

# An Earth Scientist's Periodic Table of the Elements and Their Ions

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## "Hard" or "Type A" Cations

(All electrons removed from outer shell)  
 (Thus a noble-gas-like configuration of the outer shell)  
 Coordinate  $F > O > N > Cl > Br > S$   
 Commonly coordinate with O of carboxyl groups of organic ligands  
 See also Insets 1 to 5 and 7.

Outline solid for naturally occurring elements or ions; dashed for ones that rarely or never occur in nature.

Symbol (see scale at far right)  
 Element Name  
 Atomic Mass  
 Atomic Number (number of protons)  
 Ionic Radius (r) (Å) (or elemental radius for elemental forms)  
 Most abundant (bold)  
 Radioactive (italicized)

Radioactive decay pathways

$Z_f =$  ionic charge + ionic radius

- Ions least depleted from mantle in formation of crust
- ★ Ions enriched in CAIs (Ca-Al-rich inclusions in meteorites) relative to the composition of the solar system
- Ions that enter early-forming phases in igneous rocks
- Ions commonly concentrated in residual soils and residual sediments. Small symbol (●) indicates less certainty.
- Ions concentrated in deep-sea ferromanganese nodules relative to seawater
- Ions that enter later phases in igneous rocks because of their large size (mostly "large-ion lithophiles")
- 8 most abundant solutes dissolved in seawater
- 9<sup>th</sup> to 16<sup>th</sup> most abundant
- 17<sup>th</sup> to 22<sup>nd</sup> most abundant
- Most abundant solute in average river water (HCO<sub>3</sub><sup>-</sup>)
- 2<sup>nd</sup> to 8<sup>th</sup> most abundant solutes in average river water
- Solutes that can be limiting nutrients in the growth of bacteria
- Solutes that can be limiting nutrients in the oceans
- Macronutrient solutes on land
- Micronutrient solutes on land
- Ions essential to the nutrition of at least some vertebrates ("essential minerals")

- Elements that form simple fluoride minerals
- Cations that form simple oxide minerals
- Cations that form simple sulfide minerals
- Cations that form simple bromide or iodide minerals
- Cations that form oxysalt minerals (e.g., S<sup>6+</sup> in sulfates, As<sup>5+</sup> in arsenates)
- Anions that form minerals with K<sup>+</sup> and Na<sup>+</sup>
- Anions that form minerals with Mg<sup>2+</sup>
- Anions that form minerals with Al<sup>3+</sup>, Ti<sup>4+</sup>, and Zr<sup>4+</sup>
- Anions that form minerals with Si<sup>4+</sup>
- Anions that form minerals with Cu<sup>+</sup>
- Anions that form minerals with Ag<sup>+</sup>
- Anions that form minerals with Au<sup>+</sup>

- Elements that occur as native minerals, recognized in antiquity (recognized from Middle Ages to 1862; recognized after 1863.)
- Elements that make natural mineral alloys with Fe
- Elements that make natural mineral alloys with Cu
- Elements that make natural mineral alloys with Os
- Elements that make natural mineral alloys with Pt
- Elements that make natural mineral alloys with Au
- 4 most abundant constituents in atmosphere
- 5<sup>th</sup> to 8<sup>th</sup> most abundant

- Fe 10 most abundant elements in Earth's crust
- Zr 11<sup>th</sup> to 20<sup>th</sup> most abundant elements in Earth's crust
- Li 21<sup>st</sup> to 40<sup>th</sup> most abundant elements in Earth's crust
- Lu 41<sup>st</sup> to 92<sup>nd</sup> most abundant elements in Earth's crust
- Elements that are thought to make up most of the Earth's core (Fe>Ni>Co), along with possibly S or O

## Noble Gases

(No ionization)

He	2	m=4.0026	r=1.2
Ne	10	m=20.180	r=1.5
Ar	18	m=39.948	r=1.8
Kr	36	m=83.80	r=1.9
Xe	54	m=131.29	r=2.1
Rn	86	m=222	r=2.3

## Anions

with incomplete outer electron shells

## Anions

with full outer electron shells

Anions that commonly coordinate with H<sup>+</sup> (e.g., as CH<sub>4</sub>, NH<sub>3</sub>, H<sub>2</sub>S, H<sub>2</sub>O, etc.)

H	1	m=1.0079	r=1.2
Li	3	m=6.941	r=0.31
Na	11	m=22.990	r=0.95
K	19	m=39.098	r=1.33
Rb	37	m=85.468	r=1.48
Cs	55	m=132.905	r=1.69
Fr	87	m=223	r=1.75

## Elemental Forms

(uncharged) other than noble gases

C	6	m=12.011	r=0.77
N	7	m=14.007	r=0.71
O	8	m=15.999	r=0.73
Si	14	m=28.086	r=1.11
Al	13	m=26.982	r=1.19
Fe	26	m=55.845	r=1.26
Cu	29	m=63.546	r=1.28
Zn	30	m=65.38	r=1.25
Ag	47	m=107.868	r=1.44
Au	79	m=196.967	r=1.75

## Rare earth elements (REEs)

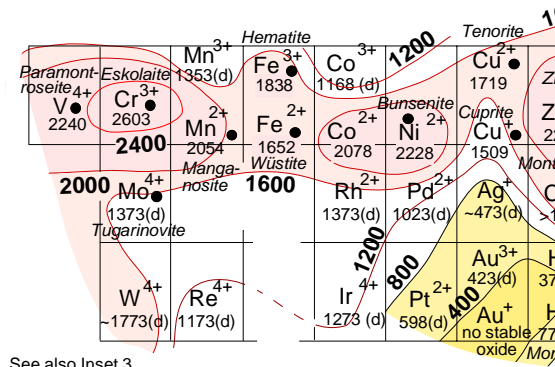
(effectively "Hard" or "Type A" cations in their 3+ state)

Ce	58	m=140.908	r=1.09
Pr	59	m=140.908	r=1.09
Nd	60	m=144.24	r=1.08
Sm	62	m=150.36	r=1.04
Eu	63	m=151.964	r=1.03
Gd	64	m=157.25	r=1.02
Tb	65	m=158.925	r=1.00
Dy	66	m=162.50	r=0.99
Ho	67	m=164.930	r=0.97
Er	68	m=167.26	r=0.96
Tm	69	m=168.934	r=0.95
Yb	70	m=173.04	r=0.94
Lu	71	m=174.967	r=0.93

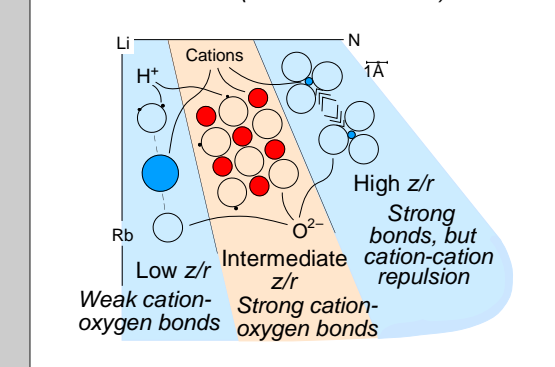
## Inset 5: Typical simple oxysalt minerals

B <sup>3+</sup>	C <sup>4+</sup>	N <sup>5+</sup>	Minerals with cations of very low ionic potential (e.g., K <sup>+</sup> , Na <sup>+</sup> , Ba <sup>2+</sup> )
MgAlBO <sub>3</sub> (Sinhaitite)	Na <sub>2</sub> CO <sub>3</sub> (e.g., Calcite)	NaNO <sub>3</sub> (Niter)	
K <sup>+</sup>	Ca <sup>2+</sup>	Ti <sup>4+</sup>	Minerals with cations of low (e.g., K <sup>+</sup> ) ionic potential
Rb <sup>+</sup>	Sr <sup>2+</sup>	Zr <sup>4+</sup>	
Cs <sup>+</sup>	Ba <sup>2+</sup>	Hf <sup>4+</sup>	

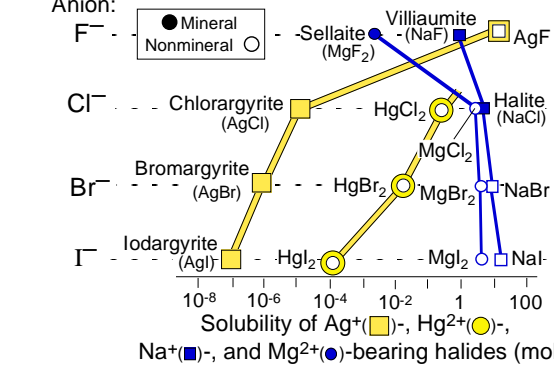
## Inset 6: Melting and decomposition (d) temperatures (K) of oxides of intermediate and soft cations



## Inset 7: Conceptual model of the behavior of oxides of hard (and intermediate) cations



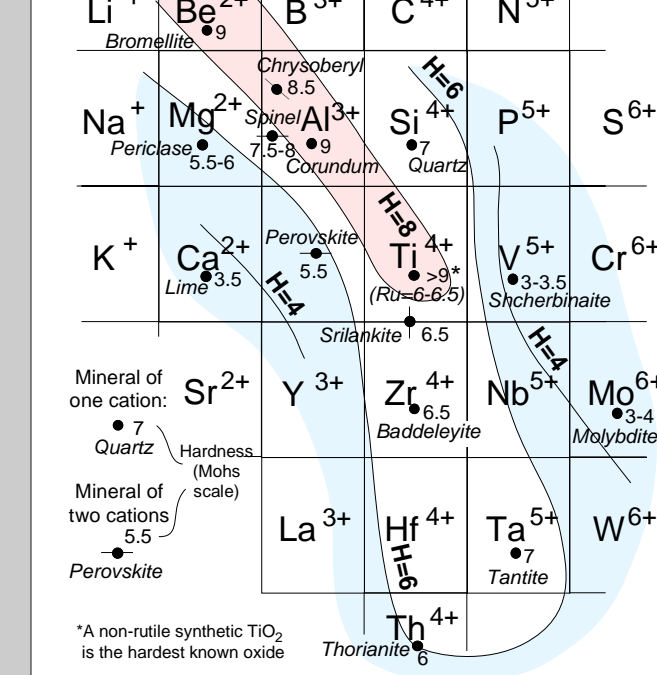
## Inset 8: Solubility of halides of hard and soft cations



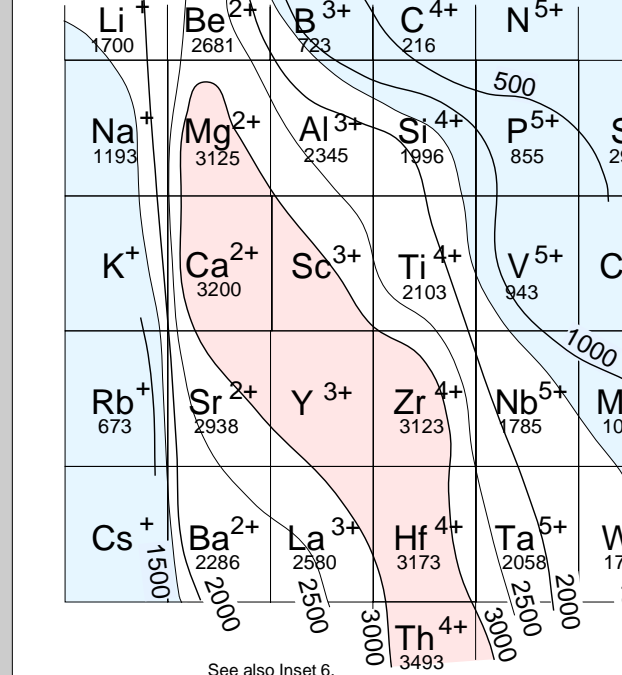
## Inset 9: The many valence states of nitrogen

Valence state	Example
+5	NO <sub>3</sub> <sup>-</sup> (nitrate)
+4	NO <sub>2</sub> (nitrogen dioxide)
+3	NO <sub>2</sub> <sup>-</sup> (nitrite)
+2	NO (nitric oxide)
+1	N <sub>2</sub> O (nitrous oxide)
0	N <sub>2</sub> (nitrogen)
-3	NH <sub>3</sub> (ammonia)

## Inset 2: Hardness of oxide minerals of hard cations



## Inset 3: Melting T(K) of oxides of hard cations



## Inset 4: Solubility of oxide minerals of hard cations

