Asteroids

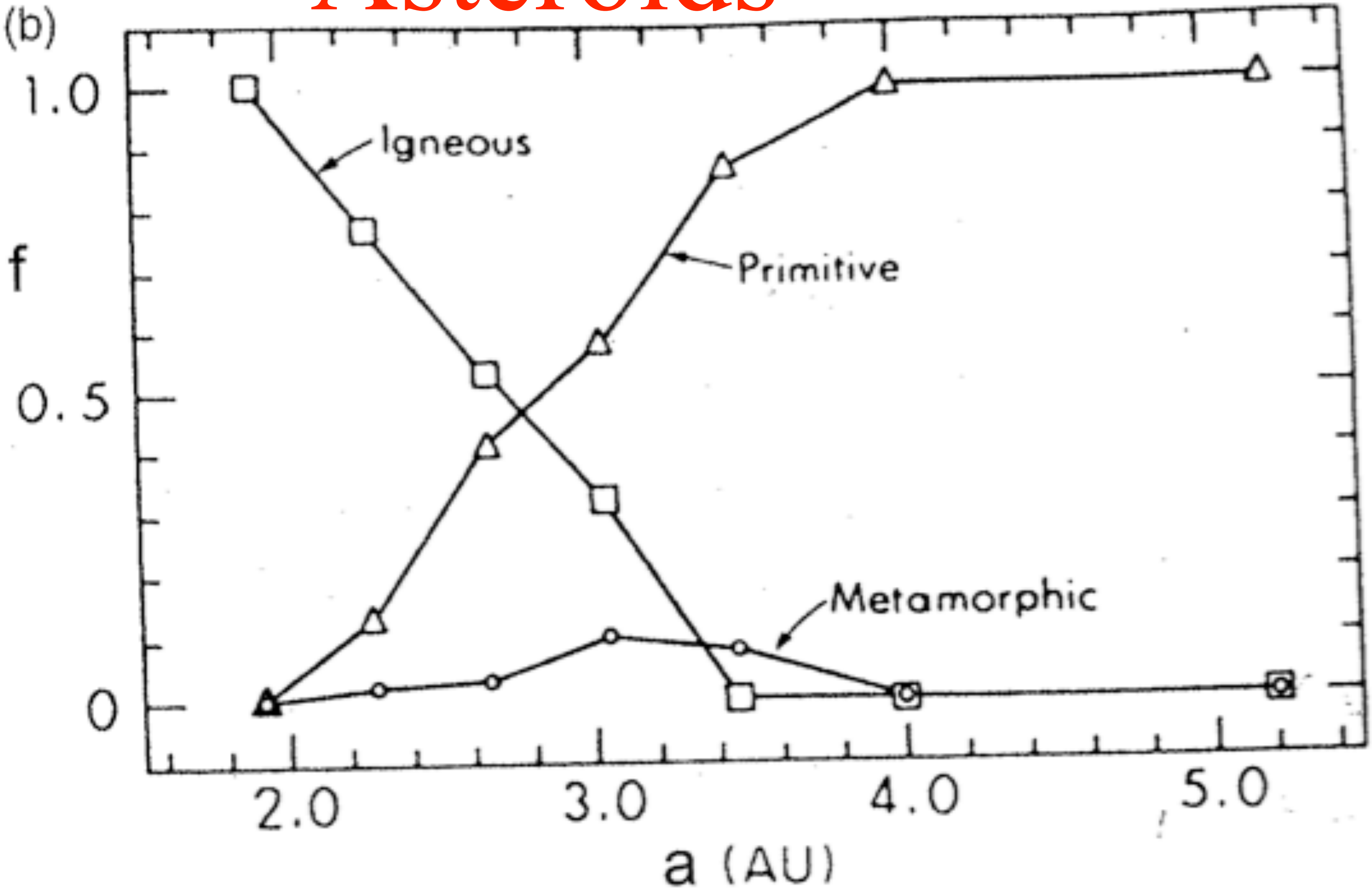


FIGURE 9.18 (a) Graph showing the relative distribution of the asteroid taxonomic classes as a function of heliocentric distance.

Igneous Rocks

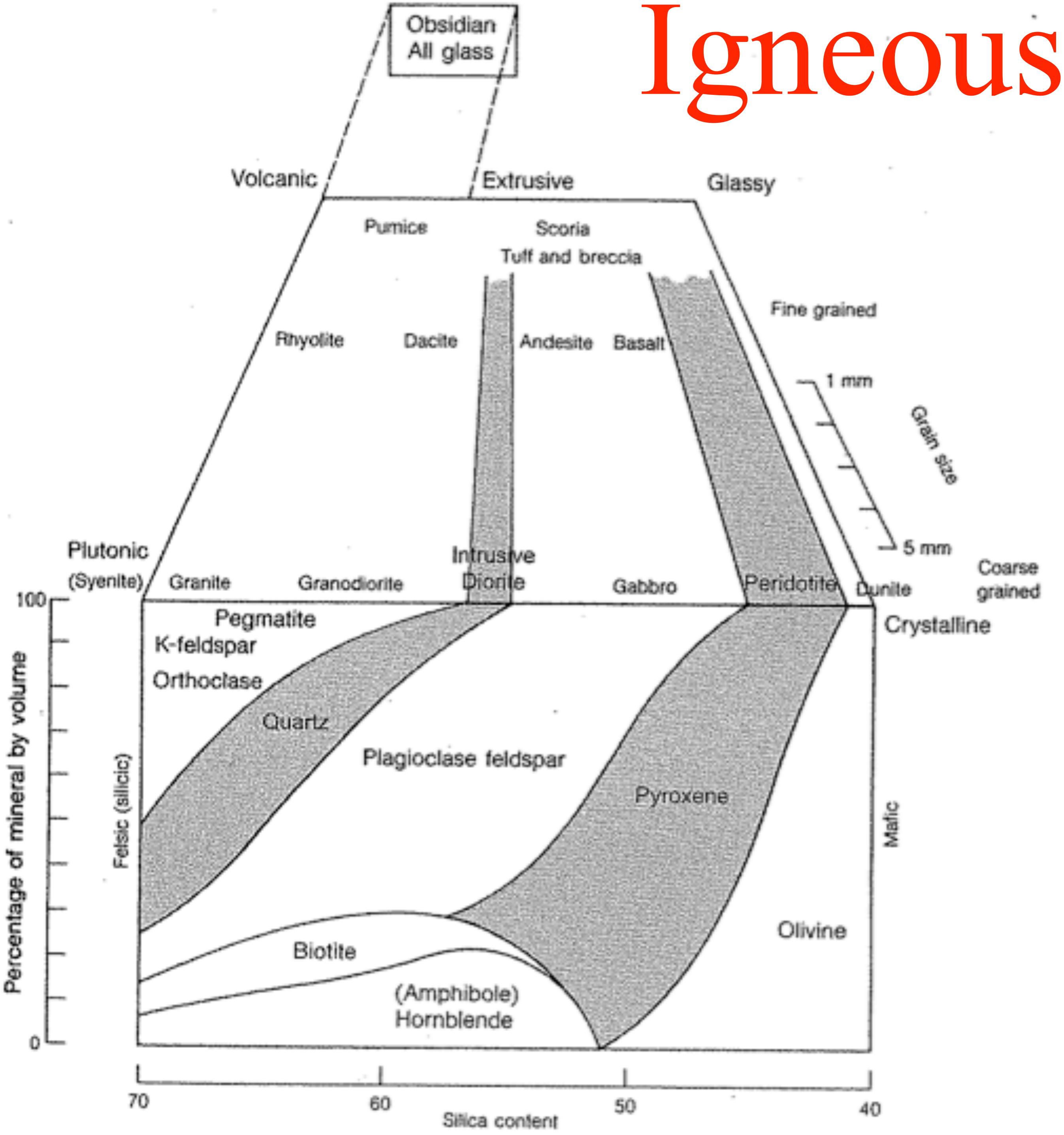
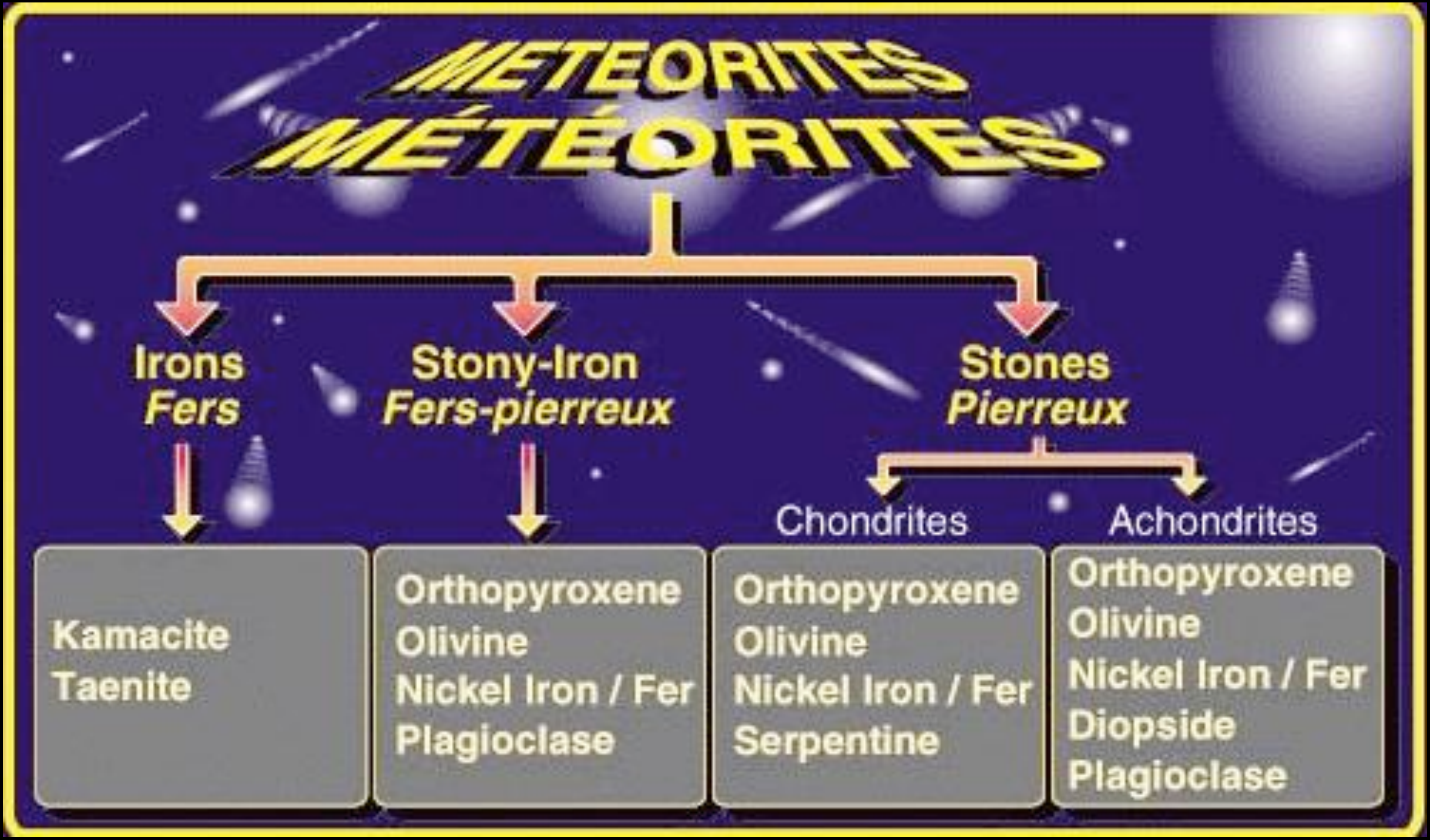


Figure 5.4 A classification cube for igneous rocks. The horizontal axis shows the silica content of the rocks (percent by volume), and the vertical axis the percentage of a given mineral. The texture of the rocks is indicated as a function of grain size along the receding axis, at the top of the cube. A granite with a silica content of 70% contains about 25% quartz (SiO_2), less than 10% of each biotite, hornblende and plagioclase feldspar, and 50% K-feldspar or orthoclase. Fine-grained granites are called rhyolite. Rocks with a lower silica content are more mafic. Peridotite consists of varying fractions of pyroxene and olivine. Rocks that contain more than 90% olivine are called dunite. (Press and Siever 1986)

Classification: Beginner’s Guide



METEORITES
MÉTÉORITES

Irons
Fers

- Kamacite
- Taenite

Stony-Iron
Fers-pierreux

- Orthopyroxene
- Olivine
- Nickel Iron / Fer
- Plagioclase

Stones
Pierreux

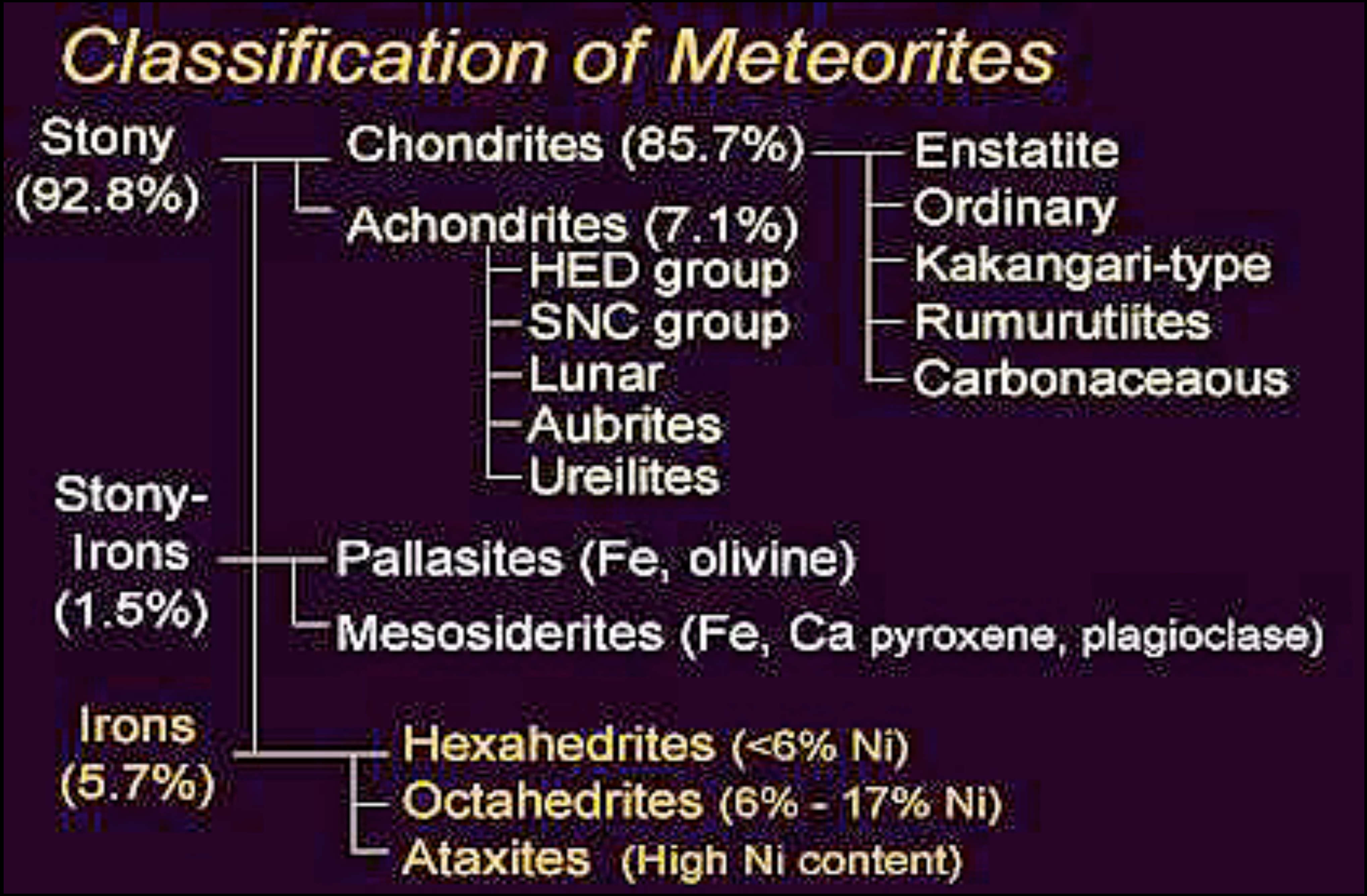
Chondrites

- Orthopyroxene
- Olivine
- Nickel Iron / Fer
- Serpentine

Achondrites

- Orthopyroxene
- Olivine
- Nickel Iron / Fer
- Diopside
- Plagioclase

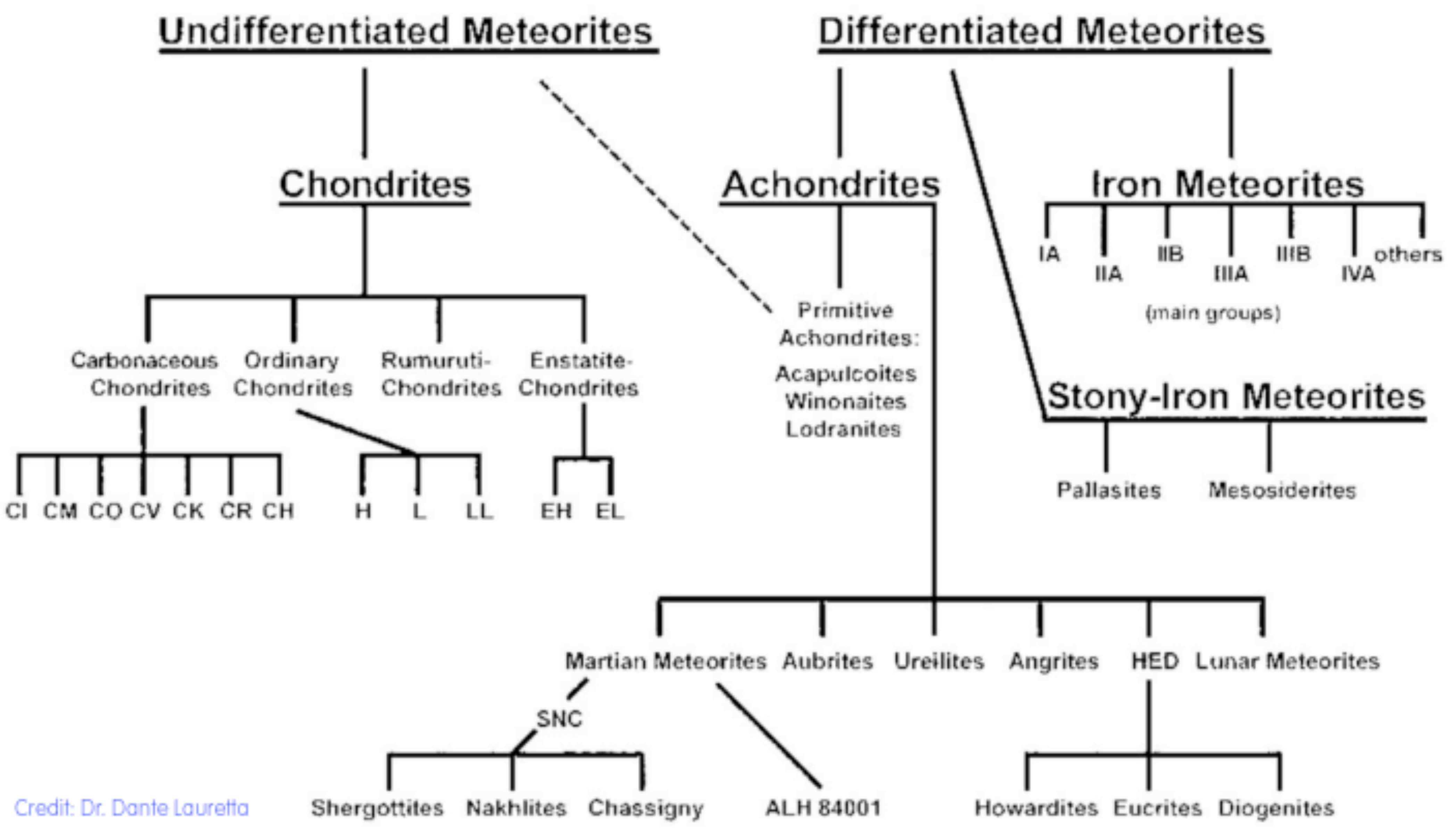
Classification: Intermediate Guide



Classification of Meteorites

- Stony (92.8%)
  - Chondrites (85.7%)
    - Enstatite
    - Ordinary
    - Kakangari-type
    - Rumurutiites
    - Carbonaceaous
  - Achondrites (7.1%)
    - HED group
    - SNC group
    - Lunar
    - Aubrites
    - Ureilites
- Stony-Irons (1.5%)
  - Pallasites (Fe, olivine)
  - Mesosiderites (Fe, Ca pyroxene, plagioclase)
- Irons (5.7%)
  - Hexahedrites (<6% Ni)
  - Octahedrites (6% - 17% Ni)
  - Ataxites (High Ni content)

Classification: Advanced Guide



Credit: Dr. Dante Lauretta

Table 8.2 Meteorite Classes and Numbers (as of September 2008).

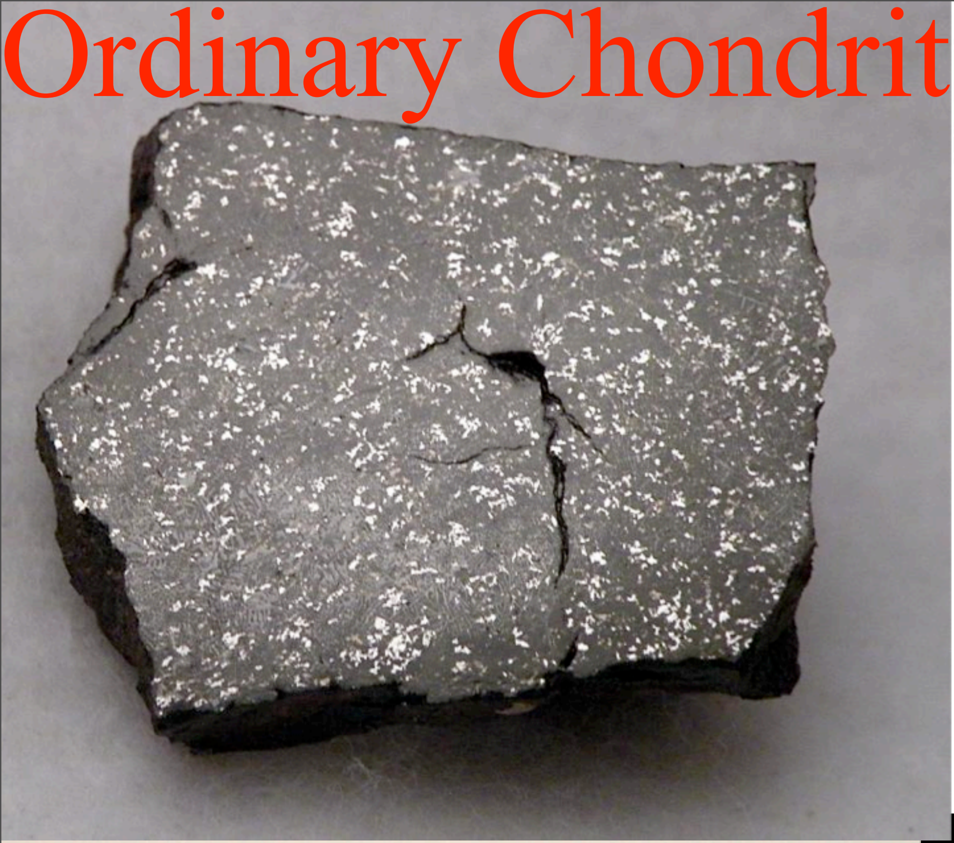
	Falls	Fall frequency (%)	Non-Antarctic finds	Antarctic finds[a]
Total cataloged	1070	–	9582	15 660
Stones	1009	94.3	8648	15 495
Chondrites	916	85.6	7964	15 082
Carbonaceous chondrites	42	3.8	319	494
Achondrites	87	8.1	684	413
Martian meteorites	4	0.4	53	9
Lunar meteorites	0		93	19
Stony-irons	12	1.1	139	56
Irons	49	4.5	795	109

Data from Meteoritical Bulletin Database (http://tin.er.usgs.gov/meteor/metbull.php).

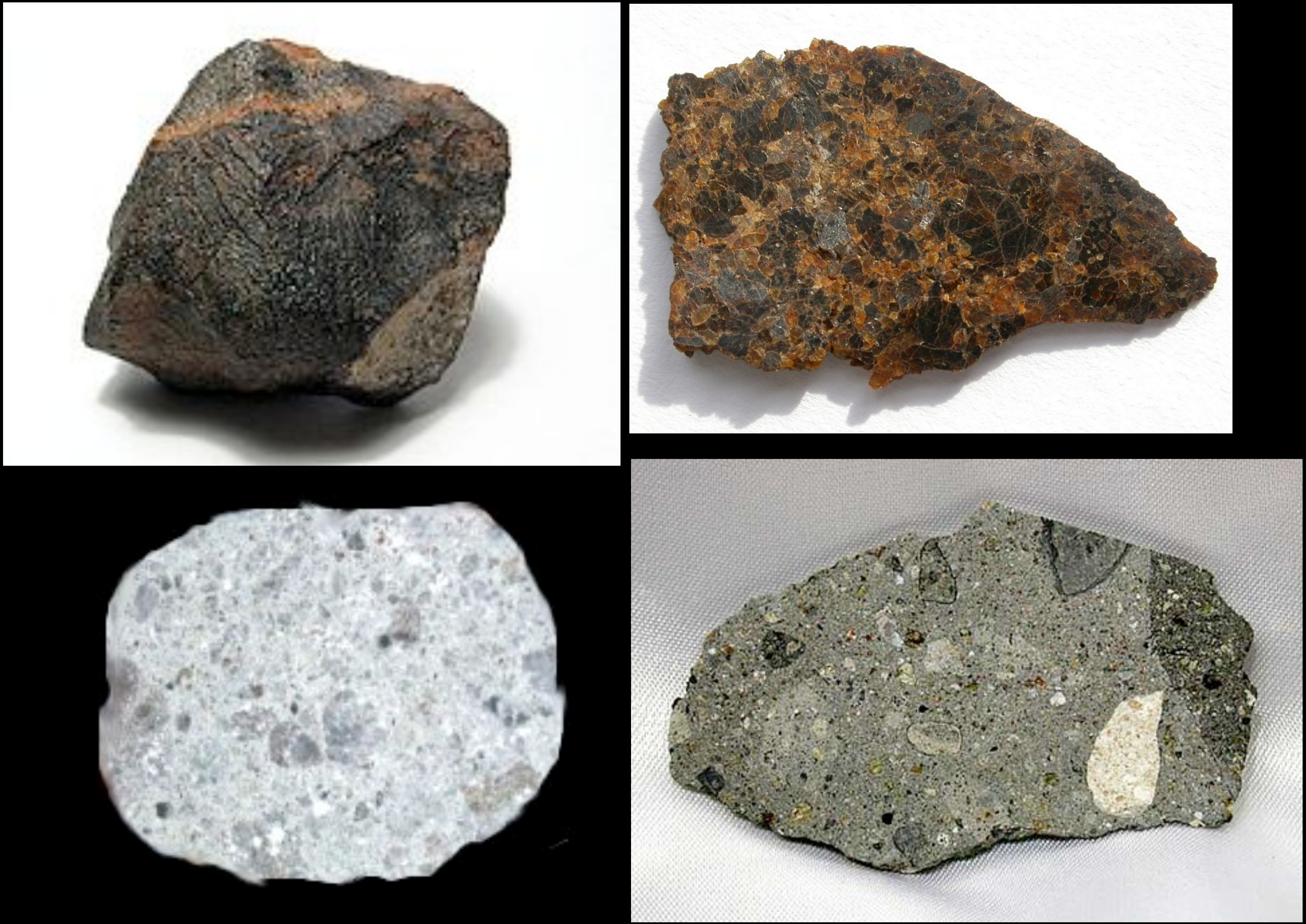
[a] Lists the well-cataloged ANSMET collection only.

Carbonaceous Chondrite

Ordinary Chondrites

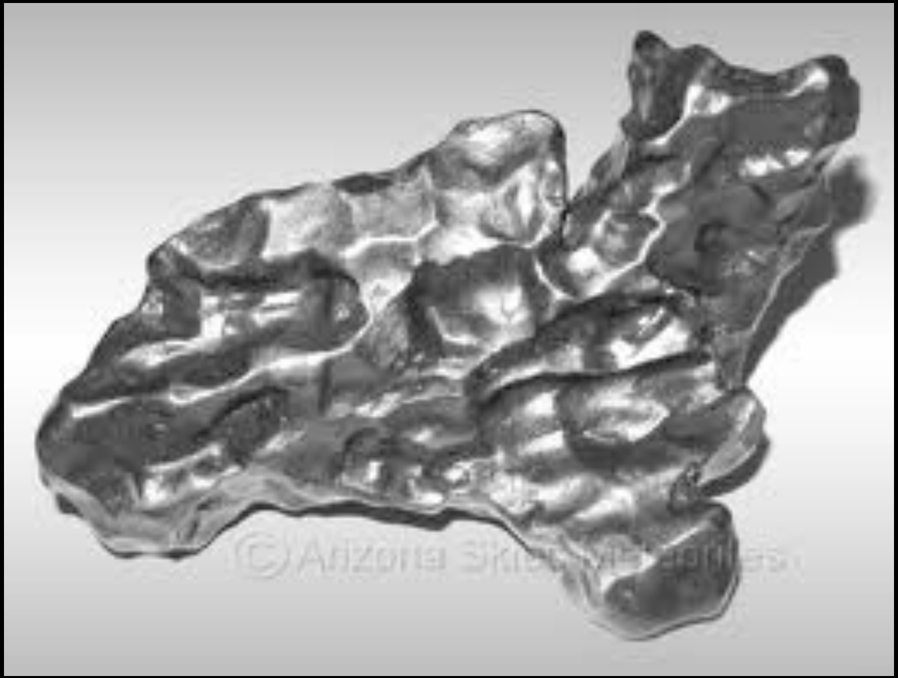


Achondrites



Pallasites (Stony-Iron)

Iron Meteorites



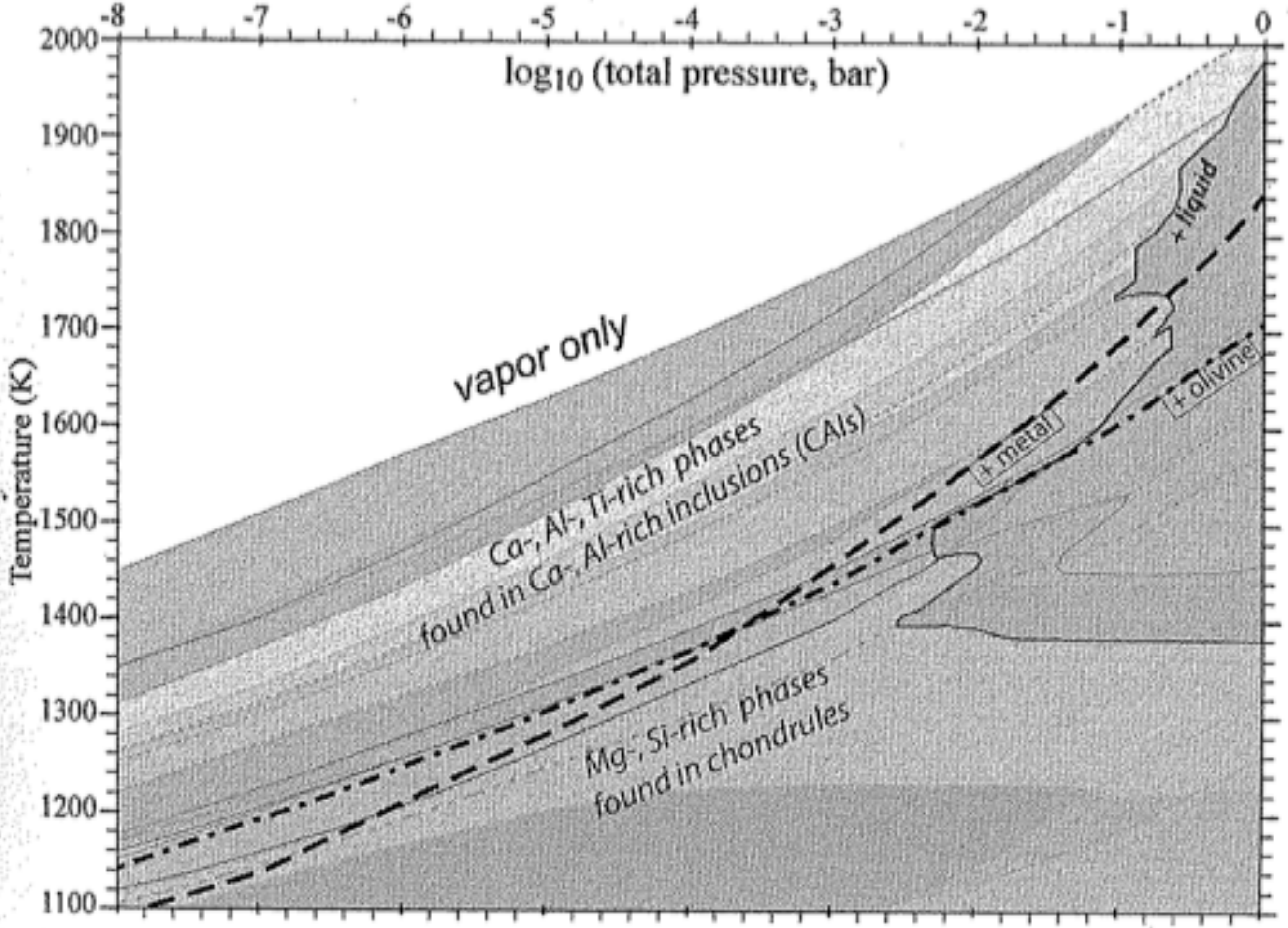


Figure 8.21 Phase diagram showing the principal constituents of chondrules and CAIs. The various lines show the condensation boundaries for different minerals, with the most important constituents labeled. (Ebel 2006)

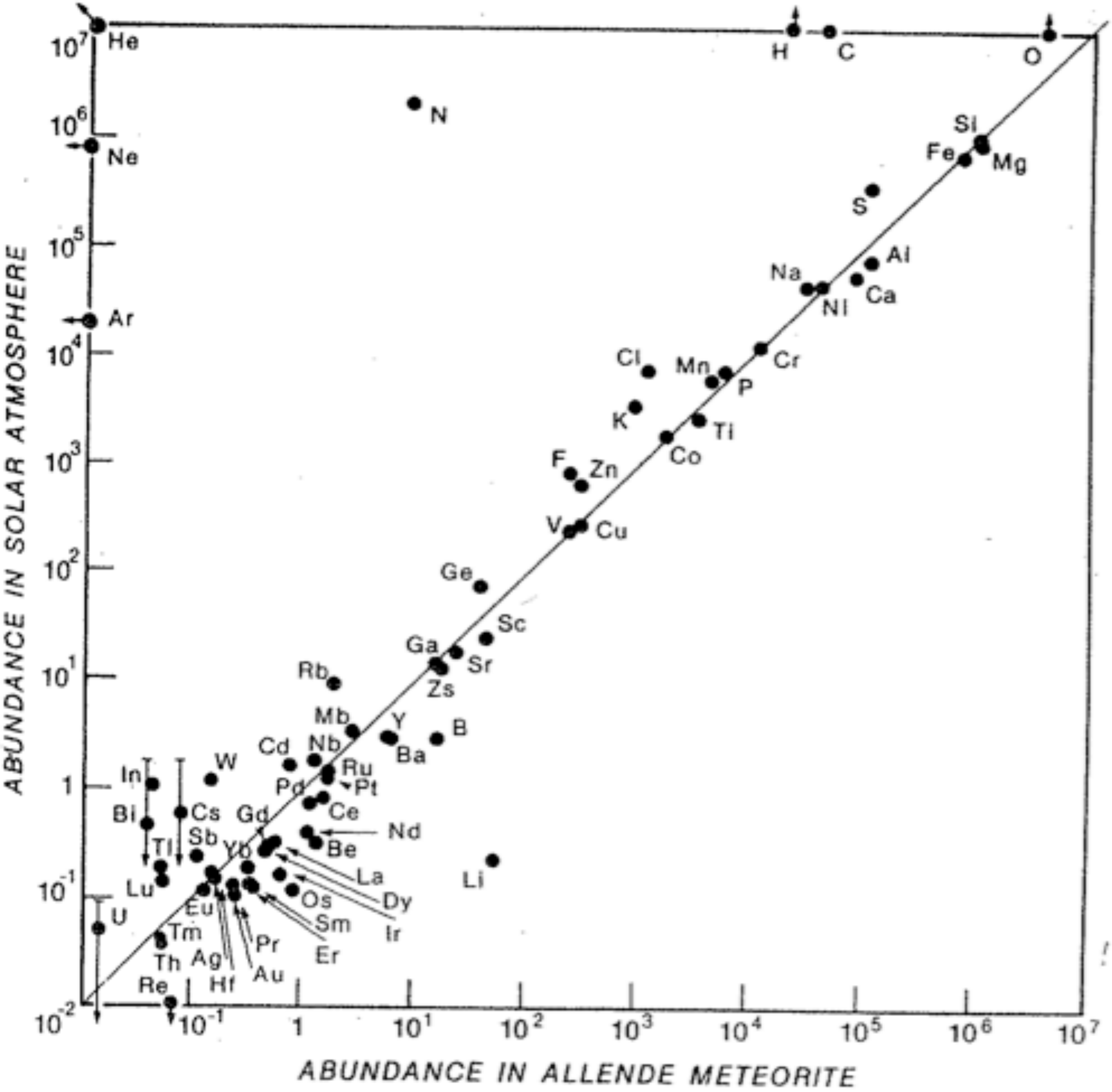


Figure 8.2 The abundance of elements in the Sun's photosphere plotted against their abundance in the Allende CV3 chondrite. Most elements lie very close to the curve of equal abundance (normalized to silicon). Several volatile elements lie above this curve, presumably because they are depleted in meteorites (rather than being enriched in the Sun), while only lithium lies substantially below the curve; lithium is depleted in the solar photosphere because it is destroyed by nuclear reactions near the base of the Sun's convective zone.

TABLE 8.3 Half-lives of Selected Isotopes.

Parent	Measurable stable daughter(s)	Half-life $t_{1/2}$
Long-lived radionuclides		
^{40}K	^{40}Ar, ^{40}Ca	1.25 Gyr
(Rubidium) ^{87}Rb	^{87}Sr (Strontium)	48.8 Gyr
^{147}Sm	^{143}Nd, ^{4}He	106 Gyr
^{187}Re	^{187}Os	46 Gyr
^{232}Th	^{208}Pb, ^{4}He	14 Gyr
^{235}U	^{207}Pb, ^{4}He	0.704 Gyr
^{238}U	^{206}Pb, ^{4}He	4.47 Gyr
Extinct radionuclides		
^{22}Na	^{22}Ne	2.6 yr
^{26}Al	^{26}Mg	0.72 Myr
^{41}Ca	^{41}K	0.1 Myr
^{53}Mn	^{53}Cr	3.6 Myr
^{60}Fe	^{60}Ni	1.5 Myr
^{107}Pd	^{107}Ag	6.5 Myr
^{129}I	^{129}Xe	17 Myr
^{182}Hf	^{182}W	9 Myr
^{244}Pu	$^{131-136}Xe$	82 Myr

$$ {}^{238}_{92}\mathrm{U} \xrightarrow[t_{1/2}=4.51\times10^{9}\mathrm{y}]{\alpha} {}^{234}_{90}\mathrm{Th} \xrightarrow[21.4\mathrm{d}]{\beta} {}^{234}_{91}\mathrm{Pa} \xrightarrow[6.75\mathrm{h}]{\beta} {}^{234}_{92}\mathrm{U} $$

$$ \xrightarrow[2.47\times10^{5}\mathrm{y}]{\alpha} {}^{230}_{90}\mathrm{Th} \xrightarrow[8\times10^{4}\mathrm{y}]{\alpha} {}^{226}_{88}\mathrm{Ra} \xrightarrow[1600\mathrm{y}]{\alpha} {}^{222}_{86}\mathrm{Rn} $$

$$ \xrightarrow[3.8\mathrm{d}]{\alpha} {}^{218}_{84}\mathrm{Po} \xrightarrow[3\mathrm{m}]{\alpha} {}^{214}_{82}\mathrm{Pb} \xrightarrow[27\mathrm{m}]{\beta} {}^{214}_{83}\mathrm{Bi} \xrightarrow[19.7\mathrm{m}]{\beta} {}^{214}_{84}\mathrm{Po} $$

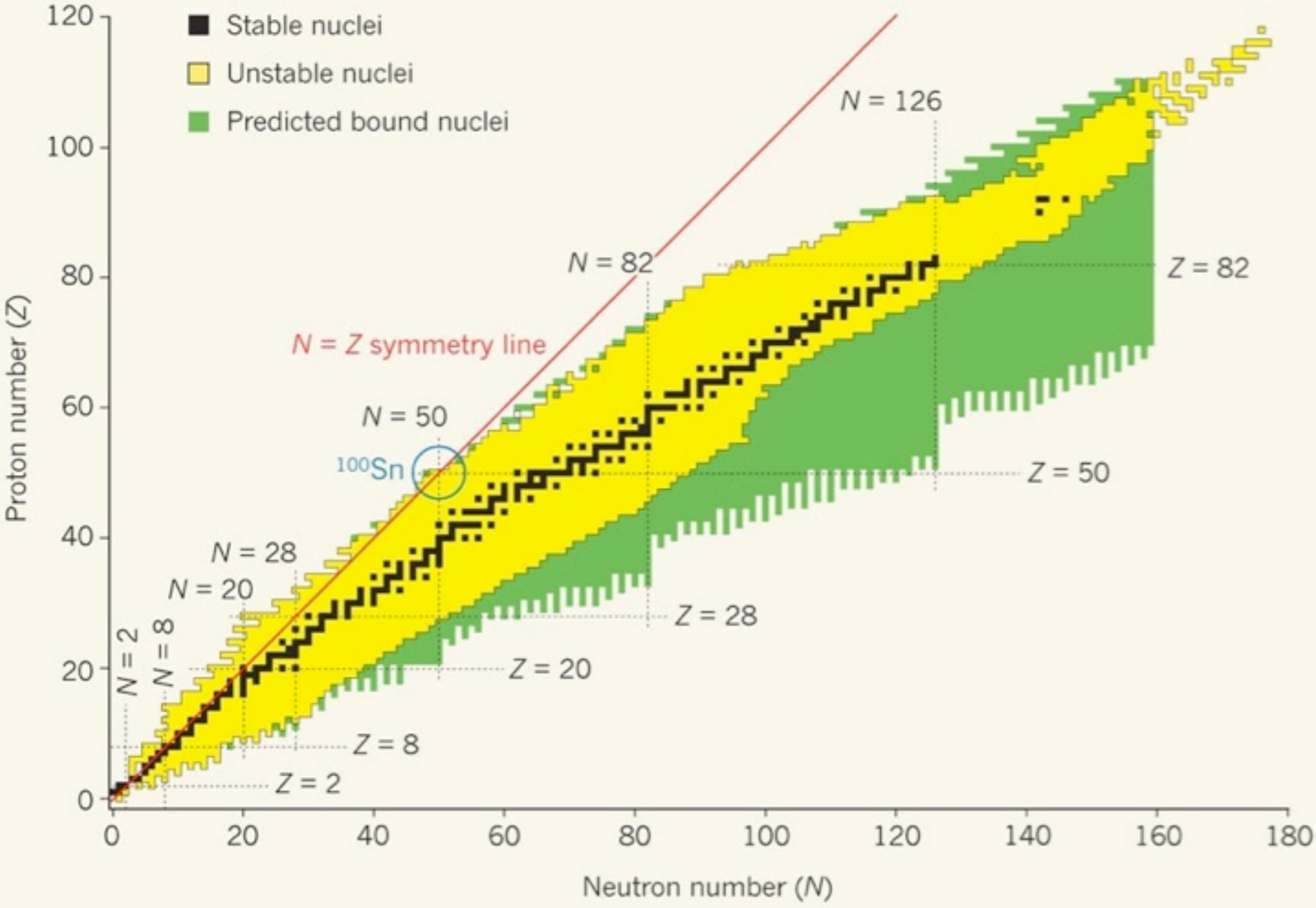
$$ \xrightarrow[1.64\times10^{-4}\mathrm{s}]{\alpha} {}^{210}_{82}\mathrm{Pb} \xrightarrow[21\mathrm{y}]{\beta} {}^{210}_{83}\mathrm{Bi} \xrightarrow[5\mathrm{d}]{\beta} {}^{210}_{84}\mathrm{Po} \xrightarrow[183\mathrm{d}]{\alpha} {}^{206}_{82}\mathrm{Pb}\ (\text{stable}), $$

$$ {}^{235}_{92}\mathrm{U} \xrightarrow[t_{1/2}=7.1\times10^{8}\mathrm{y}]{\alpha} {}^{231}_{90}\mathrm{Th} \xrightarrow[25.5\mathrm{h}]{\beta} {}^{231}_{91}\mathrm{Pa} \xrightarrow[3.25\times10^{4}\mathrm{y}]{\alpha} {}^{227}_{89}\mathrm{Ac} $$

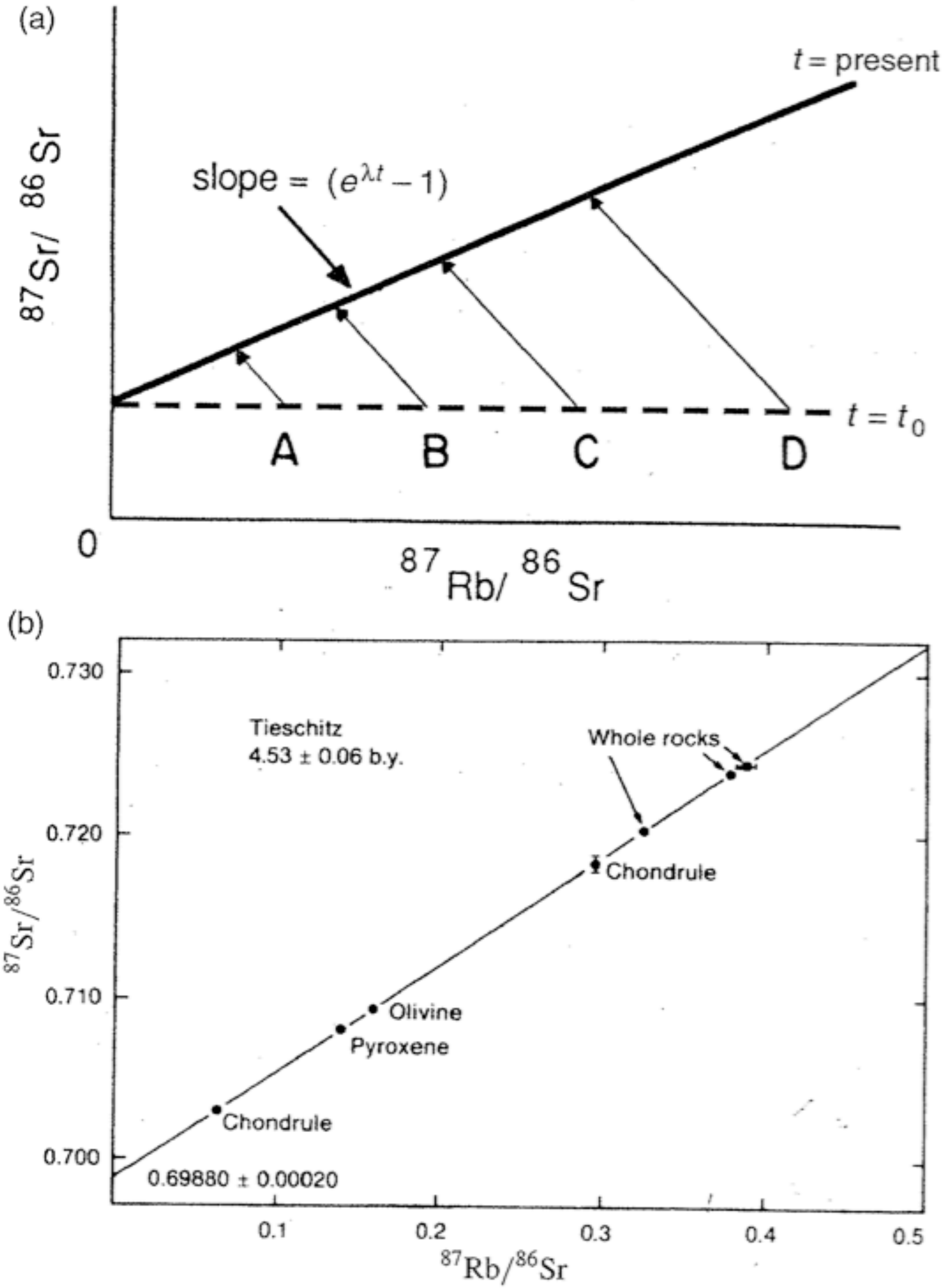
$$ \xrightarrow[21.6\mathrm{y}]{\beta} {}^{227}_{90}\mathrm{Th} \xrightarrow[18.5\mathrm{d}]{\alpha} {}^{223}_{88}\mathrm{Ra} \xrightarrow[11.43\mathrm{d}]{\alpha} {}^{219}_{86}\mathrm{Rn} \xrightarrow[4\mathrm{s}]{\alpha} {}^{215}_{84}\mathrm{Po} $$

$$ \xrightarrow[1.8\times10^{-3}\mathrm{s}]{\alpha} {}^{211}_{82}\mathrm{Pb} \xrightarrow[36\mathrm{m}]{\beta} {}^{211}_{83}\mathrm{Bi} \xrightarrow[2.15\mathrm{m}]{\alpha} {}^{207}_{81}\mathrm{Tl} $$

$$ \xrightarrow[4.8\mathrm{m}]{\beta} {}^{207}_{82}\mathrm{Pb}\ (\text{stable}). \qquad (8.6b) $$



■ Stable nuclei
▢ Unstable nuclei
■ Predicted bound nuclei
N = Z symmetry line
100Sn
N = 2
N = 8
N = 20
N = 28
N = 50
N = 82
N = 126
Z = 2
Z = 8
Z = 20
Z = 28
Z = 50
Z = 82
Proton number (Z)
Neutron number (N)
0
20
40
60
80
100
120
140
160
180


(a)
t = present
slope = $(e^{\lambda t} - 1)$
^{87}Sr/ ^{86}Sr
$t = t_0$
A
B
C
D
0
^{87}Rb/ ^{86}Sr
(b)
0.730
0.720
0.710
0.700
Tieschitz
4.53 ± 0.06 b.y.
Whole rocks
Chondrule
Olivine
Pyroxene
Chondrule
0.69880 ± 0.00020
^{87}Sr/^{86}Sr
0.1
0.2
0.3
0.4
0.5
^{87}Rb/^{86}Sr

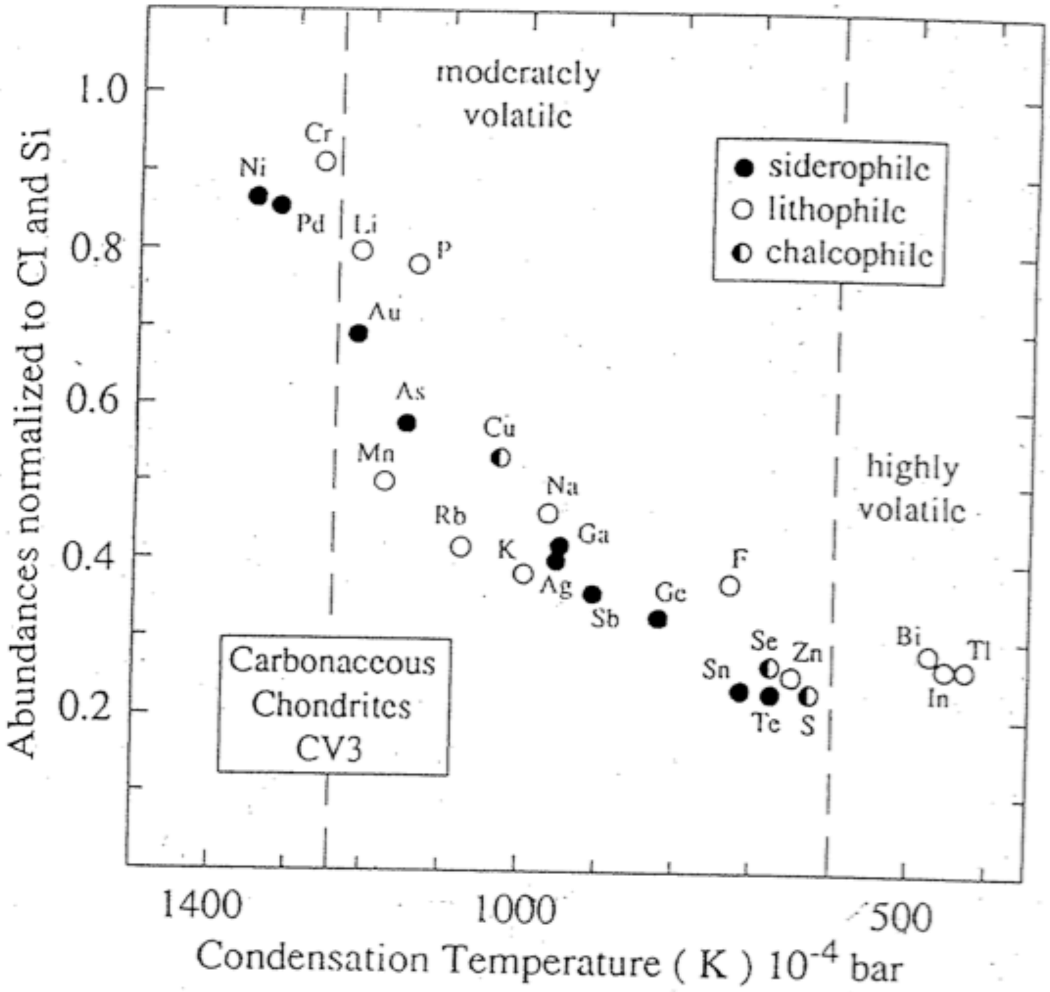


FIGURE 8.15 The abundances of moderately volatile elements in bulk CV chondrites compared to their abundances relative to silicon in CI chondrites are plotted against the condensation temperatures of the elements in a solar composition gas. Note the gradual decrease in abundance with decreasing condensation temperature, and the lack of dependence of abundances on the geochemical character of the elements.

Implies Signficant

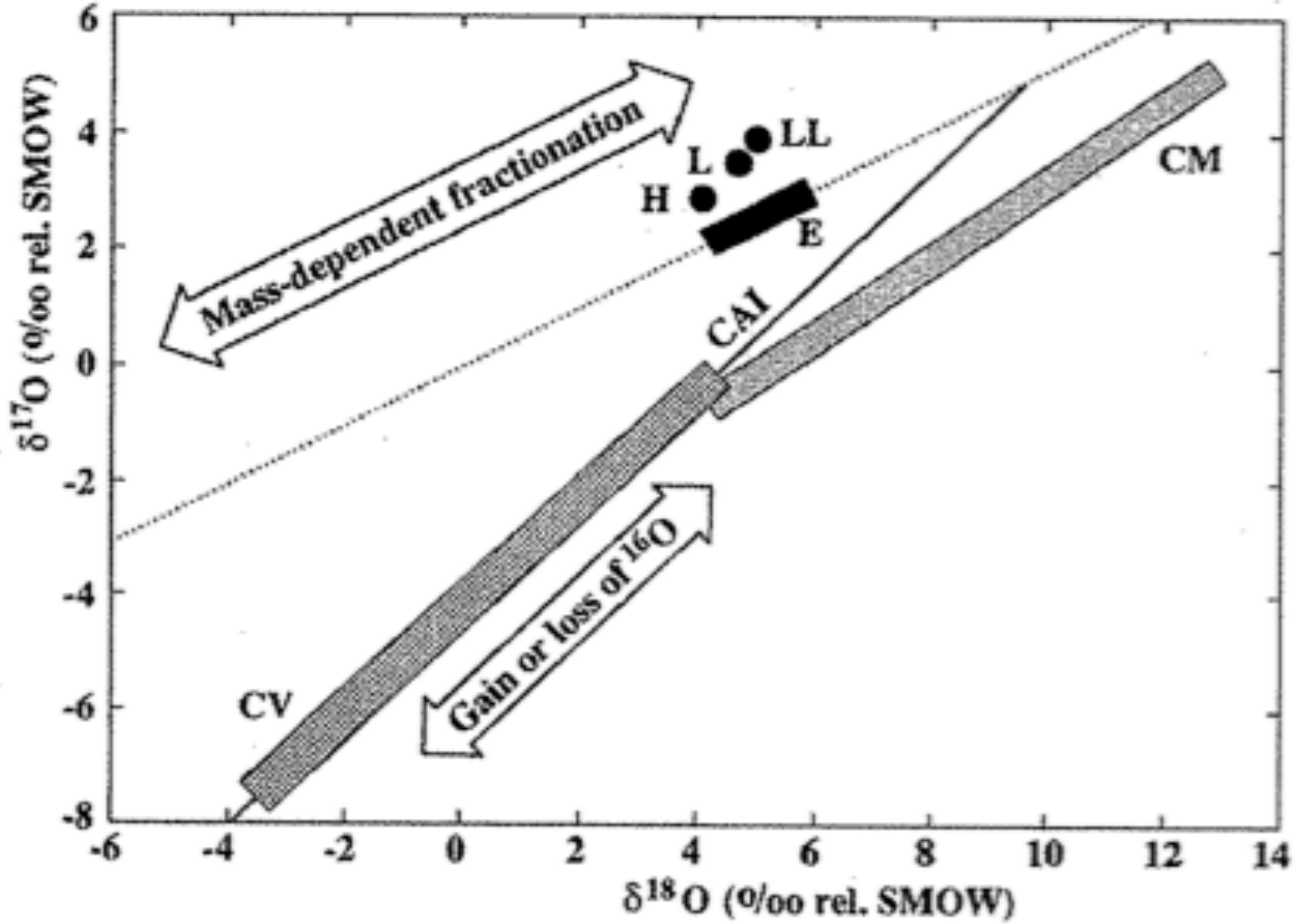
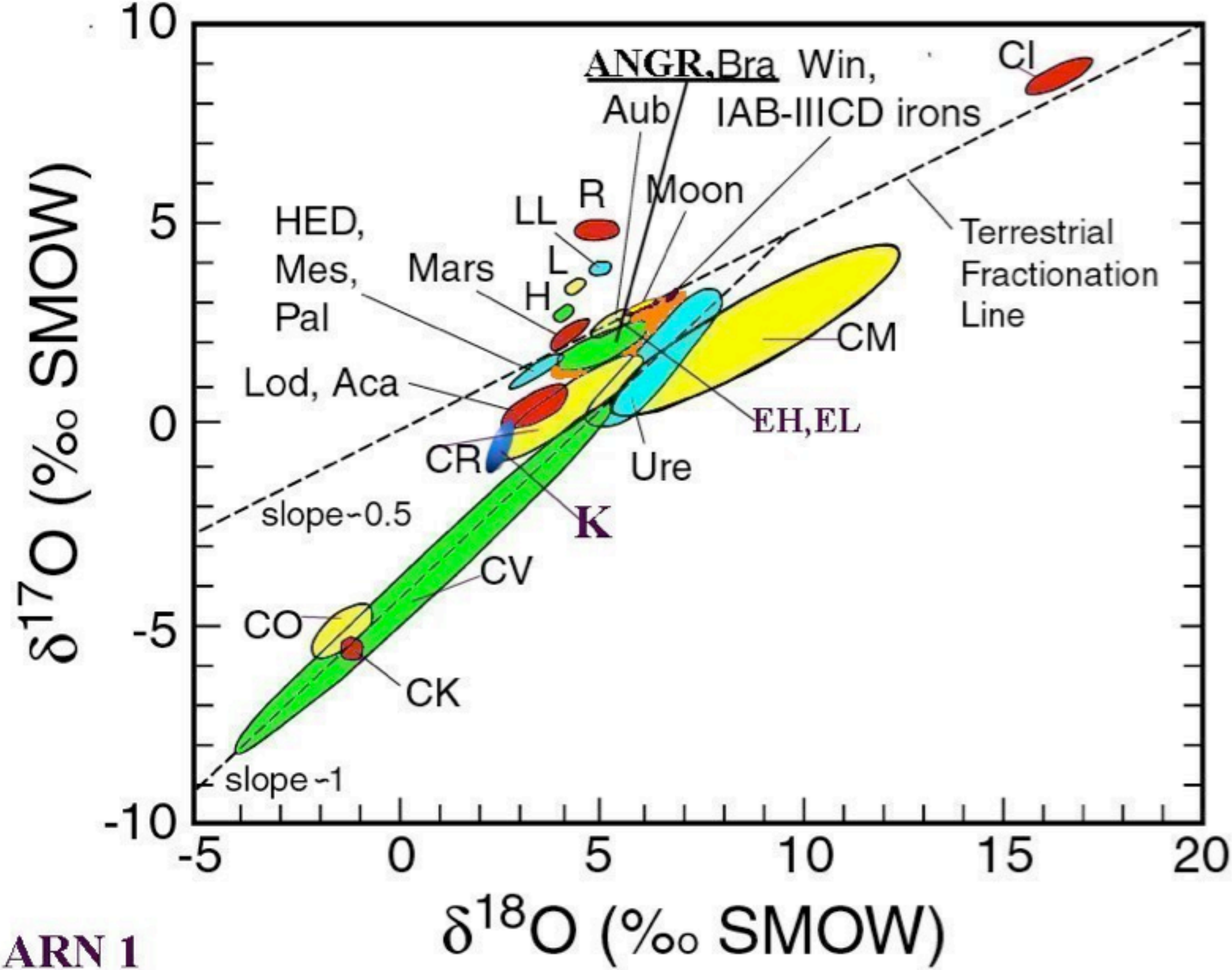


Figure 8.16 Plot showing the distribution of the three stable oxygen isotopes in various Solar System bodies. Isotope abundance ratios are shown relative to the Standard (terrestrial) Mean Ocean Water (SMOW), with units being parts per thousand variations. The dotted line represents the mass-dependent fractionation pattern observed in terrestrial samples. (Kerridge 1993)


δ17O (‰ SMOW)
δ18O (‰ SMOW)
10
5
0
-5
-10
-5
0
5
10
15
20
ANGR, Bra
Win,
Aub
IAB-IIICD irons
CI
Moon
R
LL
L
H
HED,
Mes,
Pal
Mars
Terrestrial
Fractionation
Line
CM
Lod, Aca
EH,EL
CR
Ure
K
slope~0.5
CV
CO
CK
slope~1

ARN 1

Table 8.1 Elemental abundances.[a]

Element		Solar System[b] (atoms/10^6 Si)	CI chondrites (mass fraction)
1	H	2.431×10^{10}	21.0 mg/g
2	He	2.343×10^{9}	56 nL/g
3	Li	55.5	1.46 μg/g
4	Be	0.74	25.2 ng/g
5	B	17.3	713 ng/g
6	C	7.08×10^{6}	35.2 mg/g
7	N	1.95×10^{6}	2.94 mg/g
8	O	1.41×10^{7}	458.2 mg/g
9	F	841	60.6 μg/g
10	Ne	2.15×10^{6}	218 pL/g
11	Na	5.75×10^{4}	5.01 mg/g
12	Mg	1.02×10^{6}	95.9 mg/g
13	Al	8.41×10^{4}	8.50 mg/g
14	Si	1.00×10^{6}	106.5 mg/g
15	P	8370	920 μg/g
16	S	4.45×10^{5}	54.1 mg/g
17	Cl	5240	704 μg/g
18	Ar	1.03×10^{5}	888 pL/g
19	K	3690	530 μg/g
20	Ca	6.29×10^{4}	9.07 mg/g
21	Sc	34.2	5.83 μg/g
22	Ti	2420	440 μg/g
23	V	288	55.7 μg/g
24	Cr	1.29×10^{4}	2.59 mg/g
25	Mn	9170	1.91 mg/g
26	Fe	8.38×10^{5}	182.8 mg/g
27	Co	2320	502 μg/g
28	Ni	4.78×10^{4}	10.6 mg/g
29	Cu	527	127 μg/g
30	Zn	1230	310 μg/g
31	Ga	36.0	9.51 μg/g
32	Ge	121	33.2 μg/g
33	As	6.09	1.73 μg/g
34	Se	65.8	19.7 μg/g
35	Br	11.3	3.43 μg/g
36	Kr	55.2	15.3 pL/g
37	Rb	6.57	2.13 μg/g
38	Sr	23.6	7.74 μg/g
39	Y	4.61	1.53 μg/g
40	Zr	11.3	3.96 μg/g
41	Nb	0.76	265 ng/g
42	Mo	2.60	1.02 μg/g
44	Ru	1.90	692 ng/g
45	Rh	0.37	141 ng/g
46	Pd	1.44	588 ng/g
47	Ag	0.49	201 ng/g
48	Cd	1.58	675 ng/g
49	In	0.18	78.8 ng/g
50	Sn	3.73	1.68 μg/g
51	Sb	0.33	152 ng/g
52	Te	4.82	2.33 μg/g
53	I	1.00	480 ng/g
54	Xe	5.39	31.3 pL/g
55	Cs	0.37	185 ng/g
56	Ba	4.35	2.31 μg/g
57	La	0.44	232 ng/g
58	Ce	1.17	621 ng/g
59	Pr	0.17	92.8 ng/g
60	Nd	0.84	457 ng/g
62	Sm	0.25	145 ng/g
63	Eu	0.095	54.6 ng/g
64	Gd	0.33	198 ng/g
65	Tb	0.059	35.6 ng/g
66	Dy	0.39	238 ng/g
67	Ho	0.090	56.2 ng/g
68	Er	0.26	162 ng/g
69	Tm	0.036	23.7 ng/g
70	Yb	0.25	163 ng/g
71	Lu	0.037	23.7 ng/g
72	Hf	0.17	115 ng/g
73	Ta	0.021	14.4 ng/g
74	W	0.13	89 ng/g
75	Re	0.053	37 ng/g
76	Os	0.67	486 ng/g
77	Ir	0.64	470 ng/g
78	Pt	1.36	1.00 μg/g
79	Au	0.20	146 ng/g
80	Hg	0.41	314 ng/g
81	Tl	0.18	143 ng/g
82	Pb	3.26	2.56 μg/g
83	Bi	0.14	110 ng/g
90	Th	0.044	30.9 ng/g
92	U	0.0093	8.4 ng/g

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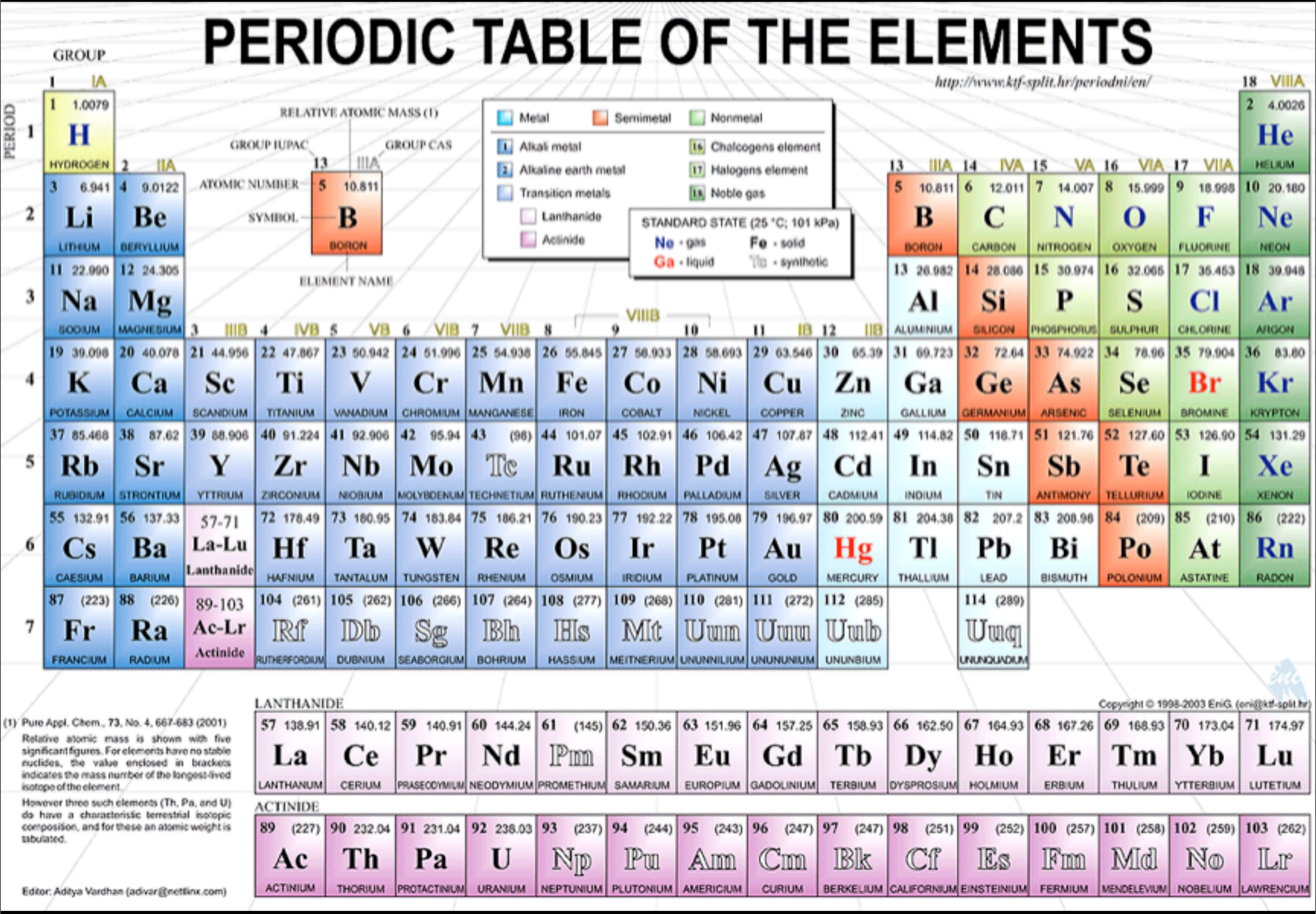
[a] Uncertainties of these estimates are generally larger than suggested by the number of digits quoted. Concentration of noble gases within meteorites is calculated by scaling the values for the principal isotopes from Anders and Grevesse (1989) to all isotopes using the isotopic abundances given in Lodders (2003). All other data from Lodders (2003), who also lists uncertainties.



PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/

🟦 Metal 🟥 Semimetal 🟩 Nonmetal

1 Alkali metal
2 Alkaline earth metal
Transition metals
Lanthanide
Actinide
16 Chalcogens element
17 Halogens element
18 Noble gas

STANDARD STATE (25 °C; 101 kPa)
Ne - gas Fe - solid
Ga - liquid Tc - synthetic

PERIOD \ GROUP	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
3	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNILIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM		114 (289) Uuq UNUNQUADIUM				

LANTHANIDE

57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERBIUM	71 174.97 Lu LUTETIUM

ACTINIDE

89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)

Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

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