | 142 | 11.114 | 26 | 0.01220390 |
| Pr | 59 | 141 | 100 | 23 | 0.04546612 |

| | | | | | |
|---|---|---|---|---|---|
| | 57 | 139 | 99.9112 | 25 | 0.01728178 |
| Ce | 58 | 136 | 0.185 | 20 | 0.06971405 |
| | 58 | 138 | 0.251 | 22 | 0.05054400 |
| | 58 | 140 | 88.45 | 24 | 0.03137395 |
| | 58 | 142 | 11.114 | 26 | 0.01220390 |
| Pr | 59 | 141 | 100 | 23 | 0.04546612 |
| Nd | 60 | 142 | 27.153 | 22 | 0.05955829 |
| | 60 | 143 | 12.173 | 23 | 0.04997327 |
| | 60 | 144 | 23.798 | 24 | 0.04038824 |
| | 60 | 145 | 8.293 | 25 | 0.03080322 |
| | 60 | 146 | 17.189 | 26 | 0.02121820 |
| | 60 | 148 | 5.756 | 28 | 0.00204815 |
| | 60 | 150 | 5.638 | 30 | -0.01712190 |
| Pm | 61 | 145 | | 23 | 0.05448042 |
| | 61 | 146 | | 24 | 0.04489539 |
| | 61 | 147 | | 25 | 0.03531037 |
| Sm | 62 | 144 | 3.083 | 20 | 0.08774263 |
| | 62 | 147 | 15.017 | 23 | 0.05898756 |
| | 62 | 148 | 11.254 | 24 | 0.04940254 |
| | 62 | 149 | 13.83 | 25 | 0.03981751 |
| | 62 | 150 | 7.351 | 26 | 0.03023249 |
| | 62 | 152 | 26.735 | 28 | 0.01106244 |
| | 62 | 154 | 22.73 | 30 | -0.00810761 |

| | | | | | |
|---|---|---|---|---|---|
| Eu | 63 | 151 | 47.81 | 25 | 0.04432466 |
| | 63 | 153 | 52.19 | 27 | 0.02515461 |
| Gd | 64 | 152 | 0.2 | 24 | 0.05841683 |
| | 64 | 154 | 2.18 | 26 | 0.03924678 |
| | 64 | 155 | 14.8 | 27 | 0.02966176 |
| | 64 | 156 | 20.47 | 28 | 0.02007674 |
| | 64 | 158 | 24.84 | 30 | 0.00090669 |
| | 64 | 160 | 21.86 | 32 | -0.01826336 |
| Tb | 65 | 159 | 100 | 29 | 0.01499886 |
| Dy | 66 | 156 | 0.056 | 24 | 0.06743113 |
| | 66 | 158 | 0.095 | 26 | 0.04826108 |
| | 66 | 160 | 2.329 | 28 | 0.02909103 |
| | 66 | 161 | 18.889 | 29 | 0.01950601 |
| | 66 | 162 | 25.475 | 30 | 0.00992098 |
| | 66 | 163 | 24.896 | 31 | 0.00033596 |
| | 66 | 164 | 28.26 | 32 | -0.00924907 |
| Ho | 67 | 165 | 100 | 31 | 0.00484311 |
| Er | 68 | 162 | 0.139 | 26 | 0.05727537 |
| | 68 | 164 | 1.601 | 28 | 0.03810532 |
| | 68 | 166 | 33.503 | 30 | 0.01893528 |
| | 68 | 167 | 22.869 | 31 | 0.00935025 |
| | 68 | 168 | 26.978 | 32 | -0.00023477 |
| | 68 | 170 | 14.91 | 34 | -0.01940482 |
| Tm | 69 | 169 | 100 | 31 | 0.01385740 |
| Yb | 70 | 168 | 0.13 | 28 | 0.04711962 |
| | 70 | 170 | 3.04 | 30 | 0.02794957 |
| | 70 | 171 | 14.28 | 31 | 0.01836455 |
| | 70 | 172 | 21.83 | 32 | 0.00877952 |
| | 70 | 173 | 16.13 | 33 | -0.00080550 |
| | 70 | 174 | 31.83 | 34 | -0.01039053 |
| | 70 | 176 | 12.76 | 36 | -0.02956057 |
| Lu | 71 | 175 | 97.41 | 33 | 0.00370165 |
| | 71 | 176 | 2.59 | 34 | -0.00588338 |
| Hf | 72 | 174 | 0.16 | 30 | 0.03696386 |
| | 72 | 176 | 5.26 | 32 | 0.01779382 |
| | 72 | 177 | 18.6 | 33 | 0.00820879 |
| | 72 | 178 | 27.28 | 34 | -0.00137623 |
| | 72 | 179 | 13.62 | 35 | -0.01096126 |
| | 72 | 180 | 35.08 | 36 | -0.02054628 |
| Ta | 73 | 180 | 0.01 | 34 | 0.00313092 |
| | 73 | 181 | 99.988 | 35 | -0.00645411 |
| W | 74 | 180 | 0.12 | 32 | 0.02680811 |
| | 74 | 182 | 26.5 | 34 | 0.00763806 |

| | | | | | |
|---|---|---|---|---|---|
| | 72 | 179 | 13.62 | 35 | -0.01096126 |
| | 72 | 180 | 35.08 | 36 | -0.02054628 |
| Ta | 73 | 180 | 0.01 | 34 | 0.00313092 |
| | 73 | 181 | 99.988 | 35 | -0.00645411 |
| W | 74 | 180 | 0.12 | 32 | 0.02680811 |
| | 74 | 182 | 26.5 | 34 | 0.00763806 |
| | 74 | 183 | 14.31 | 35 | -0.00194696 |
| | 74 | 184 | 30.64 | 36 | -0.01153199 |
| | 74 | 186 | 28.43 | 38 | -0.03070203 |
| Re | 75 | 185 | 37.4 | 35 | 0.00256019 |
| | 75 | 187 | 62.6 | 37 | -0.01660986 |
| Os | 76 | 184 | 0.02 | 32 | 0.03582240 |
| | 76 | 186 | 1.59 | 34 | 0.01665236 |
| | 76 | 187 | 1.96 | 35 | 0.00706733 |
| | 76 | 188 | 13.24 | 36 | -0.00251769 |
| | 76 | 189 | 16.15 | 37 | -0.01210272 |
| | 76 | 190 | 26.26 | 38 | -0.02168774 |
| | 76 | 192 | 40.78 | 40 | -0.04085779 |
| Ir | 77 | 191 | 37.3 | 37 | -0.00759557 |
| | 77 | 193 | 62.7 | 39 | -0.02676562 |
| Pt | 78 | 190 | 0.014 | 34 | 0.02566665 |
| | 78 | 192 | 0.782 | 36 | 0.00649660 |
| | 78 | 194 | 32.967 | 38 | -0.01267345 |
| | 78 | 195 | 33.832 | 39 | -0.02225847 |
| | 78 | 196 | 25.242 | 40 | -0.03184349 |
| | 78 | 198 | 7.163 | 42 | -0.05101354 |
| Au | 79 | 197 | 100 | 39 | -0.01775132 |
| Hg | 80 | 196 | 0.15 | 36 | 0.01551090 |
| | 80 | 198 | 9.97 | 38 | -0.00365915 |
| | 80 | 199 | 16.87 | 39 | -0.01324418 |
| | 80 | 200 | 23.101 | 40 | -0.02282920 |
| | 80 | 201 | 13.18 | 41 | -0.03241422 |
| | 80 | 202 | 29.86 | 42 | -0.04199925 |
| | 80 | 204 | 6.87 | 44 | -0.06116930 |
| Tl | 81 | 203 | 29.524 | 41 | -0.02790708 |
| | 81 | 205 | 70.476 | 43 | -0.04707712 |
| Pb | 82 | 204 | 1.4 | 40 | -0.01381491 |
| | 82 | 206 | 24.1 | 42 | -0.03298495 |

| | | | | | |
|---|---|---|---|---|---|
| | 82 | 207 | 22.1 | 43 | -0.04256998 |
| | 82 | 208 | 52.4 | 44 | -0.05215500 |
| Bi | 83 | 209 | 100 | 43 | -0.03806283 |
| Po | 84 | 208 | | 40 | -0.00480061 |
| | 84 | 209 | | 41 | -0.01438564 |
| At | 85 | 210 | | 40 | -0.00029346 |
| Rn | 86 | 211 | | 39 | 0.01379871 |
| Fr | 87 | 212 | | 38 | 0.02789088 |
| | 87 | 222 | | 48 | -0.06795936 |
| | 87 | 223 | | 49 | -0.07754439 |
| Ra | 88 | 226 | | 50 | -0.08262226 |
| | 88 | 228 | | 52 | -0.10179231 |
| Ac | 89 | 227 | | 49 | -0.06853009 |
| Th | 90 | 232 | | 52 | -0.09277802 |
| Pa | 91 | 231 | | 49 | -0.05951580 |
| | 91 | 233 | | 51 | -0.07868585 |
| U | 92 | 234 | 0.0054 | 50 | -0.06459368 |
| | 92 | 235 | 0.7204 | 51 | -0.07417870 |
| | 92 | 238 | 99.2742 | 54 | -0.10293377 |
| Np | 93 | 236 | | 50 | -0.06008653 |
| | 93 | 237 | | 51 | -0.06967155 |
| Pu | 94 | 238 | | 50 | -0.05557938 |
| | 94 | 239 | | 51 | -0.06516441 |
| | 94 | 240 | | 52 | -0.07474943 |
| | 94 | 241 | | 53 | -0.08433445 |
| | 94 | 242 | | 54 | -0.09391948 |
| | 94 | 244 | | 56 | -0.11308953 |
| Am | 95 | 241 | | 51 | -0.06065726 |
| | 95 | 243 | | 53 | -0.07982731 |
| Cm | 96 | 240 | | 48 | -0.02739504 |
| | 96 | 242 | | 50 | -0.04656509 |
| | 96 | 243 | | 51 | -0.05615011 |
| | 96 | 244 | | 52 | -0.06573514 |
| | 96 | 245 | | 53 | -0.07532016 |
| | 96 | 246 | | 54 | -0.08490518 |
| | 96 | 247 | | 55 | -0.09449021 |
| | 96 | 248 | | 56 | -0.10407523 |
| | 96 | 249 | | 57 | -0.11366026 |
| | 96 | 250 | | 58 | -0.12324528 |
| Bk | 97 | 247 | | 53 | -0.07081301 |
| | 97 | 249 | | 55 | -0.08998306 |
| Cf | 98 | 248 | | 52 | -0.05672084 |

| | | | | | |
|---|---|---|---|---|---|
| | 96 | 248 | | 56 | -0.10407523 |
| | 96 | 249 | | 57 | -0.11366026 |
| | 96 | 250 | | 58 | -0.12324528 |
| Bk | 97 | 247 | | 53 | -0.07081301 |
| | 97 | 249 | | 55 | -0.08998306 |
| Cf | 98 | 248 | | 52 | -0.05672084 |
| | 98 | 249 | | 53 | -0.06630587 |
| | 98 | 250 | | 54 | -0.07589089 |
| | 98 | 251 | | 55 | -0.08547591 |
| | 98 | 253 | | 57 | -0.10464596 |
| Es | 99 | 252 | | 54 | -0.07138374 |
| | 99 | 254 | | 56 | -0.09055379 |
| Fm | 100 | 252 | | 52 | -0.04770655 |
| | 100 | 254 | | 54 | -0.06687660 |
| | 100 | 257 | | 57 | -0.09563167 |

**Table I. Masses of Isotopes (u)**

**Table Notes**

1) All calculated and observed mass values are in u, rather than amu. The average ratio of calc/obs = .9998.

2) The mass defect for elements with atomic number < 10 is multiplied by 2/3 and subtracted in the M_A_calc_u column--so the mass defect column does not have the 2/3 factor for these elements.

3) Observed atomic mass values come from Ref. [5], pp. 11-56 to 11-209. This reference appears to be the most authoritative. But it's interesting to see the considerable differences between this source and, say, Ref. [6], among others. Ref. [5] says that $Fe^{56}$ has a mass of 55.934938 u, whereas Ref. [6] says it's 55.939395. The Reciprocal System calculation in the table is 55.903357, which is .9994 of the value from Ref. [5]. Ref. [5] is newer than Ref. [6], so the direction of the observations is toward the Reciprocal System value.

4) $O^{16}$ should be precisely 16 amu = 15.9949152 u. In the table, the value is calculated to be 16.010357 u. $C^{12}$ should, of course, be precisely 12 u, but in the table the value is calculated to be 12.007768 u. If this value is multiplied by .999353085 we would obtain the precise value, but then the average ratio of calc/obs for the isotopes tabulated would change to .9992. Regardless, the linear equation provided by the Reciprocal System is clearly a vast improvement over the bizarre nonlinear empirical equation provided by conventional theory.

The Appendix at the end of the paper provides the empirical proof that the level of the ambient neutrino flux is directly tied to isotopic mass.

## 2. Average Lifetimes and Half-Lives

Larson describes alpha radioactivity as follows (Ref. [7], p. 192):

"In an ordinary explosion, the action begins at one or more points in the aggregate and is propagated outward in space from these points at a high velocity. Each atom of the aggregate remains in its original state until the progress of the action reaches the location in space which this atom occupies, whereupon it suddenly disintegrates. The explosion as a hole therefore takes the form of a series of individual explosions at different locations in space initiated successively by an agency propagated through space at a finite velocity. In a radioactive explosion, the action begins at one or more points in the aggregate and is propagated outward in time from these points at a high inverse velocity (that is, slowly). Each atom of the aggregate remains in its original state until the progress of the action reaches the location in time which this atom occupies, whereupon it suddenly disintegrates. The explosion as a whole therefore takes the form of a series of individual explosions at different locations in time initiated successively by an agency propagated through time at a finite velocity. Aside from substituting time for space, this description of the radioactive explosion is identical with the preceding description of the ordinary explosion."

Because we do not know, *a priori*, the coordinate time locations of the atoms of a radioactive solid, we must make use of the probability relations to describe the situation. Any work on radioactivity (such as Ref. [8], pp. 79-80), includes these equations, which we'll summarize here. If, in a radioactive substance, there are N radioactive atoms present at time t, then the number of disintegrations per second (measured, say, by a Geiger counter) is expressed as

$$A := -\frac{d}{dt}N \qquad \text{disintegrations/sec}$$

or

$$A := \lambda \cdot N \qquad \text{disintegrations/sec}$$

where $\lambda$ is the radioactive decay constant, in $sec^{-1}$.

If at t = 0, there are $N_0$ atoms present, then the above equation can be solved for N:

$$N := N_0 \cdot e^{-\lambda \cdot t}$$

Likewise, if at t = 0 there are $A_0$ disintegrations per second, there will be

$$A := A_0 \cdot e^{-\lambda \cdot t} \qquad \text{disintegrations/sec}$$

at t. The average lifetime of an atom of the substance is then

$$\tau := \frac{1}{\lambda} \qquad \text{sec}$$

This is the theoretical time which we would like to determine. But the half-life is more commonly used, and it's actually a "group" phenomenon. The half-life is the time required to reduce the amount of radioactive material by a factor of 2. Thus

$$\frac{A}{A_0} := \frac{1}{2}$$

$$\frac{1}{2} := e^{-\lambda \cdot t_{.5}}$$

$$t_{.5} := \frac{\ln(2)}{\lambda} \qquad t_{.5} := \frac{.693}{\lambda}$$

Most of the radioactivity tables in the scientific literature list half-lives, rather than average lifetimes. Therefore it's necessary to multiply these values by 1.443 to obtain the average lifetime, which is the real theoretical quantity.

$$\tau := \frac{t_{.5}}{.693} \qquad \tau := 1.443 \cdot t_{.5}$$

Many attempts have been made to calculate the half-life of the radioactive atoms, but none have truly succeeded. Ref. [9] gives a good review of the attempts to find an empirical equation; the authors themselves come up with this:

$$\log\left(t_{.5}\right) := 1.5372 \cdot Z \cdot Q_{\alpha}^{-.5} - .1607 \cdot Z - 36.573$$

where $Q_{\alpha}$ is the energy of the emitted alpha particle, in MeV. The CRC Handbook, Ref. [5], p. 11-56, gives the Heisenberg approximation:

$$t_{.5} := \frac{4.56 \cdot 10^{22}}{\Gamma\left(Q_{\alpha}\right)} \qquad \text{sec}$$

Neither of these relations work very well, as can be proved by doing a few spot checks.

Alpha radioactivity involves the emission of an alpha particle, so the first step in a Reciprocal System calculation is to determine the value of the secondary mass changed to energy; the primary mass is conserved. The secondary mass of the helium atom is (from Eq. (26c)):

$$m_{s\_He} := .001930186 \cdot 2 \qquad m_{s\_He} = 0.003860372 \quad \text{u}$$

The change in the secondary mass from the parent atom (atomic number Z) to the daugher atom (atomic number Z - 2) is (from Eq. (26b)):

$$delta\_m_{s} := (.004507147 \cdot Z - .009585024 \cdot G) - [.004507147 \cdot (Z - 2) - .00958024 \cdot G] - m_{s\_He} \qquad (27a)$$

The Z's and G's cancel, which leaves

$$delta\_m_{s} := .004507147 \cdot 2 - m_{s\_He} \qquad delta\_m_{s} = 0.005153922 \quad \text{u} \qquad (27b)$$

Converting to energy, we have

$$conv_{u\_to\_MeV} := 931.494061$$

$$Q_S := delta\_m_S \cdot conv_{u\_to\_MeV} \qquad Q_S = 4.800847734 \quad \text{MeV} \qquad (27c)$$

This should be the energy of the emitted alpha particle. But: the empirical data show that for various isotopes the energy ranges from 2 MeV to 8 MeV, so the calculation gives us a value in the middle of the range. Some other factor must be involved, and it seems clear that the magnetically-charged neutrinos entrained within the substance can provide both an energy source or sink, as necessary. The energy of the daughter atom will be neglected in the following analysis.

In any Reciprocal System expression involving time, the natural unit of time, $t_u$, must be used.

$$t_u := 1.520655 \cdot 10^{-16} \quad \text{sec}$$

This will necessarily prefix the equation for $\tau$. Also: the greater the rotational mass of the isotope, 2Z, the longer the average lifetime; but the greater the number of isotopic charges, G, the shorter the average lifetime. And: given that average lifetimes can range over more than 14 orders of magnitude, there is no doubt that an exponential equation is necessary. The correct natural unit value of energy to use as divisor is that found from two atomic electric time units and two atomic electric charge units--the essential composition of an alpha particle:

$$Q_u := \left(2 \cdot E_u + 2 \cdot C_u\right) \cdot conv_{u\_to\_MeV} \qquad Q_u = 1.700366946 \quad \text{MeV} \qquad (28)$$

Putting all this together, we have

$$\tau := t_u \cdot e^{\left[\left[\frac{2\cdot Z}{\left(\frac{Q_S+G\cdot x}{Q_u}\right)^{\frac{1}{2}}}-G\right]\right]^{\blacksquare}} \quad \text{sec} \tag{29}$$

x is the value of the unknown amount of energy supplied to the alpha particle by each of the entrained magnetically-charged neutrinos. Normally these neutrinos are moving at speed c, just like uncharged electrons, in all directions (randomly). And just as energy may be imparted to or taken from the electrons, energy may be imparted to or taken from the neutrinos--but currently we do not have a theoretical expression for the amount available. If $\tau$ is known experimentally, then x may be calculated, as follows (in function format):

$$x(Z, G, Q_S, \tau) := \frac{-Q_S\cdot G^2 - 2\cdot Q_S\cdot G\cdot \ln\left(\frac{\tau}{t_u}\right) - Q_S\cdot \ln\left(\frac{\tau}{t_u}\right)^2 + 4\cdot Z^2\cdot Q_u}{G\cdot\left(G^2 + 2\cdot G\cdot \ln\left(\frac{\tau}{t_u}\right) + \ln\left(\frac{\tau}{t_u}\right)^2\right)} \tag{30}$$

The value of $Q_s + G\cdot x$ may then be compared with the observed decay energy (which is slightly more than the alpha particle energy).

For Po, Z = 84, and G ranging from 42 to 50, we have the following calculations for x (using $t_{.5}$ data from Ref. [5]):

$Z := 84$

| average lifetime | isotopic charge | MeV per neutrino | Calculated Q | $Q_{obs}$ |
|---|---|---|---|---|
| $\tau := 1.195776\cdot 10^{7}\cdot 1.443$ | $G := 42$ | $x(Z, G, Q_S, \tau) = 0.012074661$ | $Q_S + G\cdot .0121 = 5.309047734$ | 5.407 |
| $\tau := .516\cdot 1.443$ | $G := 43$ | $x(Z, G, Q_S, \tau) = 0.066606718$ | $Q_S + G\cdot .0666 = 7.664647734$ | 7.594 |
| $\tau := .298\cdot 10^{-6}\cdot 1.443$ | $G := 44$ | $x(Z, G, Q_S, \tau) = 0.143091702$ | $Q_S + G\cdot .1431 = 11.097247734$ | 8.953 |
| $\tau := 3.7\cdot 10^{-6}\cdot 1.443$ | $G := 45$ | $x(Z, G, Q_S, \tau) = 0.115497478$ | $Q_S + G\cdot .1155 = 9.998347734$ | 8.537 |
| $\tau := 163.6\cdot 10^{-6}\cdot 1.443$ | $G := 46$ | $x(Z, G, Q_S, \tau) = 0.08578913$ | $Q_S + G\cdot .0858 = 8.747647734$ | 7.833 |
| $\tau := 1.780\cdot 10^{-3}\cdot 1.443$ | $G := 47$ | $x(Z, G, Q_S, \tau) = 0.068043902$ | $Q_S + G\cdot .0680 = 7.996847734$ | 7.526 |
| $\tau := .145\cdot 1.443$ | $G := 48$ | $x(Z, G, Q_S, \tau) = 0.045612689$ | $Q_S + G\cdot .0456 = 6.989647734$ | 6.906 |
| $\tau := 1.53\cdot 1.443$ | $G := 49$ | $x(Z, G, Q_S, \tau) = 0.033790743$ | $Q_S + G\cdot .0338 = 6.457047734$ | 6.662 |
| $\tau := 182.4\cdot 1.443$ | $G := 50$ | $x(Z, G, Q_S, \tau) = 0.017395665$ | $Q_S + G\cdot .0174 = 5.670847734$ | 6.114 |

($Q_{obs}$ is the observed total decay energy, in MeV; it is slightly more than the observed $\alpha$-energy.) The Reciprocal System Data Base will allow the user to enter the value of G (and of course already has Z) for any isotope; knowing $\tau$ or $t_{.5}$, one can obtain the required neutrino energy to obtain that time. Eventually, of course, we will be able to figure out the value of x theoretically and so will have a precise method to calculate $\tau$ and $t_{.5}$. That the calculated Q are close to $Q_{obs}$ provides an *indirect* proof of the validity of Eq. (29). Other isotopic series have similar results. Energy interchanges with the ambient neutrino flux bring the energy of the entrained magnetically-charged neutrinos back to the normal value for the daughter isotope.

## Conclusion

From the principles of the Reciprocal System, the mass of the subatoms and the mass of numerous isotopes of the elements are computed and compared to observation, with good agreement. The masses, mass defects, and secondary masses are all computed using *linear* equations. Primary mass is conserved in radioactive transformations, but secondary mass may be converted to energy. A new equation for average lifetime of a radioactive atom, and thus the half-life of a radioactive substance, is derived and applied to the Po series of isotopes; other series are similar. Agreement of theory to experiment is shown to be good.

## Acknowledgements

Funding for this work came from Transpower Corporation, not the government!. Of course, great thanks go to Dewey B. Larson, who served as my theoretical physics mentor from 1965 until his death in 1990. He was, by far, the most intelligent and most logical of any individual I've ever known.

## References

[1] D. Larson, *The Structure of the Physical Universe* (Portland, OR: North Pacific Publishers, 1959); *Nothing But Motion* (Portland, OR: North Pacific Publishers, 1979). The latter is Volume I of the 2nd ed. of *The Structure of the Physical Universe*.

[2] H. Young, R. Freedman, *Sears and Zemansky's University Physics*, Vol. 3, 11th ed. (San Francisco, CA: Pearson, Addison-Wesley, 2004).

[3] R. Satz, "Further Mathematics of the Reciprocal System," *Reciprocity*, Vol. X, No. 3, Autumn 1980.

[4] D. Larson, *Basic Properties of Matter* (Salt Lake City, UT: International Society of Unified Science, 1988). This is Volume II of the revised and enlarged *The Structure of the Physical Universe*.

[5] D. Lide, ed., *CRC Handbook of Chemistry and Physics*, *88th ed*. (Boca Raton, FL: CRC Press, 2008).

[6] R. Gautreau, W. Savin, *Theory and Problems of Modern Physics* (New York, NY: McGraw-Hill Book Company, 1978).

[7] D. Larson, *New Light on Space and Time* (Portland, OR: North Pacific Publishers, 1965).

[8] G. Choppin, J. Liljenzin, J. Rydberg, *Radiochemistry and Nuclear Chemistry*, 3rd ed. (Oxford, UK: Butterworth-Heinemann, 2002).

[9] A. Parkhomenko, A. Sobiczewski, "Phenomenological Formula for $\alpha$-Decay Half-Lives of Heaviest Nuclei," *Acta Physica Polonia B*, Vol. 36, No. 10, 2005.

## Appendix: Observational Evidence of the Relationship of Neutrinos to Isotopes

Davide Castelvecchi, *Science News,* 09 November 2008

Physicists are stirred by claims that the sun may change what's unchangeable - the rate of radioactive decay It's nuclear physics 101: Radioactivity proceeds at its own pace. Each type of radioactive isotope, be it plutonium-238 or carbon-14, changes into another isotope or element at a specific, universal, immutable rate. This much has been known for more than a century, since Ernest Rutherford defined the notion of half-life--the time it takes for half of the atoms in a radioactive sample to transmute into something else. So when researchers suggested in August that the sun causes variations in the decay rates of isotopes of silicon, chlorine, radium and manganese, the physics community reacted with curiosity, but mostly with skepticism.

Physicists have responded with curiosity and skepticism to reports that the sun causes variations in the decay rates of some isotopes.In one experiment, a team at Purdue University in West Lafayette, Ind., was monitoring a chunk of manganese-54 inside a radiation detector box to precisely measure the isotope's half-life. At 9:37 p.m. on December 12, 2006, the instruments recorded a dip in radioactivity. At the same time, satellites on the day side of the Earth detected X-rays coming from the sun, signaling the beginning of a solar flare. The sun's atmosphere was spewing out matter, some of which would reach Earth the day after. Charged particles would contort the planet's magnetic field, disrupt satellite communications and pose a threat to astronauts on the International Space Station. But that dip in the manganese-54 radioactivity was not a coincidental experimental fluke, nor was it the solar flare discombobulating the measurements, the Purdue researchers claim in a paper posted online (arxiv.org/abs/0808.3156). In West Lafayette the sun had set while X-rays were hitting the atmosphere on the other side of the globe, and the electrically charged matter that created electromagnetic disturbances worldwide was still in transit. After a solar flare has begun, "the charged particles arrive several hours later," points out theorist Ephraim Fischbach, coauthor of the paper with his Purdue colleague Jere Jenkins. In a separate paper, also posted online in August, Fischbach, Jenkins and their collaborators compared puzzling and still unexplained results from two separate experiments from the 1980s - one on silicon-32 at the Brookhaven National Laboratory in Upton, N.Y., and the other on radium-226 done at the PTB, an institute that sets measurement standards for the German federal government. Both experiments had lasted several years, and both had seen seasonal variations of a few tenths of a percent in the decay rates of the respective isotopes.

A change of less than a percent may not sound like a lot. But if the change is real, rather than an anomaly in the detector, it would challenge the entire concept of half-life and even force physicists to rewrite their nuclear physics textbooks. In those experiments, the decay rate changes may have been related to Earth's orbit around the sun, the Purdue team says. In the Northern Hemisphere, Earth is closer to the sun in the winter than in the summer. So the sun may have been affecting the rate of decay, possibly through some physical mechanism that had never before been observed. For example, the researchers say, the sun constantly emits neutrinos, subatomic particles produced in the nuclear reactions that power the sun. Neutrinos can move through the entire planet without being stopped, so the sun could affect radioactivity day and night. The closer to the sun, the denser the shower of neutrinos. Or the sun may emit fewer neutrinos during a solar flare, which would explain the December 2006 event. Most physicists are dubious. For one thing, neutrinos interact negligibly with matter, so it's not clear how they would affect radioactivity. But some physicists take the results seriously and are searching old data for previously unnoticed effects. If the variations turn out to be genuine, theories may need revision, or new theories may be needed. "There's no known theory that will predict something like this," says theoretical physicist Rabindra Mohapatra of the University of Maryland in College Park.

[Yes, there is:  the Reciprocal System!  There can be minor fluctuations in the magnetic ionization flux of the neutrinos.]

If the results are confirmed, and nuclear decay is not immutable, perhaps physicists could find a way to speed it up to help get rid of waste from nuclear power plants. Such results might revise models of what goes on in the sun or change understanding of phenomena such as supernovas. Since neutrinos travel much faster than dangerous charged particles, using radioactive samples to detect solar flares when they first begin could prevent damage to satellites--and perhaps even save lives of astronauts. Some atomic nuclei are unstable, either because they are too big or they don't have the right balance of protons and neutrons. Unstable nuclei decay by releasing different kinds of radiation, including energetic subatomic particles. For example, in beta radiation an excess neutron turns into a proton and spews out an electron--a beta particle--and an antineutrino. With an additional proton, the nucleus transmutes into a different element. If a nuclide--a particular isotope of a given element--has a half-life of, say, one year, then after one year there will be half of it left. All atoms of a given nuclide are identical, and a one-year half-life means that each nucleus has a 50 percent chance of decaying over one year. If it doesn't decay this year, it won't be any more likely to decay next year - the odds will still be 50-50. Half-lives are universal constants, as any physics textbook can attest. "Since Rutherford we've taken it as [a given] that decay rates are the way they are and nothing can change them," Jenkins says.

PTB data for radium-226 and Earth-sun distance.Researchers use radioactive materials in a wide variety of applications where it's useful to know the half-life with decent precision - the classic example being carbon-14, used in carbon dating of fossils. Usually, the half-life of a nuclide is measured in experiments that last just days or weeks. But for certain nuclides longer measurements are needed. Between 1982 and 1986, a team led by David Alburger of Brookhaven monitored the radioactivity of silicon-32. The isotope's half-life was known to be at least 60 years, so researchers needed a long time to measure it with any precision. At the same time, the team monitored a chlorine-36 sample. Chlorine-36 has a half-life of more than 300,000 years, so a sample's radioactivity stays virtually unchanged for a long time and can be used to spot any spurious fluctuations. To their surprise, the researchers found that both samples had rates of decay that varied with the seasons, by about 0.3 percent. The samples were kept at constant temperature and humidity, so the changing seasons should have had no effect on the experiment. The team tried all the fixes it could to get rid of the fluctuations, but, in the end, decided to publish the results. No other lab tried to repeat the experiment, and the anomaly remained unexplained. "People just sort of forgot about it, I guess," says Alburger, who retired shortly after the results came out. Unbeknownst to Alburger, researchers at PTB in Germany had also found yearly oscillations in a decay rate, in a 15-year experiment on radium-226. (Two of those years overlapped with the Brookhaven experiment.) Now Fischbach and his collaborators' comparison shows that the oscillations are in sync. Well, almost: Mysteriously, the peaks and troughs of the two oscillations seem shifted with respect to each other, by about a month. Alburger says that the correlation between the patterns seen in his team's data and the PTB's is very convincing. "What causes it is the real question," one that nuclear physicists should now look into, he says. Mohapatra agrees that the effect looks genuine. But, he warns, genuine-looking effects are often later revealed as statistical flukes or the result of subtle defects in measuring technique. Still, he adds, "it's interesting enough that people in the nuclear field should go back and look at old data." Take two Peter Cooper of the Fermi National Accelerator Laboratory in Batavia, Ill., recently did just that. He obtained and analyzed data from the Cassini mission to Saturn. Deep-space probes usually generate power from the heat emitted by a chunk of radioactive material - plutonium-238 for the Cassini spacecraft. Cassini journeyed as close to the sun as Venus and then far back to Saturn, spanning a much wider range of distances from the sun than Earth does during its yearly orbit. If the sun had an effect on plutonium decay, the fluctuations would have been much more substantial than those seen in Earth-bound experiments. As a result, Cooper reasoned, Cassini should have measured substantial changes in its generator's output. It didn't. (His paper is posted online at arxiv.org/abs/0809.4248.) Meanwhile, Eric Norman of the Lawrence Berkeley National Laboratory in California reanalyzed data from experiments on radioactive americium, barium, silver, titanium and tin, and found no seasonal variations, he says. Fischbach is unfazed. Each nuclide, he notes, requires a different amount of energy to be nudged into decaying, and that the type of decay - be it alpha, beta or gamma radiation - may also play a role. "It's possible that plutonium is inherently less sensitive than radium," he says. More recently, Fischbach found what he says is more evidence for his case. Exhibit A: An experiment on tritium, a radioactive isotope of hydrogen, which his collaborators are running at Purdue, may be measuring a seasonal effect, he says. Exhibit B: A 1990 paper by Kenneth Ellis of Baylor College of Medicine in Houston reported seasonal variations in plutonium-238 radioactivity in a calibration experiment for a radiotherapy machine. But Fischbach, Jenkins and their colleagues have a lot of convincing to do, says Hamish Robertson of the University of Washington in Seattle. "There's no physical basis for the decay rates to vary with anything, let alone with the Earth-sun distance," he says. Neutrinos in particular seem a very unlikely explanation to most physicists. Neutrinos only interact via the weak nuclear force, which has very short range, points out Boris Kayser, a neutrino theorist at Fermilab. And ordinary matter is mostly empty space. So detecting neutrinos is notoriously hard, Kayser explains. "Unless the detector is very big, so that it gives the neutrino many chances to come close to one of its particles, the neutrino will just go sailing right through it." Fischbach, though, says that perhaps neutrinos have a small electromagnetic interaction. While they have no electric charge, neutrinos carry a magnetic field. Instead of one neutrino giving a rare kick to one nucleus, a single neutrino could be giving "a small electromagnetic kick to a lot of nuclei," potentially tipping the unstable ones into decaying. Fischbach admits that he hasn't finished calculations to show that this would be possible. The Purdue scientists are planning more experiments. In the end, the burden of proof will be on them, Cooper says. "Every experimentalist knows that the apparatus, or at least your understanding of it, is always at fault until demonstrated otherwise," he says. It's likely that seasonal weather caused the anomalies, he says, but admits that future work could prove him wrong. "Nature is really unmoved by what I, or anyone else, believes."