Announcements

- No class on Monday
- Reading for Wed: p.160-166 (switched)
- HW 3 due Monday
- Midterm: e-mail work?
  - Will be on web site ~9AM on Monday
  - Have until 5PM Monday to finish it and return it
  - Should take 2 hours or less
  - Covers through Goldschmidt's Rules
  - Can use lecture notes and textbook

Overview

- Concentration units
- Major vs. trace elements
- Mole fraction vs. concentration
- Bulk distribution coefficient
- Example

Goldschmidt's Rules: general guidelines

Cation A^{X+}:

Radius = R_A
Charge = X

Cation B^{Y+}:

Radius = R_B
Charge = Y

- Partition coefficient: K_D or D (mineral-melt)

$K_D^A = [A]_{mineral}/[A]_{melt}$

$K_D^B = [B]_{mineral}/[B]_{melt}$

$R_A \sim R_B$

$K^A \sim K^B$

+2 +2

If radii are the same but charges are different (X > Y)

$R_A \sim R_B$

$K^A > K^B$

+3 +2

If charges are the same (X = Y) but radii are different

$R_A > R_B$

$K^A < K^B$

+2 +2

Major-Minor-Trace

- Major elements: >1.0 wt%
- Minor elements: 0.1 – 1.0 wt%
- Trace elements: <0.1 wt%

- Why would we use trace elements in geochemistry?
- What are the trace elements of interest?

Major Elements

Note magnitude of major element changes

How does fractional crystallization or partial melting affect these elements?

The total mass of crystals / melt?

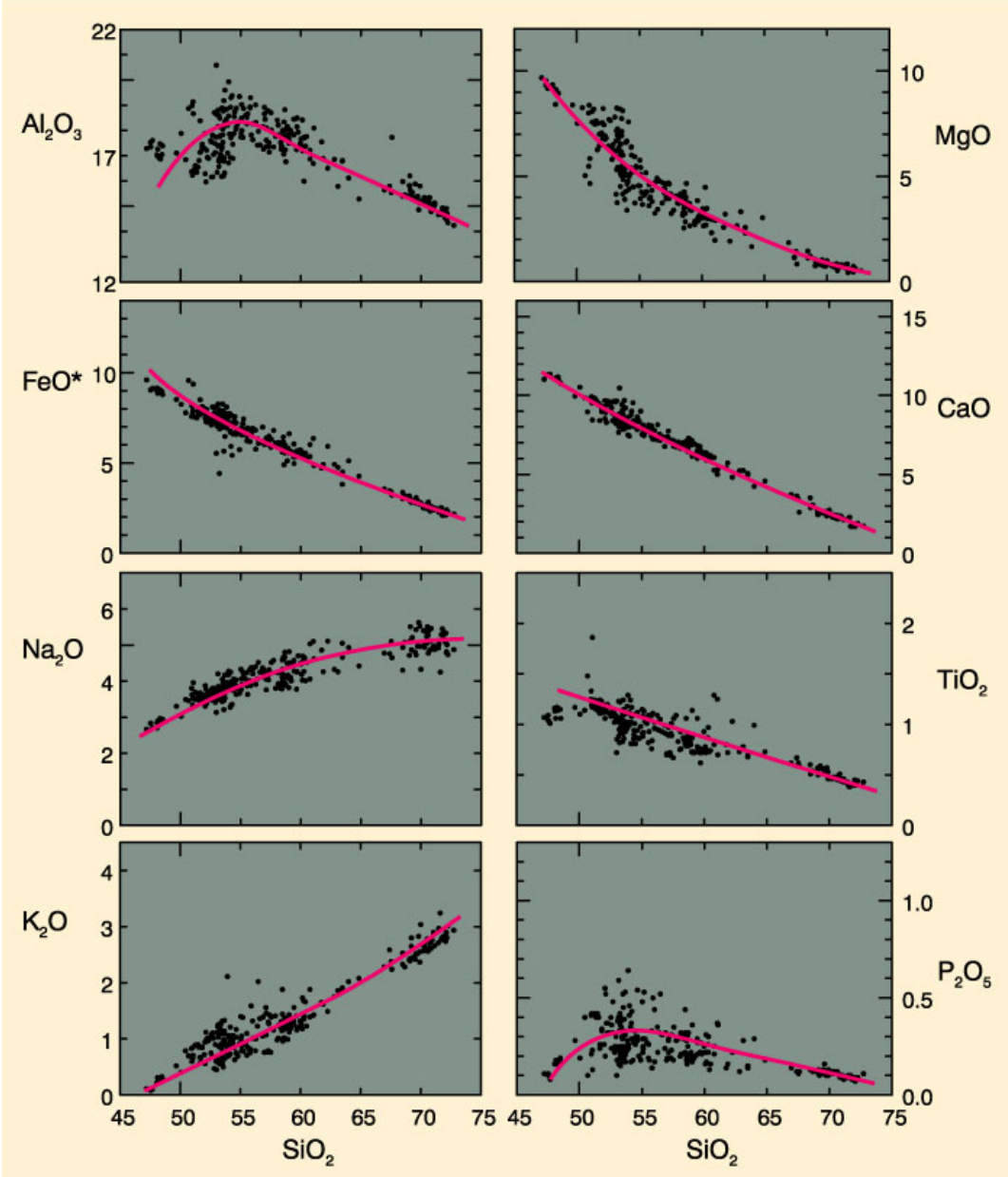
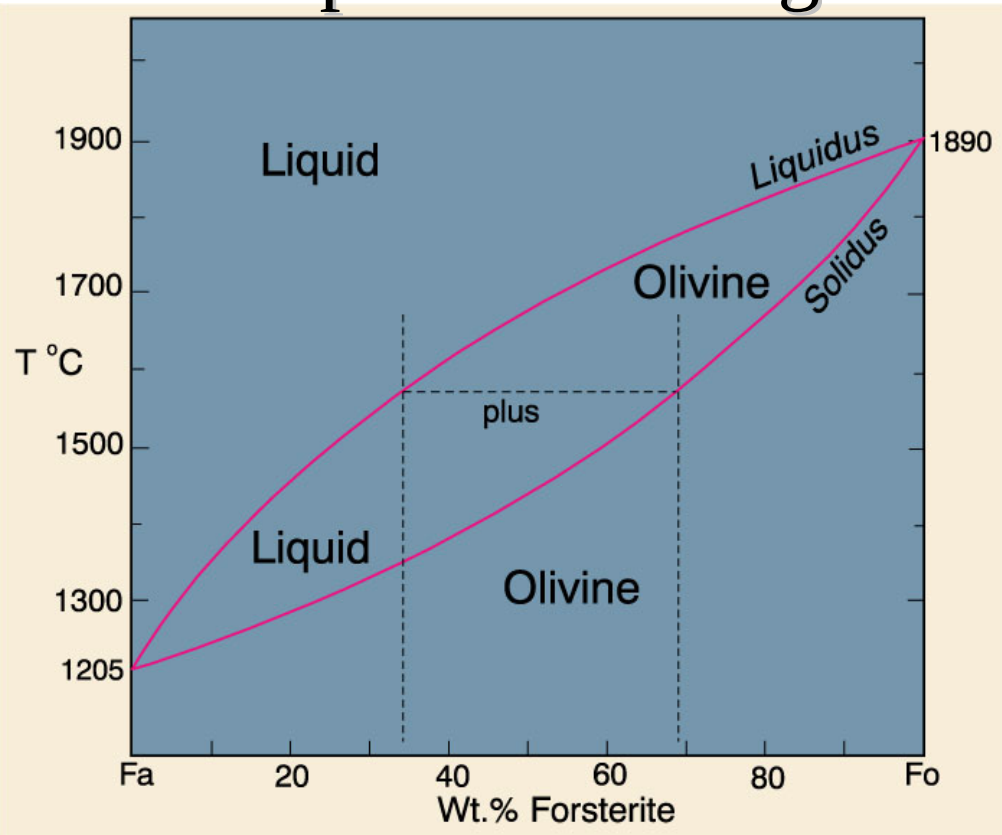


Figure 8-2. Harker variation diagram for 310 analyzed volcanic rocks from Crater Lake (Mt. Mazama), Oregon Cascades. Data compiled by Rick Conrey (personal communication). From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Major Element Behavior

- The concentration of a major element in a phase is usually buffered by the system, so that it varies little in a phase as the system composition changes



At a given T we could vary X_{bulk} from 35 → 70 % Mg/Fe without changing the composition of the melt or the olivine

Trace Elements

Units of trace element concentrations?

How does fractional crystallization or partial melting affect these elements?

The total mass of crystals / melt?

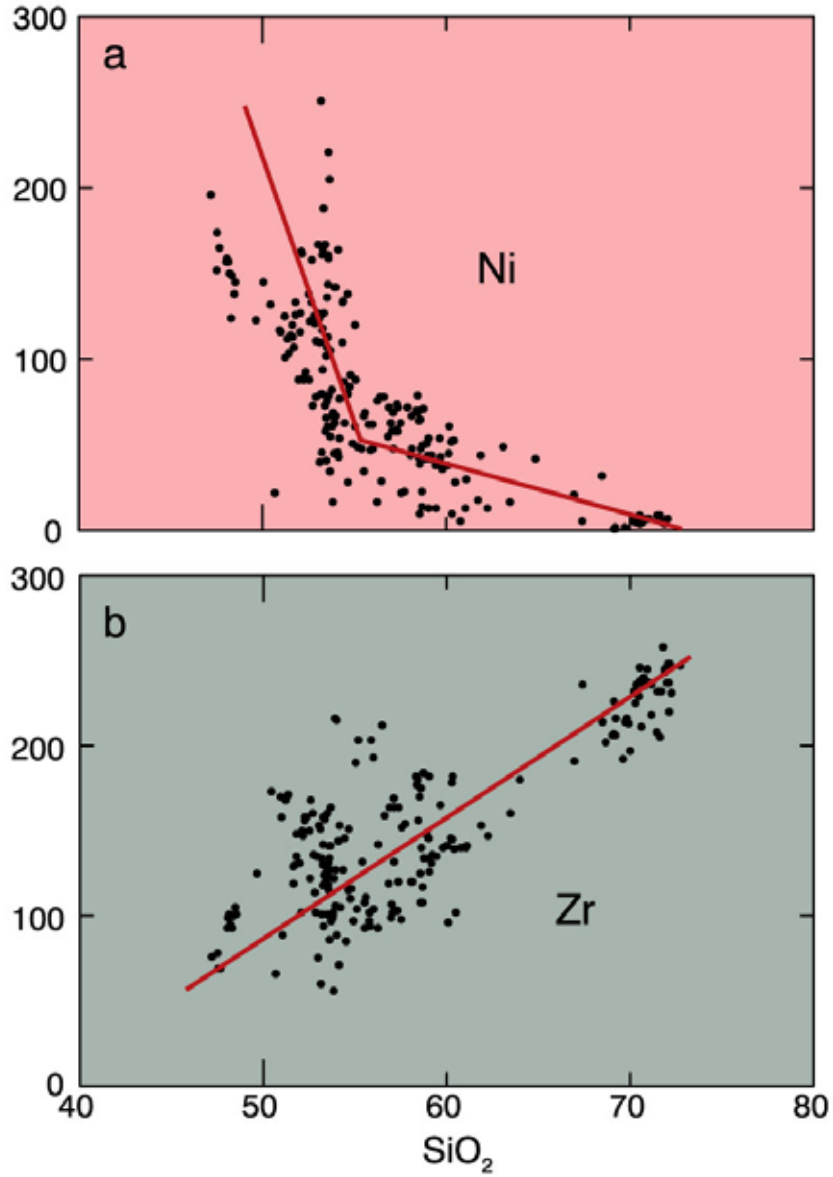


Figure 9-1. Harker Diagram for Crater Lake. From data compiled by Rick Conrey. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Units of concentration

- Weight % (usually of oxide) = g / g

  100*(x g Na_2O / 1 g melt)

- Parts per million (usually element) = μg / g

  200 g Ni / 1000000 g melt =

  0.0002 g Ni / 1 g melt =

  0.02 mg Ni / 1 g melt = 200 ppm Ni

Trace element concentrations are in the Henry's Law region of concentration, so their activity varies in direct relation to their concentration in the system

Thus if X_{Ni} in the system doubles the X_{Ni} in all phases will double

Exchange equilibrium of a component *i* between two phases (solid and liquid)

$$i_{(\text{liquid})} = i_{(\text{solid})}$$

eq. 9-2 $$K = \frac{a_i^{\text{solid}}}{a_i^{\text{liquid}}} = \frac{\gamma_i X_i^{\text{solid}}}{\gamma_i X_i^{\text{liquid}}}$$

K = equilibrium constant

- For dilute solutions (ie, trace elements) can substitute D for K_D:

$$D = \frac{C_S}{C_L}$$

Where C_S = the concentration of some element in the solid phase

- incompatible elements are concentrated in the melt

$(K_D \text{ or } D) \ll 1$

- compatible elements are concentrated in the solid

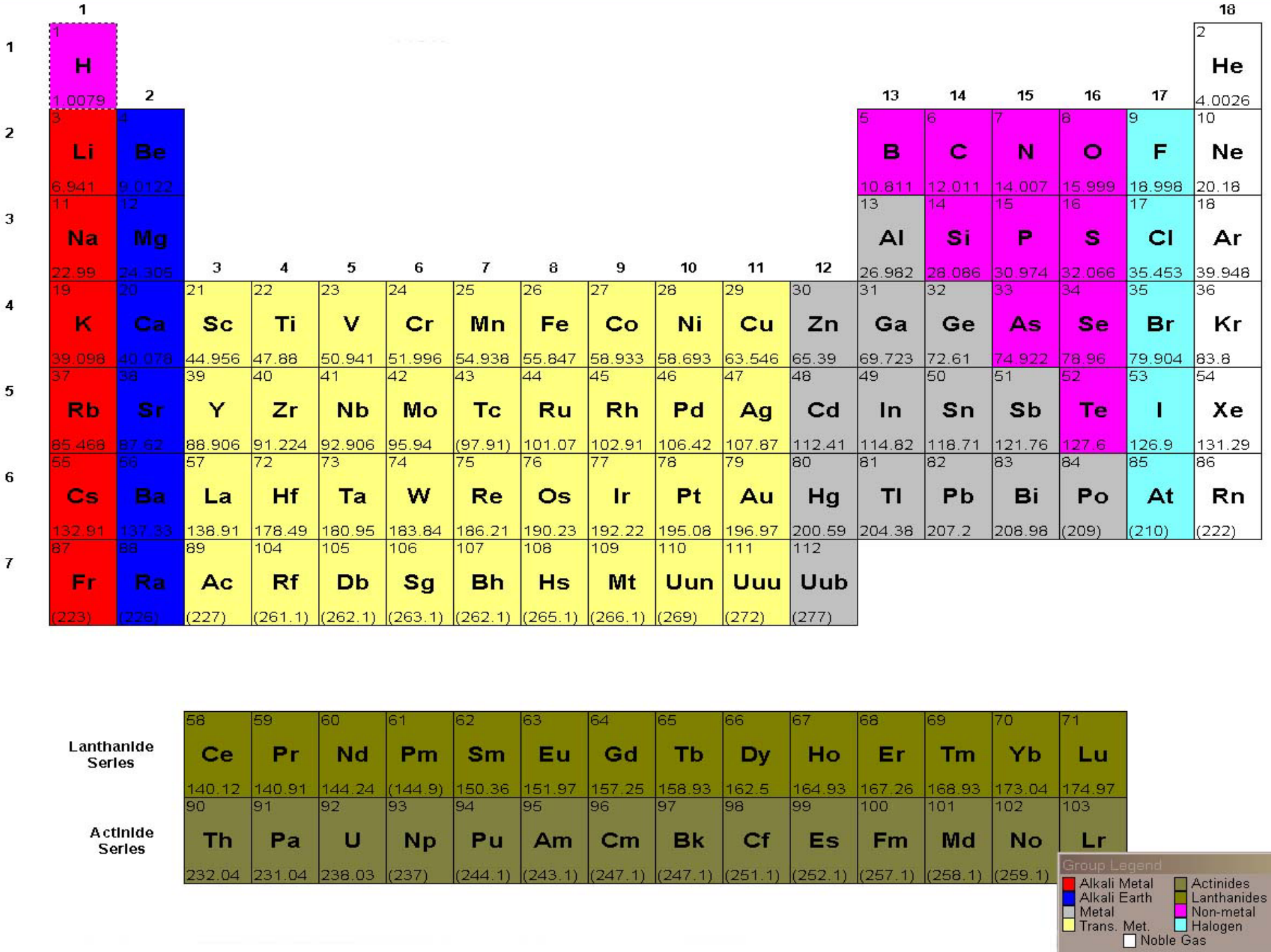
$K_D \text{ or } D \gg 1$

Bulk distribution coefficient

1. Convert to weight % minerals (W_{ol} W_{cpx} etc.)

2. Use equation eq. 9-4: $D_i = \Sigma W_A D_i$

and the table of D values for Rb and Sr in each mineral to calculate the bulk distribution coefficients


1
18
2
13
14
15
16
17
1
H
1.0079
2
He
4.0026
3
Li
6.941
4
Be
9.0122
5
B
10.811
6
C
12.011
7
N
14.007
8
O
15.999
9
F
18.998
10
Ne
20.18
11
Na
22.99
12
Mg
24.305
3
4
5
6
7
8
9
10
11
12
13
Al
26.982
14
Si
28.086
15
P
30.974
16
S
32.066
17
Cl
35.453
18
Ar
39.948
19
K
39.098
20
Ca
40.078
21
Sc
44.956
22
Ti
47.88
23
V
50.941
24
Cr
51.996
25
Mn
54.938
26
Fe
55.847
27
Co
58.933
28
Ni
58.693
29
Cu
63.546
30
Zn
65.39
31
Ga
69.723
32
Ge
72.61
33
As
74.922
34
Se
78.96
35
Br
79.904
36
Kr
83.8
37
Rb
85.468
38
Sr
87.62
39
Y
88.906
40
Zr
91.224
41
Nb
92.906
42
Mo
95.94
43
Tc
(97.91)
44
Ru
101.07
45
Rh
102.91
46
Pd
106.42
47
Ag
107.87
48
Cd
112.41
49
In
114.82
50
Sn
118.71
51
Sb
121.76
52
Te
127.6
53
I
126.9
54
Xe
131.29
55
Cs
132.91
56
Ba
137.33
57
La
138.91
72
Hf
178.49
73
Ta
180.95
74
W
183.84
75
Re
186.21
76
Os
190.23
77
Ir
192.22
78
Pt
195.08
79
Au
196.97
80
Hg
200.59
81
Tl
204.38
82
Pb
207.2
83
Bi
208.98
84
Po
(209)
85
At
(210)
86
Rn
(222)
87
Fr
(223)
88
Ra
(226)
89
Ac
(227)
104
Rf
(261.1)
105
Db
(262.1)
106
Sg
(263.1)
107
Bh
(262.1)
108
Hs
(265.1)
109
Mt
(266.1)
110
Uun
(269)
111
Uuu
(272)
112
Uub
(277)
Lanthanide Series
58
Ce
140.12
59
Pr
140.91
60
Nd
144.24
61
Pm
(144.9)
62
Sm
150.36
63
Eu
151.97
64
Gd
157.25
65
Tb
158.93
66
Dy
162.5
67
Ho
164.93
68
Er
167.26
69
Tm
168.93
70
Yb
173.04
71
Lu
174.97
Actinide Series
90
Th
232.04
91
Pa
231.04
92
U
238.03
93
Np
(237)
94
Pu
(244.1)
95
Am
(243.1)
96
Cm
(247.1)
97
Bk
(247.1)
98
Cf
(251.1)
99
Es
(252.1)
100
Fm
(257.1)
101
Md
(258.1)
102
No
(259.1)
103
Lr
Group Legend
Alkali Metal
Alkali Earth
Metal
Trans. Met.
Actinides
Lanthanides
Non-metal
Halogen
Noble Gas