UNIVERSITY OF GEORGIA
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Tree Essential Elements Manual (Part 1)

(element genesis, organization & essentiality)

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Scope & Disclaimer: This training manual is part 1 of a three part educational product designed for helping tree health care professionals appreciate and understand essential element requirements in trees. This manual is a synthesis and integration of current research and educational concepts regarding how trees utilize different essential elements and how diagnosis of essential element problems can be difficult. This educational product is for awareness building and professional development. This product does not present tree essential element fertilization processes or product formulations. This is not a tree health care fertilization standard.

At the time it was finished, this training manual contained educational models concerning tree essential elements thought by the author to provide the best means for considering fundamental tree health care issues surrounding essential element use, deficiencies and toxicities. The University of Georgia, the Warnell School of Forestry & Natural Resources, and the author are not responsible for any errors, omissions, misinterpretations, or misapplications from this educational product. The author assumed professional users would have some basic tree and soil background. This manual was not designed, nor is suited, for homeowner use. Always seek advice and assistance of professional tree health care providers.

 This manual is a revision and correction of previous publications of the same name and by the same author published in May of 2011, July of 2012, and March 2017.

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Introduction

Life on Earth is a function of water, geology, atmosphere, and genetics. Life extracts materials in many forms from the Earth system and generates more complex materials using energy derived from chemical transformations and sunlight. Past and current success in material accumulation and concentration, plus failure of any life-generated materials to be instantly decomposed, provide the basis for many trophic levels of life to exist. The foundation of Earth's ecology rests primarily with sunlight-capturing and material-extracting green plants.

Green plants use fabricated organic materials, with associated inorganic elements, to capture light within narrow wavelength windows. This light energy is momentarily held within specialized compounds which allow time for chemical reactions to transfer energy away into other materials. These energy dense materials help generate a series of mass and energy exchanges, and build and maintain concentration gradients within biological membranes. Energy extracted from light is used to perform work in a cell, and is transported on organic compounds to other cells within an organism. Trees do all of this energy capture and organic building, plus transport materials long distances and live many years.

Components

Eighty percent (80%) of all materials in a living tree is water taken from soil, with minute amounts taken directly from the atmosphere and precipitation. Of the remaining materials seen as a tree, roughly 19% are three elements derived from water and carbon-dioxide gas. These elements (i.e. carbon (C), hydrogen (H), and oxygen (O)), are chemically combined and boosted to a higher energy level (i.e. reduced) and visible as all tree parts. The remaining ~1% of tree material is composed of essential elements removed from soil, although small amounts of some essential elements (i.e. sulfur (S) and chlorine (Cl)) can be extracted from the atmosphere. Figure 1.

The sunlight powered synthesis process of a tree leads to other organisms consuming tree materials in some form, whether herbivores, parasites, scavengers, or symbionts. All organisms deriving life energy from this process generate waste, shed parts, and die. Synthesized materials outside living membranes decompose into simpler components, finally releasing all essential elements to the environment. These essential elements are usually reprocessed by other local organisms, chemically held within the soil, or eroded / leached away from the site.

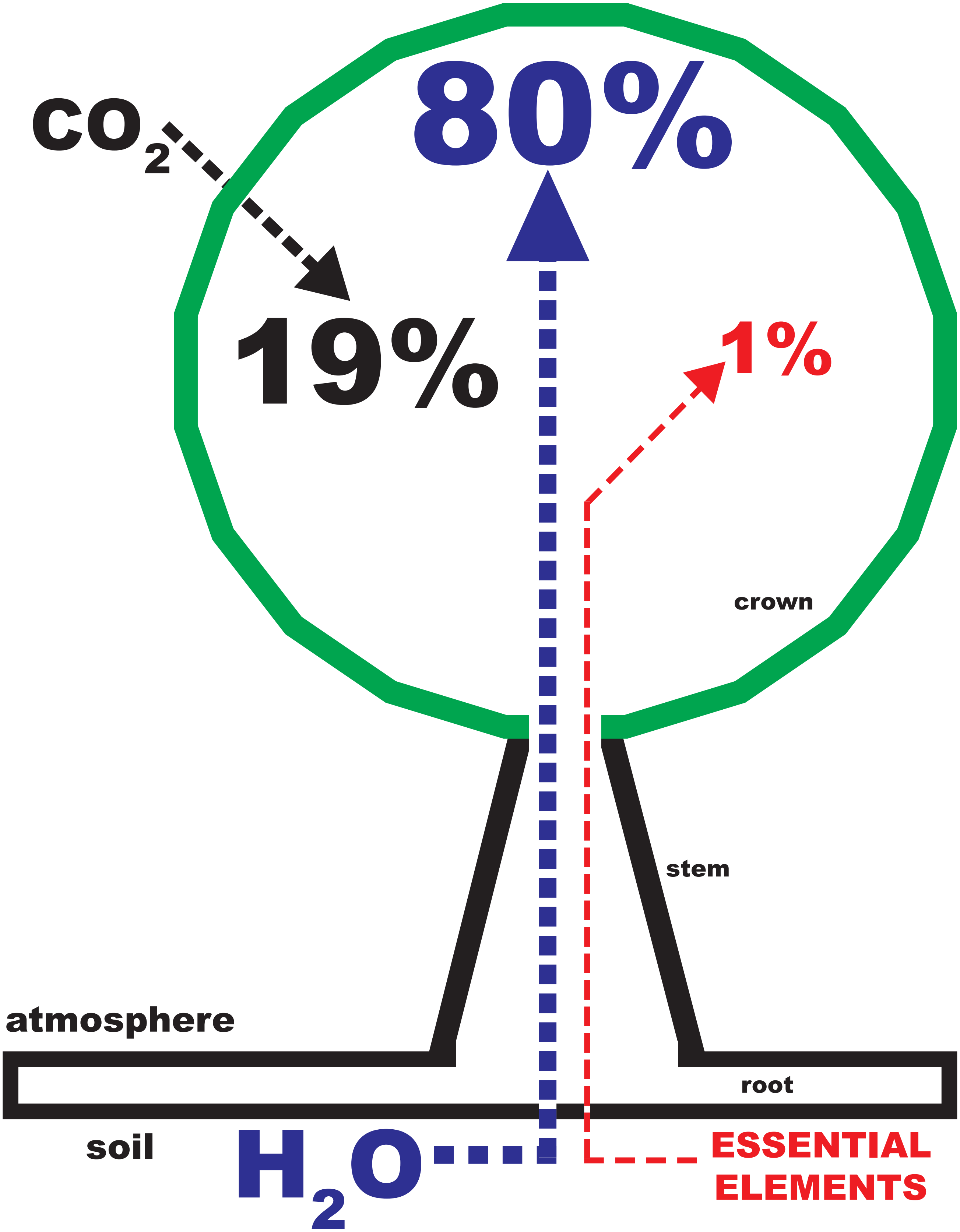


Figure 1: General sources of tree life materials.

Launching Tree Life

Trees utilize 19 elements for life processes. Many more elements can be found inside a tree, but their concentrations are related to their concentrations in the environment. Figure 2. A tree mirrors site resource quality, and element quantity, of any site upon which it grows. Elements essential for tree life are varied in chemistry and provide diverse biochemical services within a tree. Some are used in only one or two processes (i.e. molybdenum (Mo)), while others are used to swaddle everything else (i.e. potassium (K)) within a water bath.

Figure 3 shows the generic structural and biological roles essential elements play in a tree. Understanding tree essential elements help tree health care providers better manage trees and sites. Defining what is meant by an "element" and an "essential element" is a key first step to better tree health care.

Not Nutrient!

It is critical in discussing tree essential elements to place clear definitions around traditional terms sometimes mistakenly used. Failure to maintain definitional discipline generates useless jargon and can lead to mistakes. The first definitional error can occur around the term "nutrient." A tree nutrient is a compound with potential chemical energy associated within its chemical bonds, and can be used by a tree for transferring energy and / or building structural materials. For example, sugars are nutrients while nitrogen atoms are essential elements and not nutrients. The word "nutrient" has become jargon because of its highly variable and broadly defined applications under many different contexts, leading to continually imprecise and inaccurate usage.

Elemental

A tree "element" is any natural element found within a tree and its rhizosphere, or found on tree surfaces. An element is a basic unit of matter with a carefully defined number of nucleus protons, associated with various nucleus neutrons, both encased within various quantum shells of electrons. Each element is represented by a name, symbol, atomic number (number of protons), and atomic weight (number of protons plus neutrons). For example, Figure 4 provides a simple traditional view of a carbon atom.

Various elements in trees represent the concentration of an element within the environment, or may be accumulated out of equilibrium with the general environment and soil, within both tree apoplast and symplast. As many as 90 elements have been found in trees. Most serve no identifiable role in supporting tree life. Elements in trees are the result of absorption, deposition, accumulation, pollution, poisoning, or chance. Some elements are included in critical parts of biological and structural components, and as part of living processes, within a tree. Many elements are simply present in a tree as a result of where a tree grows.

Essential!

A tree "essential element" is required for normal tree growth and reproduction over many years, and cannot be completely substituted for by another element. An element is essential if when the element is unavailable or not present, a tree:

element symbol	element name
B	boron
C	carbon
Ca	calcium
Cl	clorine
Co	cobalt
Cu	copper
Fe	iron
H	hydrogen
K	potassium
Mg	magnesium
Mn	manganese
Mo	molybdinum
N	nitrogen
Ni	nickel
O	oxygen
P	phosphorus
S	sulfur
Si	silicon
Zn	zinc

19 tree essential elements

(+ water)

Figure 2: Elements essential for sustaining tree life processes in alphabetical order. All these elements are transported and utilized in a tree within a water bath.

Structural support
B, Ca, Fe, Si

Bound in small molecules
B, Cu, Co, Fe, Si

Bound in large molecules / compounds / enzymes
Co, Cu, Fe, Mn, Mo, Ni, Zn

Concentrated in cell organelles & enzyme systems
Cu, Fe, Mn, Mo, Zn

Figure 3: Tree essential element general roles.
(from Kabata-Pendias 2011)

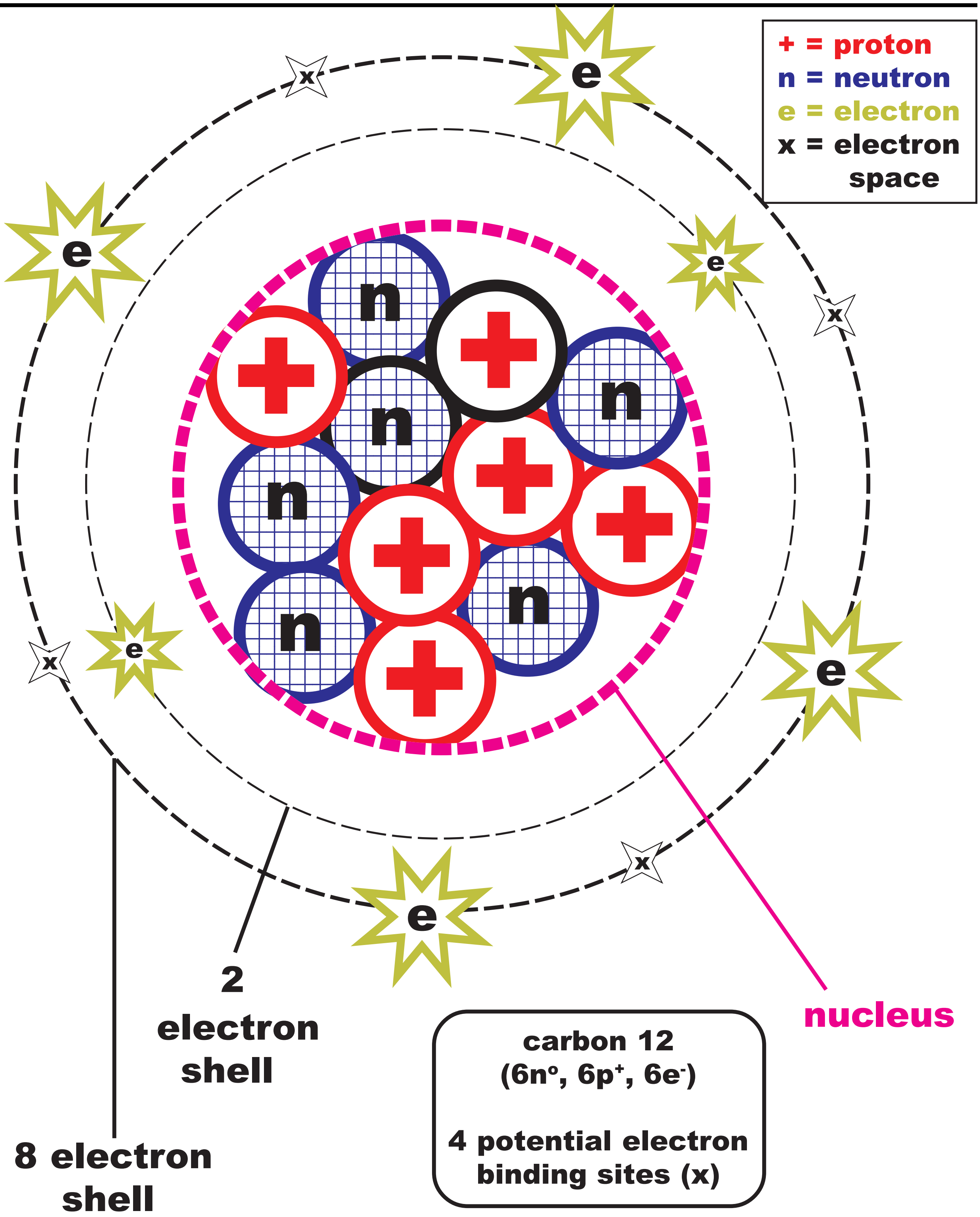


Figure 4: Diagrammatic view of a carbon (^{12}C) atom.

1) dies;
2) shows severe deficiency symptoms restricting growth, survival, and defense; or,
3) exhibits a stunted or abnormal appearance.

Some essential elements can be partially or temporarily substituted for in different metabolic or structural roles. For example, manganese (Mn) can partially substitute for both iron (Fe) and magnesium (Mg) in some enzymes and process steps over the short run, but not in all process steps all the time. Another example of partial substitution of elements is the use of nonessential sodium ions (Na^+) for essential potassium ions (K^+).

Proving Essential

There is great scientific debate and continued testing to identify essential elements in trees. There are more tree essential elements to discover. Tree essentiality is determined by carefully withholding an element (and all environmental contamination of the element) from a tree and assessing its growth. Figure 5 provides how essential elements and nonessential elements are tracked. One curve suggests essentiality by constraining tree growth when not present and one curve shows normal accumulation reaching toxicity as in any nonessential element.

Discovery of tree essential elements can be difficult. Some tree essential elements required in significant amounts were not discovered as essential until the mid 1900's (i.e. 1954, chlorine (Cl)). Others are needed in such small amounts, like nickel (Ni), its essentiality was not determined in trees until relatively recently (i.e. 1987). A few elements are essential in some other plant forms (i.e. sodium (Na) in C4 photosynthetic plants and selenium (Se) in desert plants). Plant nutritionists consider some elements as beneficial if plant growth and reproducton are enhanced. These elements have not passed all the tests of essentiallity yet. For example, silicon (Si) is considered by some plant nutritionists as beneficial in trees, but not essential.

Near Essential

Figure 6 lists additional elements suspected (but not proven) to be beneficial or essential in trees. All elements listed are beneficial or essential in some type of plant in some form. Research continues to understand which elements are nonessential, essential, beneficial, or detrimental specifically to trees. Some researchers examine elements essential in animals as being candidates for plant essentiality, (Figure 7) suggesting all life has a similar element palatte. There remains a strong divergence between animal and plant element essentiallity. For example, boron (B) and silicon (Si) are essential in plants but not in animals. Some elements may be essential in minute amounts, but any more than bare minimum may be toxic, like aluminum (Al), arsenic (As), fluorine (F), iodine (I), or platinum (Pt).

Some elements may be needed in such small amounts, environmental concentrations mask essentiality. For example, vanadium (V) is suspected of being an essential element in trees. Vanadium is used in the photosynthetic process, phospholipid maintenance and nitrogen processing (especially in legume tree nitrogen fixation). The difficulty in determining essentiality of vanadium is its requirement in a tree would be about 2 parts per billion, while its presence in the environment and its passive uptake into a tree, is about 1 part per million (i.e. 2,000 times more is available than is potentially required). Because vanadium can partially substitute for molybdenum (Mo), it is difficult to conclusively state vanadium is essential, beneficial, or non-essential in trees.

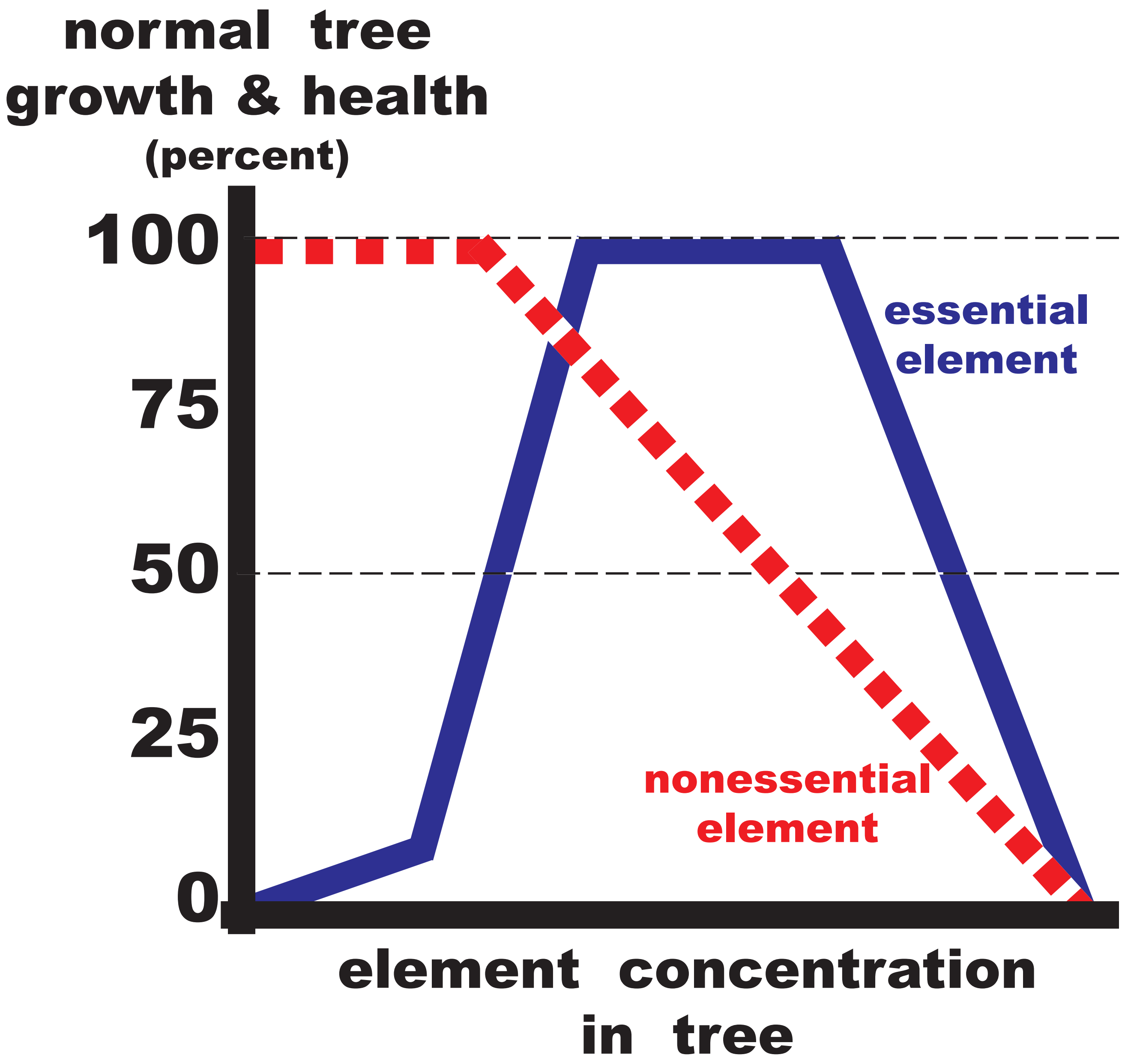


Figure 5: Tree response to increasing essential and nonessential element concentrations.

Ag	**silver**	**blocks ethylene production, modifies flower production**
Al	**aluminium**	**improves growth, minimizes P, Cu, Zn, Fe toxicity, traces in DNA / RNA, increases antioxident exzymes, enzyme activation**
As	**arsenic[1]**	**phospholipids, CHO metabolism**
Br	**bromine[1]**	**bromophenols**
Ce	**cerium**	**rare earth -- improves growth**
F	**fluorine**	**citrate conversion, fluoroacetate, carbon chain transposing**
I	**iodine[1]**	**stimulates cellulose and lignin generation, ascorbic acid formation, tyrosine synthesis in some angiosperms**
La	**lanthanium**	**rare earth -- improves growth**
Li	**lithium**	**improves sugar transport in phloem, increases photosynthesis, required in halophytes**
Na	**sodium**	**substitutes for K, minimizes starch storage, keeps carbohydrates generated in sugar forms, osmoticum in association with K**
Pt	**platinum**	**stimulated growth at extremely low concentrations, toxic at any larger concentration**
Rb	**rubidium**	**partial substitute for K when P & ammonium concentrations are large, increases sugar production**
Se	**selenium**	**mimics sulphur and can replace in some amino acids, protective functions, increases growth and reproduction, some amino acid functions, phosphate & nitrate processing, essential in some dryland range plants**
Sr	**strontium**	**partial substitution for Ca when Ca requirements are large**
Ti	**titanium**	**increases enzyme activities, photosynthesis, chlorophyll content, growth, nitrogen fixation (difficult to exclude in tests)**
V	**vanadium[1]**	**compliments / enhances Mo functions, nitrogen fixation & seed germination, porphyrins, hemoproteins, lipid metabolism, photosynthesis (difficult to exclude in tests)**

Figure 6: Beneficial elements cited to stimulate growth & reproduction for some plants, and in some situations, but are not considered or proven to be essential. (1 = essential in some algae)

element symbol	element name
As	arsenic
Cr	chromium
Co	cobalt (in vitamin B12)
F	fluorine
I	iodine
Li	lithium
Se	selenium

Figure 7: Potentially beneficial elements based only upon animal essentialallity, not plant.

Launch

Tree essential elements provide the structure, catalyst, and control framework for growing a tree. The smallest, most primative algae survives through photosythesis, but still requires all essential elements be present in its single cell in order to survive. The essential elements of trees are needed in roughly the same proportions as other plant forms. Knowing essential elements help define health, clearify deficiency and toxicity, and assist in prescribing tree health care treatments to assure tree sustainability. To begin, a little bit of element formation and chemestry is needed.

Star Ash & Debris

Where do elements come from? Elements of the universe are derived from intense fusion fires of stars and constraints of massive gravity pits. Light elements hydrogen (H) and helium (He) remain the most abundant materials in the universe. Hydrogen (H) comprises 90% of all matter in the universe and helium comprises 10%. All the other elements are barely noticeable, miniscule traces of heavier elements. Hydrogen (H) and helium (He) are the primordial elements generated by cooling from the Big Bang, and are fuel for stars.

Fusion

As stars move through their life-cycles, fusion of light elements create new heavier elements. Helium (He) nuclei (made from two hydrogen nuclei) are fusion building blocks. Figure 8. Some heavier elements are then used as fuel for more fusion. At the end of energy production phases in stars, depending upon initial mass, stars lose all remnants of fused elements (i.e. fusion ash), and all other elements captured or synthesized, to the universe either by quietly burning out or through a massive explosion.

Elemental remains from old stars can be gathered into new stars, recycling light elements to fuse into heavier elements. For example, carbon (C), oxygen (O), neon (Ne), and iron (Fe) are relatively abundant in the universe due to element fusion processes in second and later star generations. The core of stars fuse heavier elements up to iron (Fe). Heavier elements than iron require more energy to fuse than is released from the fusion process, and so can not sustain the structure of a star.

Elements Transformed

The neutron caldren and fusion furnace of a star also generates other elements. Elements from cobalt (Co) to bismuth (Bi) are generated in the core of stars where free neutrons bathe heavier elements generating radioactive isotopes which decay into the next heavier element (beta minus decay). Figure 9. This is a slow process.

For example, free neutrons interacting with iron (Fe) atoms generate heavier radioactive iron isotopes which undergo decay (i.e. beta-minus decay where a neutron decays into a proton and emits particles) to produce a stable cobalt (Co) atom. The cobalt (Co) atom interacts with free neutrons to become a heavier radioactive isotope and decays into a stable nickel (Ni) atom. This stepwise process continues across and down the periodic table of elements until bismuth (Bi) is reached. Figure 10 provides the steps in element transformation within a star.

element	atomic mass	
H	1	(fused together into He)
He	4	(2 proton + 2 neutron unit)
C	12	(3He)
O	16	(4He)
Ne	20	(5He)
Mg	24	(6He)
Si	28	(7He)
S	32	(8He)
Fe	56	(14He)

Figure 8: Star fusion using helium (He) nuclei as building blocks to generate energy and create elements.

star core
neutron cauldron

(neutron dense environment over millions of years)

^{59}Co -- ^{209}Bi

star collapse
explosion
-- supernova --

^{209}Po -- ^{238}U

Figure 9: Element transmuation process inside stars (top), and explosion generated elements (bottom) up to uranium (U).

ELEMENT GENERATION IN STARS

1. **Helium (He)** [2 protons / 2 neutrons] **nuclei used to build & add onto elements.**
2. **Even number elements more common than odd numbered.**
3. **Heavier elements generated fall to center of star.**
4. **Iron (Fe) heaviest element formed for energy generating fusion which maintains star structure.**
5. **Beyond iron (Fe) elements are transmutted into heavier elements up to bismuth (Bi).**
6. **Elements heavier than bismuth (Bi) generated in star explosion.**
7. **When light element fuels used up, star collapses (small star) or explodes (large star), spewing various elements into space.**

Figure 10: Process for generating different elements in stars.

Star Ends

When stars reach the end of their fusion lives and the lightest fuel elements are used up, stars meet one of two fates, depending upon their orginal mass. Smaller stars (like our sun) are nearly extinguished and collapse distributing all fused, transmuted, and captured elements into space. The outer layers of the star erode into space and can be captured in new star / planet systems.

Massive stars catastrophically explode as a supernova at the end of their fusion fuels. Figure 11 shows the fusion layers inside a massive star at the end of its life. The tremendous explosive pressures and massive neutron flux of the supernova can generate nine new elements between polonium (Po) and uranium (U) (i.e. heavier than bismuth (Bi)). All the elements generated by a massive star, and all elements gathered from space in its lifetime are flung out into large gas clouds. These clouds can eventually begin to coallese into new stars.

Transformers

The bathing of tightly held elements with free neutrons in star cores, and associated transmutation (decay) process, generate many new elements, as does explosive energies / pressures and free neutron saturation occurring during massive star destruction. Figure 12 shows how one element can be transmutted / transformed / decay into another element. Figure 13 provides details on the primary means of transmutation (changing) one element or isotope into another. The term decay is sometimes used to show something is lost in an element even though the element might have gained a proton or neutron.

Elements up to uranium (U) -- a rare neptunium (Np) atom can be found in uranium ores -- are generated by stars and considered native to the universe. The heavier the element, the rarer it is on average. Figure 14 shows the six primary pathways / sources to native or natural elements in the universe. The heaviest elements are radioactive and can spontaniously split to form lighter elements.

Naming

Identifying elements is based upon their mass and chemical reactivity. Each unique form is given an official name and symbol. For reference, element name, symbol, and number are listed in three following tables all sorted in different ways to help in locating each specific element name, number, or symbol:

-- Figure 15 lists elements sorted in numeric order by their atomic number.

-- Figure 16 lists elements in alphabetical order by official name.

-- Figure 17 lists elements in alphabetical order by official symbol.

Usually symbols are used to represent elements as a shorthand or simple version of the name. The heaviest elements beyond uranium (U) (i.e. trans-uranium elements) have been only generated by nuclear research laboratories.

The lists of element names and symbols can be organized into a graphic table of elements. This periodic table of elements is one way to show elemental relationships based upon atomic number and electron configurations. A period (i.e. the reason the table is called a periodic table) is a horizontal row in the periodic table. A group or family of elements are found within the same column in the periodic table.

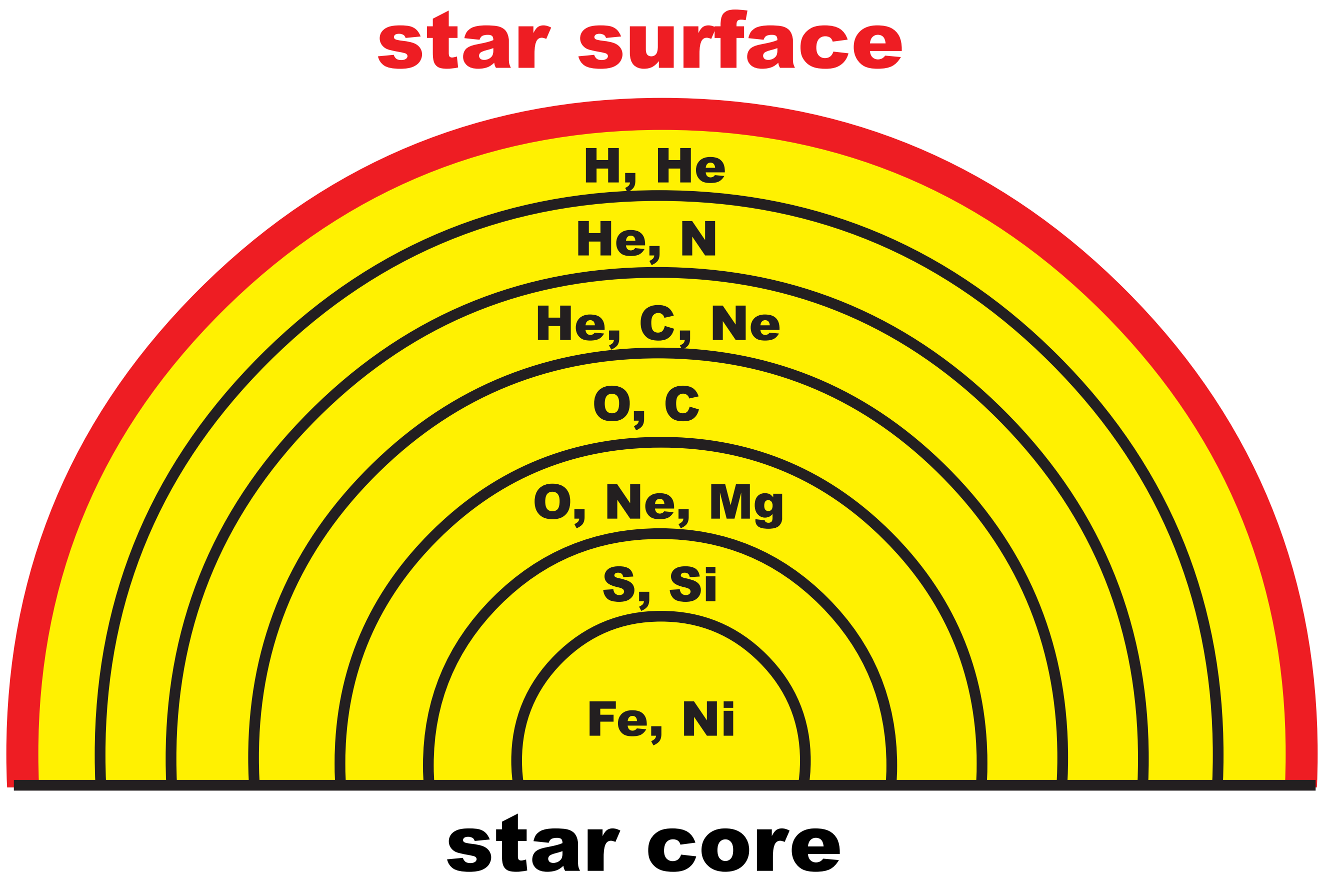


Figure 11: Cross-section through massive star showing element generation layers leading up to supernova.

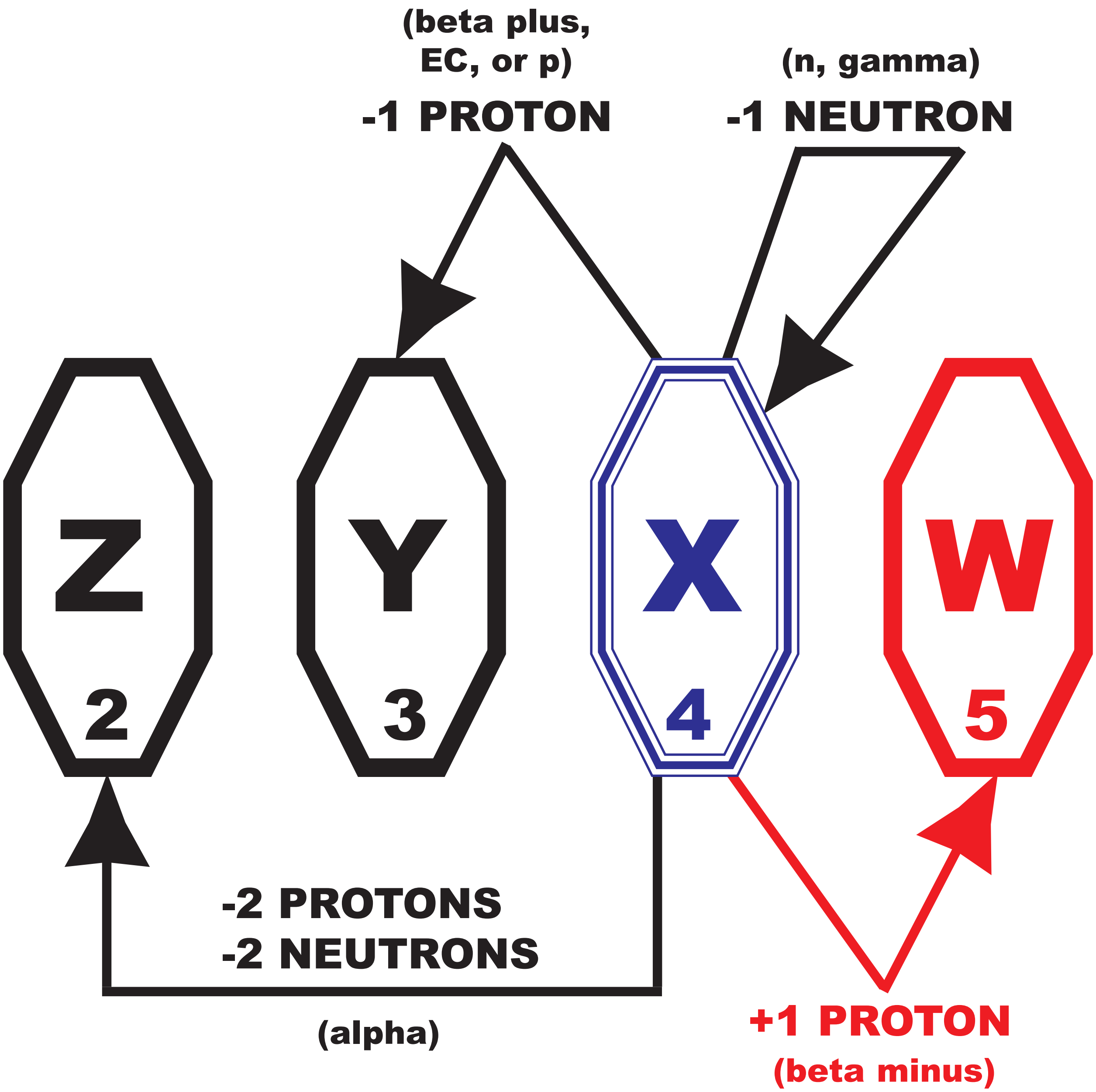


Figure 12: Element transmutation processes changing elements, or changing isotopes of the same element. Begin with element X.

alpha decay	**=**	**loss of 4 mass units & 2 atomic numbers (2 protons & 2 neutrons lost)**
beta minus decay	**=**	**same mass but increase 1 atomic number (neutron decays into 1 proton which stays in nucleous, and emits 1 electron & 1 electron anti-neutrino)**
beta plus decay	**=**	**same mass but decrease 1 atomic number (proton converted into 1 neutron which stays in nucleous, and emits 1 positron & 1 electron neutrino)**
EC (electron capture)	**=**	**same mass but decrease 1 atomic number (proton converted into 1 neutron which stays in nucleus)**
p (proton emission)	**=**	**loss of 1 mass unit and decrease in 1 atomic number**
n (neutron emission)	**=**	**loss of 1 mass unit with no change in atomic number**
gamma decay	**=**	**same mass & same atomic number but emits gamma ray (high energy photon)**
spontaneous fission	**=**	**large heavy unstable element splits into 2 (or 3) smaller nuclei, and emits gamma rays and neutrons**

Figure 13: Definitions of element and isotope transmutation / synthesis / decay forms.

Big Bang	**= H, He** **-- trace Li, Be, B**
Star Fusion	**= He - Fe / Ni**
Star Core	**= Co - Bi** **-- transmutation / decay**
Low Mass Stars	**= He - Bi** **-- ejected into space**
Cosmic Rays	**= Li, Be, B** **-- large elements split**
Supernovae	**= < U** **-- heavy natural elements blown into space**

Figure 14: Source process (nucleosynthesis) for all native elements.

#	name	symbol
1	hydrogen	H
2	helium	He
3	lithium	Li
4	beryllium	Be
5	boron	B
6	carbon	C
7	nitrogen	N
8	oxygen	O
9	fluorine	F
10	neon	Ne
11	sodium	Na
12	magnesium	Mg
13	aluminum	Al
14	silicon	Si
15	phosphorus	P
16	sulfur	S
17	chlorine	Cl
18	argon	Ar
19	potassium	K
20	calcium	Ca
21	scandium	Sc
22	titanium	Ti
23	vanadium	V
24	chromium	Cr
25	manganese	Mn
26	iron	Fe
27	cobalt	Co
28	nickel	Ni
29	copper	Cu
30	zinc	Zn
31	gallium	Ga
32	germanium	Ge
33	arsenic	As
34	selenium	Se
35	bromine	Br
36	krypton	Kr
37	rubidium	Rb
38	strontium	Sr
39	yttrium	Y
40	zirconium	Zr
41	niobium	Nb
42	molybdenum	Mo
43	technetium	Tc
44	ruthenium	Ru
45	rhodium	Rh
46	palladium	Pd
47	silver	Ag
48	cadmium	Cd
49	indium	In
50	tin	Sn
51	antimony	Sb
52	tellurium	Te
53	iodine	I
54	xenon	Xe
55	cesium	Cs
56	barium	Ba
57	lanthanum	La
58	cerium	Ce
59	praseodymium	Pr
60	neodymium	Nd
61	promethium	Pm
62	samarium	Sm
63	europium	Eu
64	gadolinium	Gd
65	terbium	Tb
66	dysprosium	Dy
67	holmium	Ho
68	erbium	Er
69	thulium	Tm
70	ytterbium	Yb
71	lutetium	Lu
72	hafnium	Hf
73	tantalum	Ta
74	tungsten	W
75	rhenium	Re
76	osmium	Os
77	iridium	Ir
78	platinum	Pt
79	gold	Au
80	mercury	Hg
81	thallium	Tl
82	lead	Pb
83	bismuth	Bi
84	polonium	Po
85	astatine	At
86	radon	Rn
87	francium	FR
88	radium	Ra
89	actinium	Ac
90	thorium	Th
91	protactinium	Pa
92	uranium	U
93	neptunium	Np
94	plutonium	Pu
95	americium	Am
96	curium	Cm
97	berkelium	Bk
98	californium	Cf
99	einsteinium	Es
100	fermium	Fm
101	mendelevium	Md
102	nobelium	No
103	lawrencium	Lr
104	rutherfordium	Rf
105	dubnium	Db
106	seaborgium	Sg
107	bhorium	Bh
108	hassium	Hs
109	meitnerium	Mt
110	darmstadtium	Ds
111	roentgenium	Rg
112	copernicium	Cn
113	nihonium	Nh
114	flerovium	Fl
115	moscovium	Mc
116	livermorium	Lv
117	tennessine	Ts
118	oganesson	Og

Figure 15: List of elements sorted in numerical order (first column).

#	name	symbol
89	actinium	Ac
13	aluminum	Al
95	americium	Am
51	antimony	Sb
18	argon	Ar
33	arsenic	As
85	astatine	At
56	barium	Ba
97	berkelium	Bk
4	beryllium	Be
107	bhorium	Bh
83	bismuth	Bi
5	boron	B
35	bromine	Br
48	cadmium	Cd
20	calcium	Ca
98	californium	Cf
6	carbon	C
58	cerium	Ce
55	cesium	Cs
17	chlorine	Cl
24	chromium	Cr
27	cobalt	Co
112	copernicium	Cn
29	copper	Cu
96	curium	Cm
110	darmstadtium	Ds
105	dubnium	Db
66	dysprosium	Dy
99	einsteinium	Es
68	erbium	Er
63	europium	Eu
100	fermium	Fm
114	flerovium	Fl
9	fluorine	F
87	francium	FR
64	gadolinium	Gd
31	gallium	Ga
32	germanium	Ge
79	gold	Au

#	name	symbol
72	hafnium	Hf
108	hassium	Hs
2	helium	He
67	holmium	Ho
1	hydrogen	H
49	indium	In
53	iodine	I
77	iridium	Ir
26	iron	Fe
36	krypton	Kr
57	lanthanum	La
103	lawrencium	Lr
82	lead	Pb
3	lithium	Li
116	livermorium	Lv
71	lutetium	Lu
12	magnesium	Mg
25	manganese	Mn
109	meitnerium	Mt
101	mendelevium	Md
80	mercury	Hg
42	molybdenum	Mo
115	moscovium	Mc
60	neodymium	Nd
10	neon	Ne
93	neptunium	Np
28	nickel	Ni
113	nihonium	Nh
41	niobium	Nb
7	nitrogen	N
102	nobelium	No
118	oganesson	Og
76	osmium	Os
8	oxygen	O
46	palladium	Pd
15	phosphorus	P
78	platinum	Pt
94	plutonium	Pu
84	polonium	Po

#	name	symbol
19	potassium	K
59	praseodymium	Pr
61	promethium	Pm
91	protactinium	Pa
88	radium	Ra
86	radon	Rn
75	rhenium	Re
45	rhodium	Rh
111	roentgenium	Rg
37	rubidium	Rb
44	ruthenium	Ru
104	rutherfordium	Rf
62	samarium	Sm
21	scandium	Sc
106	seaborgium	Sg
34	selenium	Se
14	silicon	Si
47	silver	Ag
11	sodium	Na
38	strontium	Sr
16	sulfur	S
73	tantalum	Ta
43	technetium	Tc
52	tellurium	Te
117	tennessine	Ts
65	terbium	Tb
81	thallium	Tl
90	thorium	Th
69	thulium	Tm
50	tin	Sn
22	titanium	Ti
74	tungsten	W
92	uranium	U
23	vanadium	V
54	xenon	Xe
70	ytterbium	Yb
39	yttrium	Y
30	zinc	Zn
40	zirconium	Zr

Figure 16: Elements sorted in alphabetical order by name (second column).

#	name	symbol
89	actinium	Ac
47	silver	Ag
13	aluminum	Al
95	americium	Am
18	argon	Ar
33	arsenic	As
85	astatine	At
79	gold	Au
5	boron	B
56	barium	Ba
4	beryllium	Be
107	bhorium	Bh
83	bismuth	Bi
97	berkelium	Bk
35	bromine	Br
20	calcium	Ca
48	cadmium	Cd
98	californium	Cf
17	chlorine	Cl
6	carbon	C
58	cerium	Ce
96	curium	Cm
112	copernicium	Cn
27	cobalt	Co
24	chromium	Cr
55	cesium	Cs
29	copper	Cu
105	dubnium	Db
110	darmstadtium	Ds
66	dysprosium	Dy
68	erbium	Er
99	einsteinium	Es
63	europium	Eu
9	fluorine	F
26	iron	Fe
114	flerovium	Fl
100	fermium	Fm
87	francium	Fr
31	gallium	Ga
64	gadolinium	Gd
32	germanium	Ge

#	name	symbol
1	hydrogen	H
2	helium	He
72	hafnium	Hf
80	mercury	Hg
67	holmium	Ho
108	hassium	Hs
53	iodine	I
49	indium	In
77	iridium	Ir
19	potassium	K
36	krypton	Kr
57	lanthanum	La
3	lithium	Li
103	lawrencium	Lr
71	lutetium	Lu
116	livermorium	Lv
115	moscovium	Mc
101	mendelevium	Md
12	magnesium	Mg
25	manganese	Mn
42	molybdenum	Mo
109	meitnerium	Mt
7	nitrogen	N
11	sodium	Na
41	niobium	Nb
60	neodymium	Nd
10	neon	Ne
113	nihonium	Nh
28	nickel	Ni
102	nobelium	No
93	neptunium	Np
8	oxygen	O
118	oganesson	Og
76	osmium	Os
15	phosphorus	P
91	protactinium	Pa
82	lead	Pb
46	palladium	Pd
61	promethium	Pm

#	name	symbol
84	polonium	Po
59	praseodymium	Pr
78	platinum	Pt
94	plutonium	Pu
88	radium	Ra
37	rubidium	Rb
75	rhenium	Re
104	rutherfordium	Rf
111	roentgenium	Rg
45	rhodium	Rh
86	radon	Rn
44	ruthenium	Ru
16	sulfur	S
51	antimony	Sb
21	scandium	Sc
34	selenium	Se
106	seaborgium	Sg
14	silicon	Si
62	samarium	Sm
50	tin	Sn
38	strontium	Sr
73	tantalum	Ta
65	terbium	Tb
43	technetium	Tc
52	tellurium	Te
90	thorium	Th
22	titanium	Ti
81	thallium	Tl
69	thulium	Tm
117	tennessine	Ts
92	uranium	U
23	vanadium	V
74	tungsten	W
54	xenon	Xe
39	yttrium	Y
70	ytterbium	Yb
30	zinc	Zn
40	zirconium	Zr

Figure 17: Elements sorted in alphabetical order by symbol (third column).

Tabled

Figure 18 shows a traditional periodic table of elements – both native and artificially produced elements are listed by their symbol. Elements with an asterick (*) beside their atomic number are radioactive. Note there are two places where a line of elements (i.e. a series) must be inserted into the main table. This is a standard way of showing these heavier elements to prevent the full table from being too wide for a page. Figure 19.

Artificial Elements

New ultra-heavy elements are still being crafted in nuclear research laboratories and named by international chemical research associations. These elements are all unstable and have short half-lives. The nine newest elemens are given in Figure 20 with year of creation. All are radioactive and decay to two or three smaller atoms within less than a millisecond. Names of these new elements must be agreed upon internationally, and so, some unnamed elements have generic Latin names of their atomic number until officially named.

Family Matters

In the standard periodic table of elements, several family groups (columns) and closely associated elements groups have specific names. The first family group (column 1) are the alkali metals, or the lithium (Li) family. These soft metals are extremely reactive with their one available electron, and burn or explode when pure metal contacts water. Hydrogen (H) usually placed at the head of the column due to its electron configuration, is not considered an alkali metal. Figure 21.

The second family group (column 2 from left) are called the alkaline earths, or the beryllium (Be) family. These elements have two electrons available for interactions and are highly reactive in pure form. On Earth, these metals are never found in pure form. This figure also delineates the special metals which have only one oxidation state possible and electron interactions only in their outermost shell. These elements are: aluminum (Al), gallium (Ga), indium (In), and thallium (Tl) in family group 13; tin (Sn), and lead (Pb) in family group 14; and bismuth (Bi) in family group 15.

Family group 3 are the rare earth (RE) elements and include the lanthanide series of elements, and usually the native actinide series of elements. Figure 22.

Metal Things

Family group 3-12 are transition metals (i..e. transitions between either end of the periodic table). Figure 23. These metals have multiple electron shells, conformations easily interacting with other materials, and usually generate variable oxidation states. The transition metals are usually lumped together but belong to many family groups with significantly different reactivities.

The metalloids (sometimes called semi-conductors) cut across several family groups and include: boron (B) in family group 13; silicon (Si) and germanium (Ge) in family group 14; arsenic (As) and antimony (Sb) in family group 15; and, tellurium (Te) and polonium (Po) in family group 16.

To The Right

Within the transition metals are several sub-units of elements. Figure 24. One is group 11, the coinage metals, copper (Cu), silver (Ag), and gold (Au). In group 12 are chemically unique volatile metals, zinc (Zn), cadnium (Cd), and mercury (Hg). The 17th family group (fluorine (F) family) are called the halogens and are very reactive. The 18th family group are composed of noble gases, a highly stable group of nearly inert elements.

Figure 18:

PERIODIC TABLE OF ELEMENTS

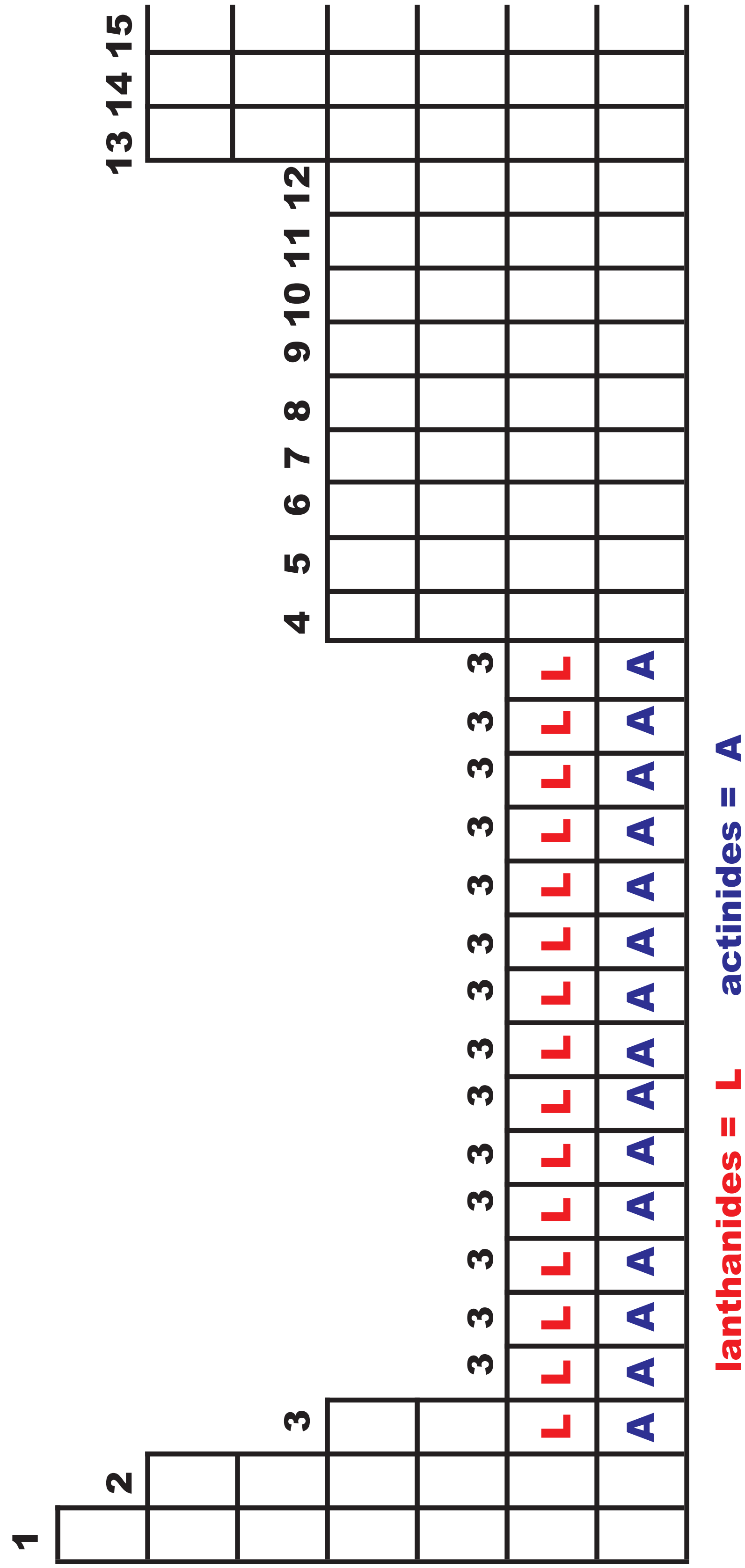
(**natural elements** / human created elements)

* = radioactive

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**H** 1																	**He** 2
2	**Li** 3	**Be** 4											**B** 5	**C** 6	**N** 7	**O** 8	**F** 9	**Ne** 10
3	**Na** 11	**Mg** 12											**Al** 13	**Si** 14	**P** 15	**S** 16	**Cl** 17	**Ar** 18
4	**K** 19	**Ca** 20	**Sc** 21	**Ti** 22	**V** 23	**Cr** 24	**Mn** 25	**Fe** 26	**Co** 27	**Ni** 28	**Cu** 29	**Zn** 30	**Ga** 31	**Ge** 32	**As** 33	**Se** 34	**Br** 35	**Kr** 36
5	**Rb** 37	**Sr** 38	**Y** 39	**Zr** 40	**Nb** 41	**Mo** 42	Tc 43*	**Ru** 44	**Rh** 45	**Pd** 46	**Ag** 47	**Cd** 48	**In** 49	**Sn** 50	**Sb** 51	**Te** 52	**I** 53	**Xe** 54
6	**Cs** 55	**Ba** 56	**La** 57	**Hf** 72	**Ta** 73	**W** 74	**Re** 75	**Os** 76	**Ir** 77	**Pt** 78	**Au** 79	**Hg** 80	**Tl** 81	**Pb** 82	**Bi** 83	**Po** 84*	**At** 85*	**Rn** 86*
7	**Fr** 87*	**Ra** 88*	**Ac** 89*	Rf 104*	Db 105*	Sg 106*	Bh 107*	Hs 108*	Mt 109*	Ds 110*	Rg 111*	Cn 112*	Nh 113*	Fl 114*	Mc 115*	Lv 116*	Ts 117*	Og 118*

Lanthanides	**Ce** 58	**Pr** 59	**Nd** 60	Pm 61*	**Sm** 62	**Eu** 63	**Gd** 64	**Tb** 65	**Dy** 66	**Ho** 67	**Er** 68	**Tm** 69	**Yb** 70	**Lu** 71
Actinides	**Th** 90*	**Pa** 91*	**U** 92*	Np 93*	Pu 94*	Am 95*	Cm 96*	Bk 97*	Cf 98*	Es 99*	Fm 100*	Md 101*	No 102*	Lr 103*

Figure 19: Full width periodic table of elements with group numbers shown and position of lanthanides and actinides series shown.



atomic number	official name	symbol	year
110	Darmstadtium	Ds	1994
111	Roentgenium	Rg	1994
112	Copernicium	Cn	1996
113	Nihonium	Nh	2003
114	Flerovium	Fl	1999
115	Moscovium	Mc	2003
116	Livermorium	Lv	2000
117	Tennessine	Ts	2010
118	Oganesson	Og	2006

Figure 20: Latest nine elements generated from nuclear research labs and placed on the periodic table of elements. Date is confirmed discovery year.

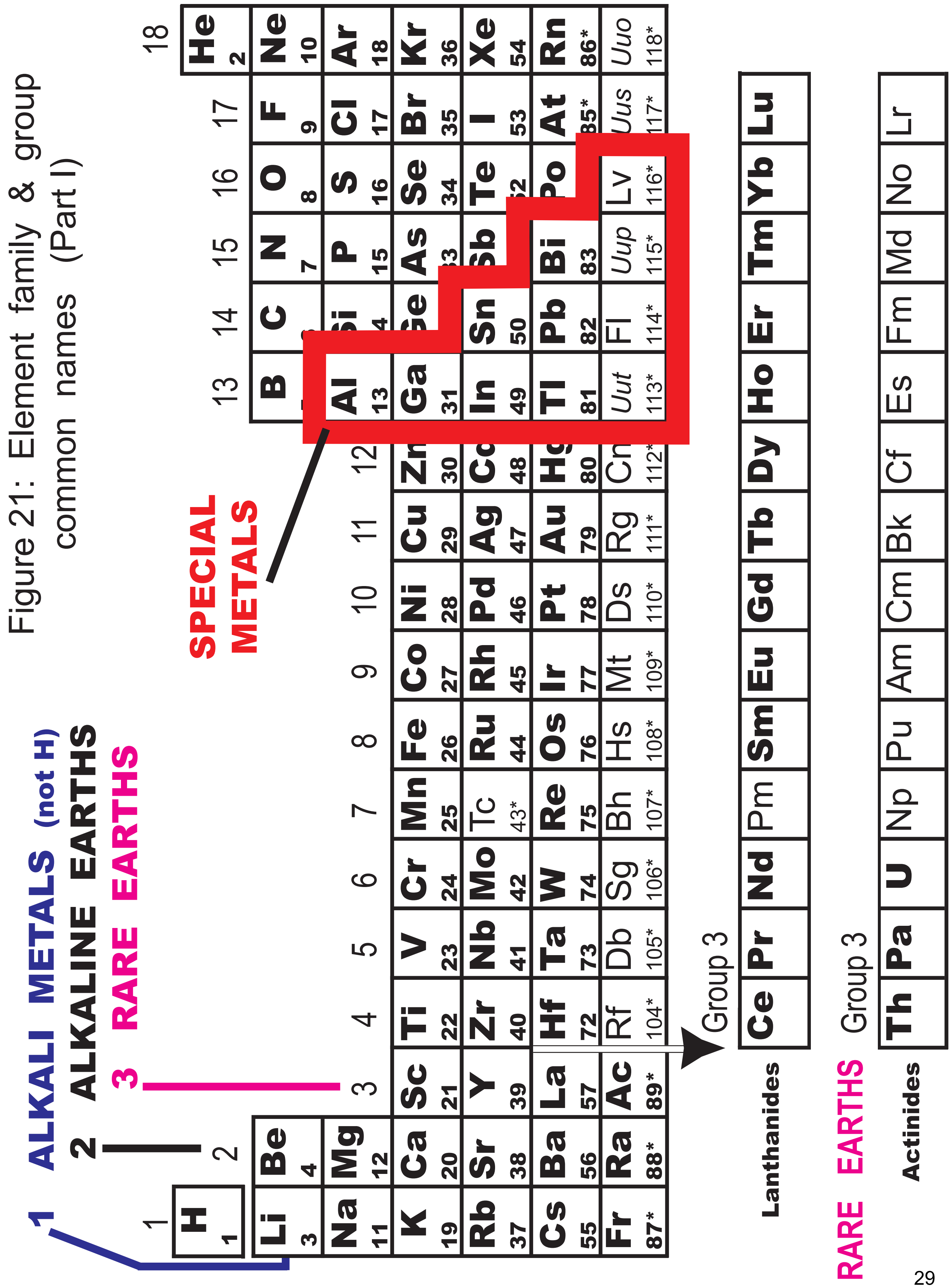


Figure 21: Element family & group common names (Part I)

Rare Earth (RE) Elements

1. **light rare earths**
   lanthanides
   La - Gd (abundant except for Pm)

2. **heavy rare earths**
   lanthanides
   Tb - Lu (abundant)

3. **group three additions**
   Sc / Y (rare)

4. **actinides -- sometines included as they are in family group 3**
   (rare & radioactive / human generated unstable & highly radioactive.)

Figure 22: Definition of Rare Earth elements (RE).

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Figure 23: Element family & group common names (Part II)

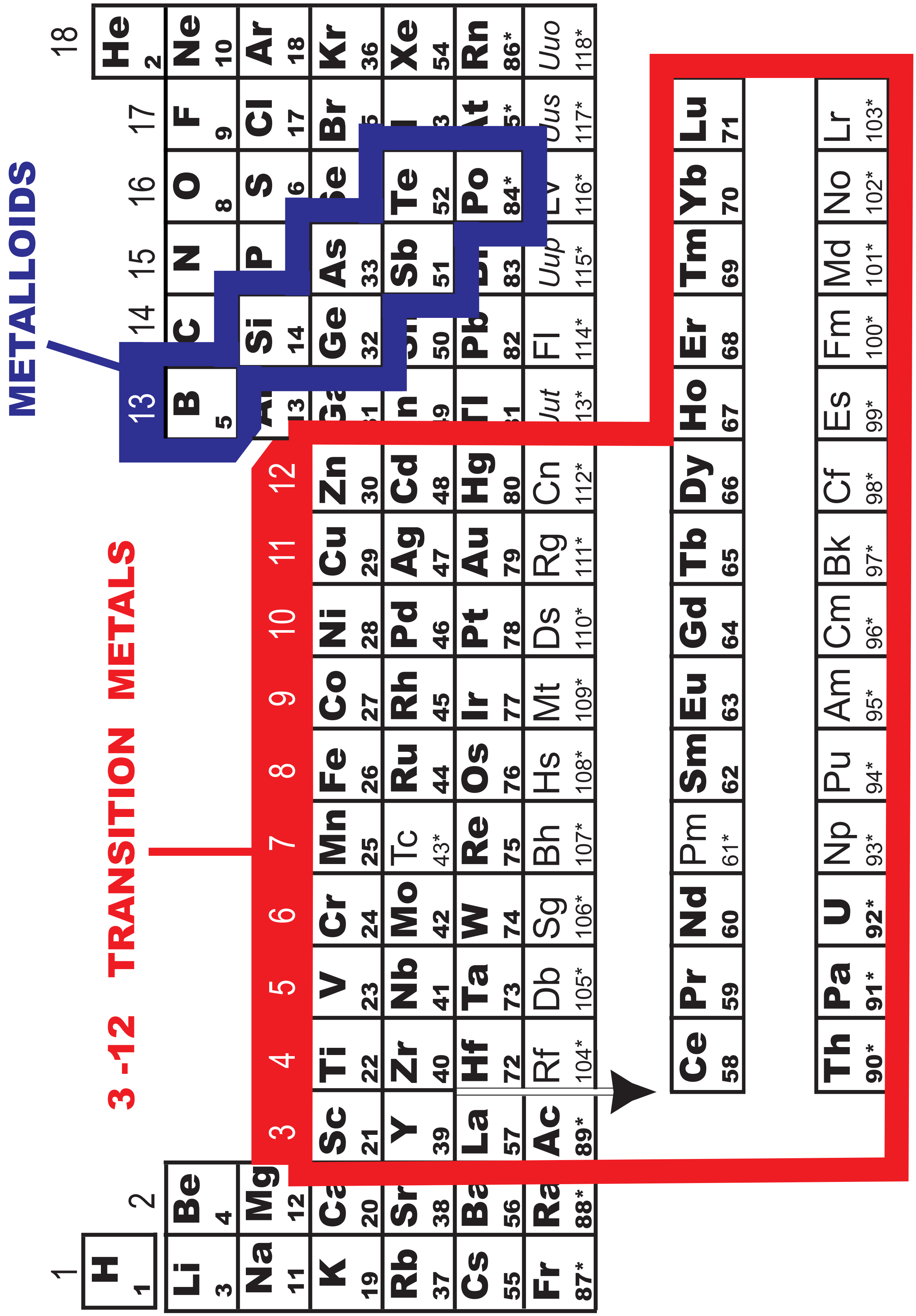

Figure 24: Element family & group common names (Part III)

VOLATILE METALS 12

NOBLE GASES 18

COINAGE METALS 11

HALOGENS 17

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43*	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84*	At 85*	Rn 86*
Fr 87*	Ra 88*	Ac 89*	Rf 104*	Db 105*	Sg 106*	Bh 107*	Hs 108*	Mt 109*	Ds 110*	Rg 111*	Cn 112*	*Uut* 113*	Fl 114*	*Uup* 115*	Lv 116*	*Uus* 117*	*Uuo* 118*

Lanthanides	Ce 58	Pr 59	Nd 60	Pm 61*	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
Actinides	Th 90*	Pa 91*	U 92*	Np 93*	Pu 94*	Am 95*	Cm 96*	Bk 97*	Cf 98*	Es 99*	Fm 100*	Md 101*	No 102*	Lr 103*

The Rest

Tucked in-between the halogens and metalloids are non-metal elements carbon (C), nitrogen (N), phosphorus (P), oxygen (O), sulfur (S), and selenium (Se). Hydrogen (H), although it has a different electron configuration, is also placed with non-metals. Figure 25.

Two more sub-divisions within the transition metals are groups 8, 9, and 10. These metals are divided between the magnetic top row called the iron (Fe) group -- elements iron (Fe), cobalt (Co), and nickel (Ni), and the heavier six metals of the platinum (Pt) group -- iridium (Ir), osmium (Os), palladium (Pd), platinum (Pt), rhodium (Rh), and ruthenium (Ru). The synthetic (human created) elements beyond (heavier than) uranium are collectively called trans-uranium elements.

Natives

Figure 26 shows a modified / simplified periodic table of elements which includes just native elements of the universe. Human generated elements are not shown. Two elements -- technetium (Te) and promethium (Pm) -- are not found on Earth. Remember the periodic table has each native element placed into vertical columns of similar electron reactivity groups or families, and horizontal rows of progressively more massive elements (i.e. periods). In this type of table, the lower and farther to the right an element is placed, the larger its atomic number (number of protons), and usually the greater its atomic mass (number of protons plus neutrons). An element is placed in the table and its idenity determined by its proton number, but can have various numbers of neutrons, yielding different isotopes of the same element.

An element's placement in the periodic table does not nessecarily determine the state it exists in at room temperature / biological temperature. The seven noble gases plus five non-metals, hydrogen (H), nitrogen (N), oxygen (O), fluorine (F), and chlorine (Cl) are clearly gases. Five elements which are either liquid or very close to melting at a warm room temperature include gallium (Ga), bromine (Br), cesium (Cs), mercury (Hg), and francium (Fr*). The rest of the elements are in a solid state at room temperature. Figure 27.

Isotopes

Figure 28 shows seven known isotopes of carbon. To be carbon, an atom's nucleus must have six protons. The number of neutrons varies between 5 and 11. Carbon with 12 mass units of six protons and six neutrons (12C), and carbon with 13 mass units of six protons and seven neutrons (13C) represent all but trace amounts of the carbon atoms on Earth. The other carbon isotopes are unstable and decay anywhere from a fraction of a second to less than 6,000 years.

Another isotope example is magnesium (Mg). Magnesium exists in three principle isotopes. Magnesium isotopes available in the environment include atomic mass 24 which represents 79% of all magnesium found in nature, atomic mass 25 which represents 10% of all magnesium found in nature, and atomic mass 26 which represents 11% of all magnesium found in nature. Each magnesium atom contains the same number of protons (12) but varies in number of neutrons present (12-14). Magnesium is considered to have an average atomic mass of 24.3 because of this mix of three isotopes and their abundanace in nature.

Odd Elements

There is a noticeable difference in element abundance across the universe between similar mass elements which have odd and even atomic numbers. Quantum effects provide more stable configura-

Figure 25: Element family & group common names (Part IV)

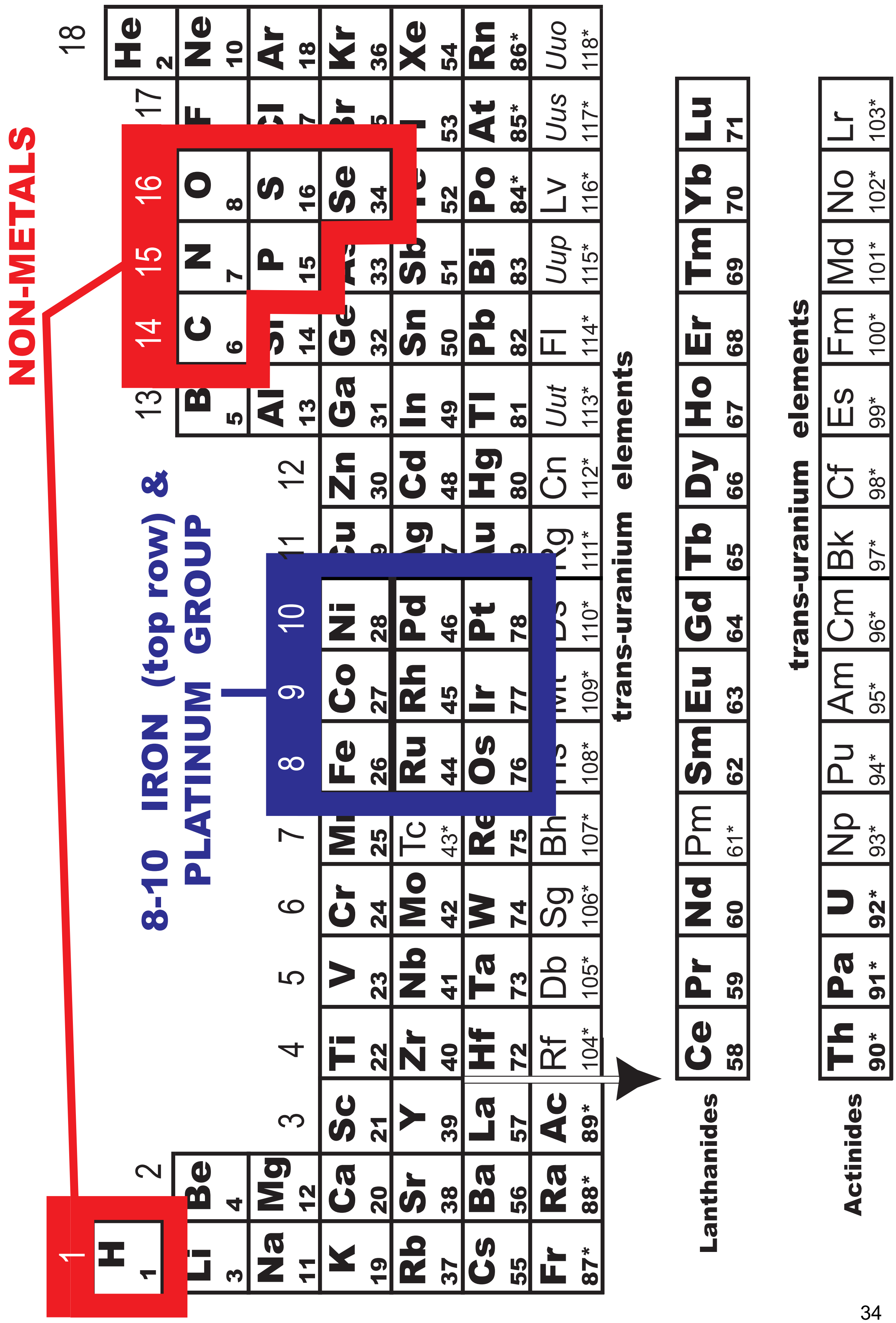

Figure 26: Periodic Table of Native / Natural Elements

element family group number (1–18); 1–6 = element periods

period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H 1																	He 2
2	Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
3	Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
4	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
5	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42		Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
6	Cs 55	Ba 56	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
insert				Ce 58	Pr 59	Nd 60		Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	
	Fr 87	Ra 88	Ac 89	Th 90	Pa 91	U 92												

Physical State of Elements

gas =

^{1}H, ^{2}He, ^{7}N, ^{8}O, ^{9}F,
^{10}Ne, ^{17}Cl, ^{18}Ar, ^{36}Kr,
^{54}Xe, ^{86}Rn*, ^{118}Uuo*

liquid =

^{31}Ga, ^{35}Br, ^{55}Cs,
^{80}Hg, ^{87}Fr*

solid =

(remaining elements)

Figure 27: State of elements at warm room temperature.
(element symbol & atomic mass given -- * = radioactive)

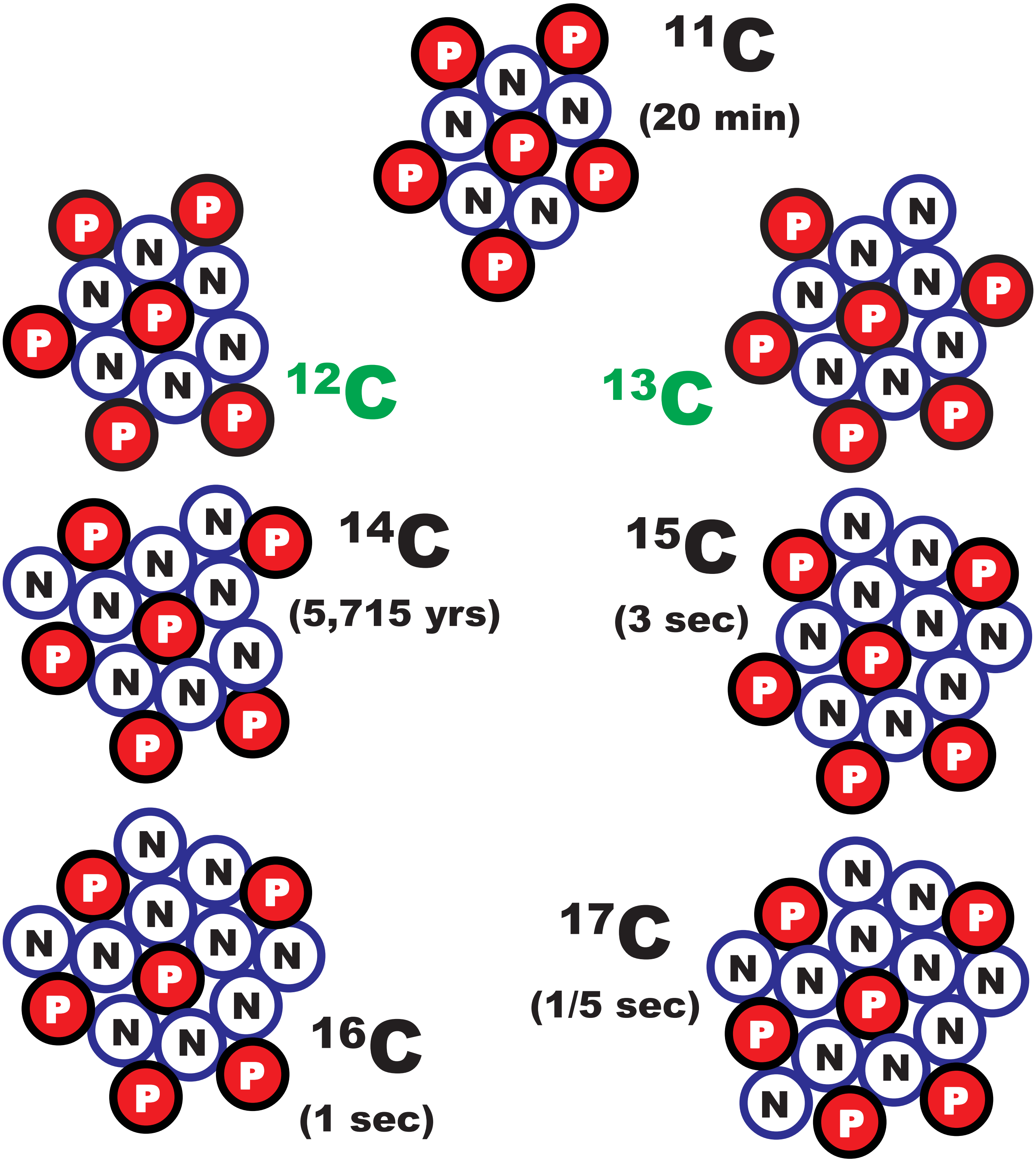

Figure 28: Isotope nuclei of carbon (C), each with six protons and various numbers of neutrons. Of carbon found in nature, ^{12}C = 99% & ^{13}C = 1%. Time values are half-lives.

tions in the nucleus of atoms with even number of protons. Elements with even atomic numbers tend to be more durable in star fusion caldrons and relatively more abundant compared with similar mass neighbors, but odd numbered (odd number of protons) elements. There are also several elements unusually rare in the universe (i.e. boron (B) is one) because they provide easily fused fuel within star cores.

Down To Earth

The elements seeded across space by several generations of stars (some burning out and some exploding) can be collected in gravity wells of new stars, or in smaller gravity eddies around these stars, forming conglomerates of elements not massive enough to sustain fusion. These fusion ash bodies are planets, moons, asteroids, and meteorites, all with different element compositions. Earth is one such body circling a medium sized, third generation star. Earth contains all but two native elements of the universe.

Figure 29 compares the presence of tree essential elements with elements common across the solar system and universe, and with elements common in the Earth's crust. Elements boron (B) and molybdenum (Mo) are needed by trees, but are rare in the universe and on the Earth's surface. Oxygen (O), magnesium (Mg), silicon (Si), potassium (K), calcium (Ca), and iron (Fe) are all essential elements in trees and common on Earth and in the solar system.

Weathered

All native elements are found on Earth in a host of mineral compounds. The minerals of Earth's crust have been formed and reworked through igneous, metamorphic, and sedimentary processes, and then weathered. Almost all the soils of Earth are derived from these mineral parent materials, containing many elements. The surface crust of Earth has been weathered and reorganized by many forces, all releasing, tying-up, and repositioning elements present.

Concentrations of some elements common in the Earth's crust are quite different from concentrations present in the solar system. The Earth is a dynamic planet and elements have been consolidated into different layers and locations, or lost to space over time. Iron (Fe) and associated metals comprise a significant portion of Earth's molten core. Deep within the mantle, lighter elements remain segregated since the early years of Earth. Most unreactive gasses (noble gases) and hydrogen have been lost to space.

Crusty

Figure 30 compares the relative amounts of various tree essential elements in the solar system with those elements only in the Earth's crust. The Earth's crust has a super abundance of silicon (Si) and oxygen (O), usually found in a silicon dioxide (SiO_2) form. Concentration of certain elements into trees demonstrates the power of life over the amount of an element found in the Earth's crust. Trees concentrate and conserve boron (B), carbon (C), nitrogen (N), phosphorus (P), and sulfur (S). Other elements are essential to trees but are not concentrated out of proportion from environmental concentrations, and can be toxic in excess, like manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), and zinc (Zn).

essential elements in trees	common elements in universe	common elements in Earth's crust
H	H	
	He	
B		
C	C	
N	N	
O	O	O
	F	
	Ne	
	Na	Na
Mg	Mg	Mg
	Al	Al
Si	Si	Si
P	P	
S	S	
Cl	Cl	
	Ar	
K	K	K
Ca	Ca	Ca
	Sc	
	Ti	
	V	
	Cr	
Mn	Mn	
Fe	Fe	Fe
Co	Co	
Ni	Ni	
Cu	Cu	
Zn	Zn	
Mo		

Figure 29: Comparision of element abundance across the universe and in the Earth's crust compared with tree essential elements. Single lines connect elements common in all three locations and double lines represent universally rare elements.

element symbol	relative concentration in solar system	relative concentration in Earth's crust	relative concentration in a tree
H	1,000,000	2,800	133,000
B	75	17	65
C	31,000	590	1,000,000
N	12,500	38	38,000
O	32,000	1,000,000	1,000,000
Mg	12,500	50,500	5,500
Si	12,500	550,000	1.5
P	625	1,800	5,000
S	5,000	1,040	3,300
Cl	625	375	550
K	500	28,000	28,000
Ca	2,000	110,000	22,000
Mn	625	2,100	100
Fe	10,000	145,000	170
Co	500	50	0.4
Ni	2,000	175	0.9
Cu	150	150	45
Zn	325	150	85
Mo	25	1.7	1.1

Figure 30: Comparison of tree essential elements as distributed in the solar system, in the Earth's crust, and in a tree. Essential elements listed in order of atomic mass. The largest element concentration in each column is set at one-million (1,000,000).

Treeman

Figure 31 shows the relative abundance of essential elements in a tree compared with these same elements in a human. There are a number of elements clearly tree-centric. Magnesium (Mg) is concentrated by trees because it is used in the photosynthetic process. Potassium (K), manganese (Mn), copper (Cu), and molybdenum (Mo) are all concentrated and conserved by trees over humans. Humans need all of the tree-essential elements, except boron (B), plus many more. Like trees, humans can contain all the elements in their environment, most nonessential.

Up To Trees

The building blocks of tree life are concentrated in lighter, more abundant elements of the universe and Earth. Figure 32 provides placement of essential elements of tree life within a periodic table of elements which only shows tree essential element family groups. Note the family (column) within which each tree-essential element resides. Each family of elements share similar electron reactivities. The lighter and more common elements tend to be essential to tree life while heavier elements in the same family can interfere with lighter essential elements listed above and poison tree life processes. Other elements not shown can still be toxic to trees.

Relative Poison

Every family group has good, neutral, and bad elements when discussing their role in trees. Some elements are essential to tree life, while other elements in the same family group (columns in the periodic table) are damaging and toxic to trees. Each family group member can potentially disrupt or poison processes involving other essential family members. Figure 33 through Figure 46 provides family group relationships of toxicity and substitution.

For example, within the nitrogen (N) and phosphorus (P) family of elements lie arsenic (As), a major physiological poison, while under carbon (C) and silicon (Si) is lead (Pb), a notorious poison. Sometimes element family interactions can be benign. For example, under potassium (K) is rubidium (Rb) which can partially substitute for potassium in some processes.

Another example of element family problems lies with zinc. The value of small concentrations of zinc and how its chemical reactivity is used by biological processes is indisputable. Zinc, with properties determined by its atomic mass and electron configuration, is essential within any tree life processes where it participates. Unfortunately, zinc family members which partially share chemical attributes include cadmium (Cd) and mercury (Hg), both serious biological poisons.

Killing Dose

It must be noted it is not the presence or absence of an element, but its concentration (i.e. dose) which can be most beneficial or damaging in a tree. The value or damage from a particular concentration (availability or dose) of any element depends upon minimum requirements (if any) and maximum tolerance of a tree. Figure 47 lists native elements which can have a toxic impact on trees, some in small amounts. A few of these elements are essential (or listed as potentially beneficial) at lower concentrations (i.e. aluminum (Al), arsenic (As), boron (B), copper (Cu), and selenium (Se)). Too much of anything is toxic!

Sometimes the presence or absence of one element impacts the beneficial or detrimental attributes of another essential element. For example, the combined total concentrations of the heavier

element symbol	relative concentration in a person	relative concentration in a tree
H	164,000	133,000
B	1.2	65
C	380,000	1,000,000
N	43,000	38,000
O	1,000,000	1,000,000
Mg	440	5,500
Si	420	1.5
P	18,000	5,000
S	3,300	3,300
Cl	2,000	550
K	3,300	28,000
Ca	23,000	22,000
Mn	0.3	100
Fe	100	170
Co	0.03	0.4
Ni	0.2	0.9
Cu	1.6	45
Zn	54	85
Mo	0.2	1.1

Figure 31: Comparison of essential elements in trees compared with a human body. Largest element concentrations in each column given a 1 million value.

Remember this is a comparision of average essential element proportions in trees with matching average element proportions found in a human body, both essential and non-essential, and may represent an excess of any requirement.

Figure 32: Tree essential element family groups, without human-made elements.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**H** 1																	
2	**Li** 3	**Be** 4											**B** 5	**C** 6	**N** 7	**O** 8	**F** 9	
3	**Na** 11	**Mg** 12											**Al** 13	**Si** 14	**P** 15	**S** 16	**Cl** 17	
4	**K** 19	**Ca** 20				**Cr** 24	**Mn** 25	**Fe** 26	**Co** 27	**Ni** 28	**Cu** 29	**Zn** 30	**Ga** 31	**Ge** 32	**As** 33	**Se** 34	**Br** 35	
5	**Rb** 37	**Sr** 38				**Mo** 42		**Ru** 44	**Rh** 45	**Pd** 46	**Ag** 47	**Cd** 48	**In** 49	**Sn** 50	**Sb** 51	**Te** 52	**I** 53	
6	**Cs** 55	**Ba** 56				**W** 74	**Re** 75	**Os** 76	**Ir** 77	**Pt** 78	**Au** 79	**Hg** 80	**Tl** 81	**Pb** 82	**Bi** 83	**Po** 84*	**At** 85*	
7	**Fr** 87*	**Ra** 88*																

Li	**lithium** **competes with K** **anatgonistic with Zn** **synergistic with Fe & Mn**	**T**
Na	**sodium** **partial substitute for K**	**S**
K	**potassium** **ESSENTIAL**	**E**
Rb	**rubidium** **toxic at high concentrations** **partial subtitute for K**	**S**
Cs	**cesium** **rare & toxic** **competes with K** **radioactive isotopes pollute**	**T**
Fr	**francium** **radioactive -- extremely rare** **second rarest element on Earth**	

Figure 33: Element family group #1 and interactions.
E = essential; S = substitution; T = toxic

Be	**beryllium** **competes with Mg & Ca** **partial substitute for Mg** **sign of pollution**	**T**
Mg	**magnesium** **ESSENTIAL**	**E**
Ca	**calcium** **ESSENTIAL**	**E**
Sr	**strontium** **competes with Ca / some Mg** **radioactive isotope pollution**	**T**
Ba	**barium** **interferes with K** **antagonistic with Mg, Ca, & S**	
Ra	**radium** **widespread but rare** **radioactive**	

Figure 34: Element family group #2 and interactions.
E = essential; T = toxic

Cr	**chromium** **slightly available** **poor tree transport**	**T**
Mo	**molybdenum** **ESSENTIAL**	**E**
W	**tungsten** **similar in soil with Mo** **partial substitute for Mo**	**S**
Sg	**seaborgium** **artificial** **highly radioactive**	

Figure 35: Element family group #6 and interactions.
E = essential; S = substitution; T = toxic

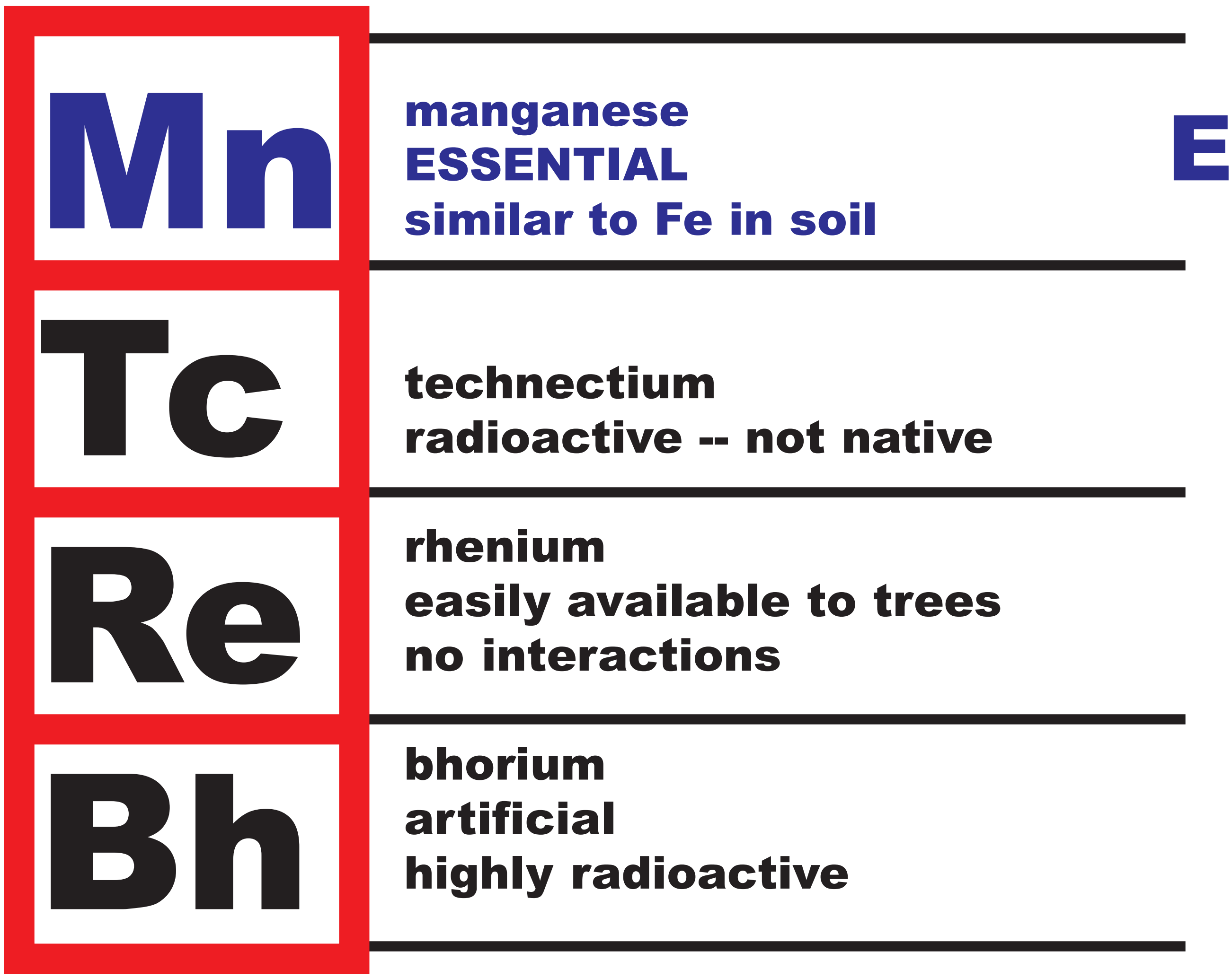

Figure 36: Element family group #7 and interactions.
E = essential

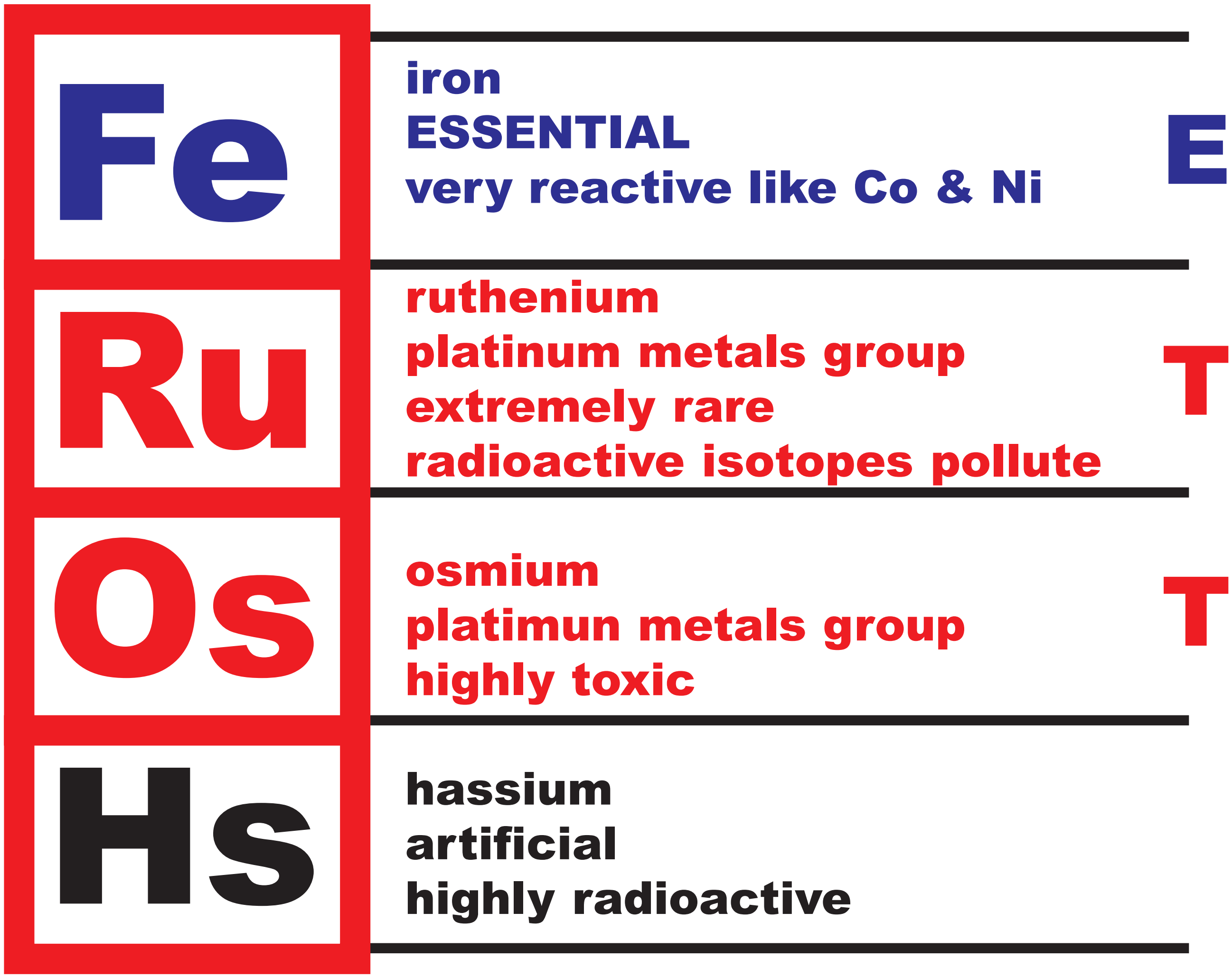

Figure 37: Element family group #8 and interactions.
E = essential; T = toxic

Co	**cobalt** **ESSENTIAL** **iron metal group**	**E**
Rh	**rhodium** **platimum metal group** **little reactivity**	
Ir	**iridium** **platimum metals group** **reactivity similar to Co & Ni**	
Mt	**meitnerium** **artificial** **highly radioactive**	

Figure 38: Element family group #9 and interactions.
E = essential

Ni	**nickel** **ESSENTIAL** **iron metal group**	**E**
Pd	**palladium** **platinum metals group**	**T**
Pt	**platinum** **platinum metals group**	**T**
Ds	**darmstadium** **artificial** **highly radioactive**	

Figure 39: Element family group #10 and interactions.
E = essential; T = toxic

Cu — copper
ESSENTIAL
can become esily toxic
E

Ag — silver
reactivity similar to Cu
1,000 times rarer than Cu
T

Au — gold
toxic at higher concentrations
inhibits membrane functions

Rg — roentgenium
artificial
highly radioactive

Figure 40: Element family group #11 and interactions.
E = essential; T = toxic

Zn	**zinc** **ESSENTIAL**	**E**
Cd	**cadnium** **bad eco-toxic element** **similar to Zn**	**T**
Hg	**mercury** **highly toxic** **easily volatile**	**T**
Cn	**copernicium** **artificial** **highly radioactive**	

Figure 41: Element family group #12 and interactions.
E = essential; T = toxic

B	**boron** **ESSENTIAL** **only metalloid in group**	**E**
Al	**alluminum / alluminium** **3rd most abundant element** **toxic at high concentrations**	
Ga	**gallium** **widely distributed but rare** **similar but less reactive than Al**	
In	**indium** **widely distributed but rare** **tree root toxicity**	**T**
Tl	**thallium** **highly toxic** **similar soil ractivity to K**	**T**

Figure 42: Element family group #13 and interactions.
E = essential; T = toxic

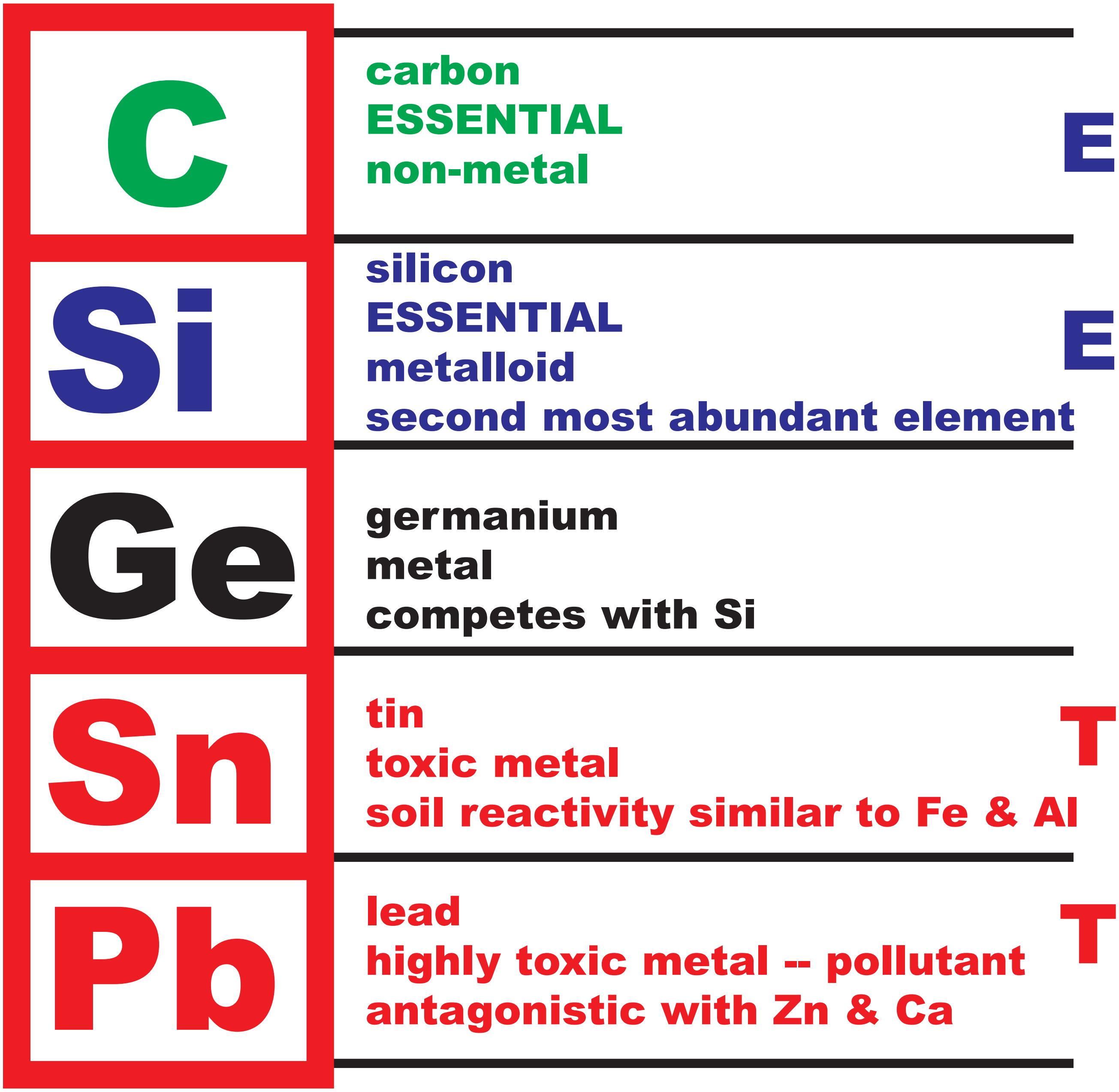

Figure 43: Element family group #14 and interactions.
E = essential; T = toxic

N	**nitrogen** **ESSENTIAL** **non-metal**	**E**
P	**phosphorus** **ESSENTIAL** **non-metal**	**E**
As	**arsenic** **metalloid** **similar reactivity to P**	**T**
Sb	**antimony** **metalloid** **pollutant -- mildly toxic**	
Bi	**bismuth** **rare** **benign -- non-toxic heavy metal**	

Figure 44: Element family group #15 and interactions.
E = essential; T = toxic

O	**oxygen** **ESSENTIAL** **non-metal**	**E**
S	**sulfur** **ESSENTIAL** **non-metal**	**E**
Se	**selenium** **non-metal** **similar to S**	**S**
Te	**tellurium** **metalloid** **similar to S & Se**	
Po	**polonium** **radioactive metalloid** **similar reactivity to Te, Bi, & Se**	**T**

Figure 45: Element family group #16 and interactions.
E = essential; S = substitution; T = toxic

F	**fluorine** **halogen non-metal** **highly reactive -- toxic pollutant**	**T**
Cl	**chlorine** **ESSENTIAL** **halogen non-metal** **soil & atmospheric source**	**E**
Br	**bromine** **halogen non-metal** **highly reactive** **competes with Cl**	**T**
I	**iodine** **halogen non-metal** **toxic at high concentrations**	
At	**astatine** **rarest native element on Earth** **highly radioactive**	

Figure 46: Element family group #17 and interactions.
E = essential; T = toxic

name	symbol	tree system disrupted
aluminum	Al	phosphate use & energy
antimony	Sb	competitive
arsenic	As	phosphate & nitrate use, competitive
beryllium	Be	phosphate use & energy
boron	B	phosphate & nitrate use
bromine	Br	phosphate & nitrate use, membranes
cadmium	Cd	membranes
cesium	Cs	replaces essential element
chromium	Cr	phosphate use & energy, competitive
copper	Cu	membranes
fluorine	F	phosphate & nitrate use, membranes, competitive
gallium	Ga	phosphate & nitrate use, competitive
germanium	Ge	membranes, sulfur use
gold	Au	membranes
iodine	I	membranes
lanthanum & heavier metals		phosphate use & energy, membranes
lead	Pb	membranes, sulfur use
lithium	Li	replaces essential element
mercury	Hg	sulfur use, membranes
rubidium	Rb	replaces essential element
scandium	Sc	phosphate use & energy
selenium	Se	replaces essential element, phosphate & nitrate use, competitive
silver	Ag	sulfur use, membranes
sodium	Na	osmoticum
strontium	Sr	replaces essential element
tellurium	Te	phosphate & nitrate use, competitive
tin	Sn	membranes, sulfur use
titanium	Ti	phosphate use & energy, competitive
tungsten	W	phosphate & nitrate use, competitive
uranium	U	membranes
yttrium	Y	phosphate use & energy
zirconium	Zr	phosphate use & energy

Figure 47: List of toxic impacts on trees

essential metals can impact tree health. If manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) concentrations are individually at the upper end of their beneficial value (i.e. individually nontoxic), addition of less than toxic amounts of cobalt and nickel could still generate a combined metal toxicity problem in a tree.

Heavy

Figure 48 presents the heavy metals (heavy metals = >50amu). These metals include tree damaging elements under high concentrations. Some of these heavy metals are damaging even at low concentrations. In this figure these metals can all be found as trace pollutants in organic materials and fertilizers used in landscapes. Site accumulation over time can be significant.

Figure 49 demonstrates the type of damge trees sustain from select toxic elements. Most tree toxic elements impact cell membranes, nitrogen and phosphorus processing, sulfur metabolism, and / or interfer with tree essential elements. For life in general, and trees in particular, there are a number of severe poison elements which have almost no safe concentration. These elements are notorious from detective novels, royal histories, and international spy thrillers. Figure 50 presents a list of the most toxic elemnet to trees and tree sites. Microorganisms which support soil health and tree life can be baly damaged by these elements.

Conclusions

Elements came from fusion fires and explosions. Element distribution across the universe varies by location. Elements come in many sizes, reactivities and forms. Most are not essential in trees. There are a few tree essential elements and a number of similar but toxic elements, sometimes within the same family group. Tree health care requires understanding tree essential elements.

Bi	**bismuth**	**Ni***	**nickle**
Cd	**cadnium**	**Os**	**osmium**
Co*	**cobalt**	**Pb**	**lead**
Cr	**chromium**	**Pd**	**palladium**
Cu*	**copper**	**Pt**	**platinum**
Fe*	**iron**	**Re**	**rhenium**
Ga	**gallium**	**Ru**	**rhodium**
Hg	**mercury**	**Sn**	**tin**
In	**indium**	**Ta**	**tantalum**
Ir	**iridium**	**Tl**	**thallium**
Mn*	**manganese**	**V**	**vanadium**
Mo*	**molybdenum**	**W**	**tungsten**
Nb	**niobium**	**Zn***	**zinc**

Figure 48: Heavy metals (transition metals & metals greater than 50 atomic weight) present as an impurity or pollution legacy in sewage sludge, organic fertilizers, organic compost products, and inorganic fertilizers which accumulate in tree landscapes.

(* = tree essential element)

Cell membrane disruption

Ag, Au, Br, Cd, F, Hg, I, Pb, U

Nitrate / phosphate disruption

Al, As, B, Be, Br, F, Sc, Se, Te, W, Y, Zr, lanthanides

Sulfur compounds disruption

Ag, Hg, Pb

Competition / replacement of essential elements

As, Cs, Li, Rb, Sb, Se, Sr, Te, W, F

Figure 49: Primary toxic impacts of selected native and pollution added elements in trees.
(from Kabata-Pendias 2011)

TREE SITE KILLERS

Ag	silver	In	indium
As	arsenic	Li	lithium
Be	beryllium	Os	osmium
Br	bromine	Pb	lead
Cd	cadnium	Pd	palladium
Co	cobalt	Po*	polonium
Cr	chromium	Pt	platinum
Cs	cesium	Ru	ruthenium
Cu	copper	Sn	tin
F	fuorine	Sr	strontium
Hg	mercury	Tl	titanium

Figure 50: The most toxic elements for trees and soil microorganisms. Does not include general radioactive elements / isotopes.
(from Kabata-Pendias 2011)