ELEMENTS

Understanding

Robert Boyle (1661) The Sceptical Chymist

I mean by elements, as those chymists that speak plainest do by their Principles, certain primitive and simple, or perfectly unmingled bodies, which not being made of any other bodies of of one another, are the ingredients of which all perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved ...

Rutherford ... Bohr ... Moseley ---> Atomic number

For the first time, Moseley had called the roll of the elements and we could say definitely the number of possible elements between the beginning and the end, and the number that still remained to be found.'

Frederick Soddy

ELEMENTS

STABLE ELEMENTS:

H (Z=1) to Bi (Z=83) except for Tc (Z=43) and Pm (Z=61)

UNSTABLE ELEMENTS beyond Bi

Th (Z=90) and U (Z=92) and their decay products

SUPERHEAVY ELEMENTS

Z>93 to Z=118
Named to Z=116 Livermorium

Very short half-lives but is there an island of stability beyond Z=118?

No astrophysical significance? Detection? Synthesis?

RADIOACTIVE ISOTOPES

proton dripline not far off valley of stability rather well defined experimentally

neutron dripline far off valley of stability subject to uncertain theoretical extrapolation and far from most neutron-rich nuclides manufactured.

LABORATORY MANUFACTURE vital to several processes of nucleosynthesis
-- nuclear masses
-- reaction rates
-- half-lives
with several new experimental tools (radioactive beams, Penning traps, ...)

THE PERIODIC TABLE

Key: H — SYMBOL; 1 — ATOMIC NUMBER; 1.008 — ATOMIC WEIGHT; Hydrogen — NAME. ( ) = ESTIMATES

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	H 1 1.008																	He 2 4.00
2	Li 3 6.94	Be 4 9.01											B 5 10.81	C 6 12.01	N 7 14.01	O 8 16.00	F 9 19.00	Ne 10 20.18
3	Na 11 22.99	Mg 12 24.31											Al 13 26.98	Si 14 28.09	P 15 30.97	S 16 32.07	Cl 17 35.45	Ar 18 39.95
4	K 19 39.10	Ca 20 40.08	Sc 21 44.96	Ti 22 47.88	V 23 50.94	Cr 24 52.00	Mn 25 54.94	Fe 26 55.85	Co 27 58.93	Ni 28 58.69	Cu 29 63.55	Zn 30 65.39	Ga 31 69.72	Ge 32 72.61	As 33 74.92	Se 34 78.96	Br 35 79.90	Kr 36 83.80
5	Rb 37 85.47	Sr 38 87.62	Y 39 88.91	Zr 40 91.22	Nb 41 92.91	Mo 42 95.94	Tc 43 (97.9)	Ru 44 101.07	Rh 45 102.91	Pd 46 106.42	Ag 47 107.87	Cd 48 112.41	In 49 114.82	Sn 50 118.71	Sb 51 121.76	Te 52 127.60	I 53 126.90	Xe 54 131.29
6	Cs 55 132.91	Ba 56 137.33	La 57 138.91	Hf 72 178.49	Ta 73 180.95	W 74 183.85	Re 75 186.21	Os 76 190.2	Ir 77 192.22	Pt 78 195.08	Au 79 196.97	Hg 80 200.59	Tl 81 204.38	Pb 82 207.2	Bi 83 208.98	Po 84 (209)	At 85 (210)	Rn 86 (222)
7	Fr 87 223.02	Ra 88 226.03	Ac 89 227.03	Rf 104 (261)	Db 105 (262)	Sg 106 (263)	Bh 107 (262)	Hs 108 (265)	Mt 109 (266)	110	111	112		114		116		118
	ALKALI METALS	ALKALINE EARTH METALS															HALOGENS	NOBLE GASES

LANTHANIDES	Ce 58 140.12	Pr 59 140.91	Nd 60 144.24	Pm 61 (145)	Sm 62 150.36	Eu 63 151.97	Gd 64 157.25	Tb 65 158.93	Dy 66 162.50	Ho 67 164.93	Er 68 167.26	Tm 69 168.93	Yb 70 173.04	Lu 71 174.97
ACTINIDES	Th 90 232.04	Pa 91 231.04	U 92 238.03	Np 93 237.05	Pu 94 (244)	Am 95 243.06	Cm 96 (247)	Bk 97 (247)	Cf 98 (251)	Es 99 252.08	Fm 100 257.10	Md 101 (257)	No 102 259.10	Lr 103 262.11

ABUNDANCES OF THE ELEMENTS

METEORITES - Essentially all that was known in 1957 The Annus Mirabilis

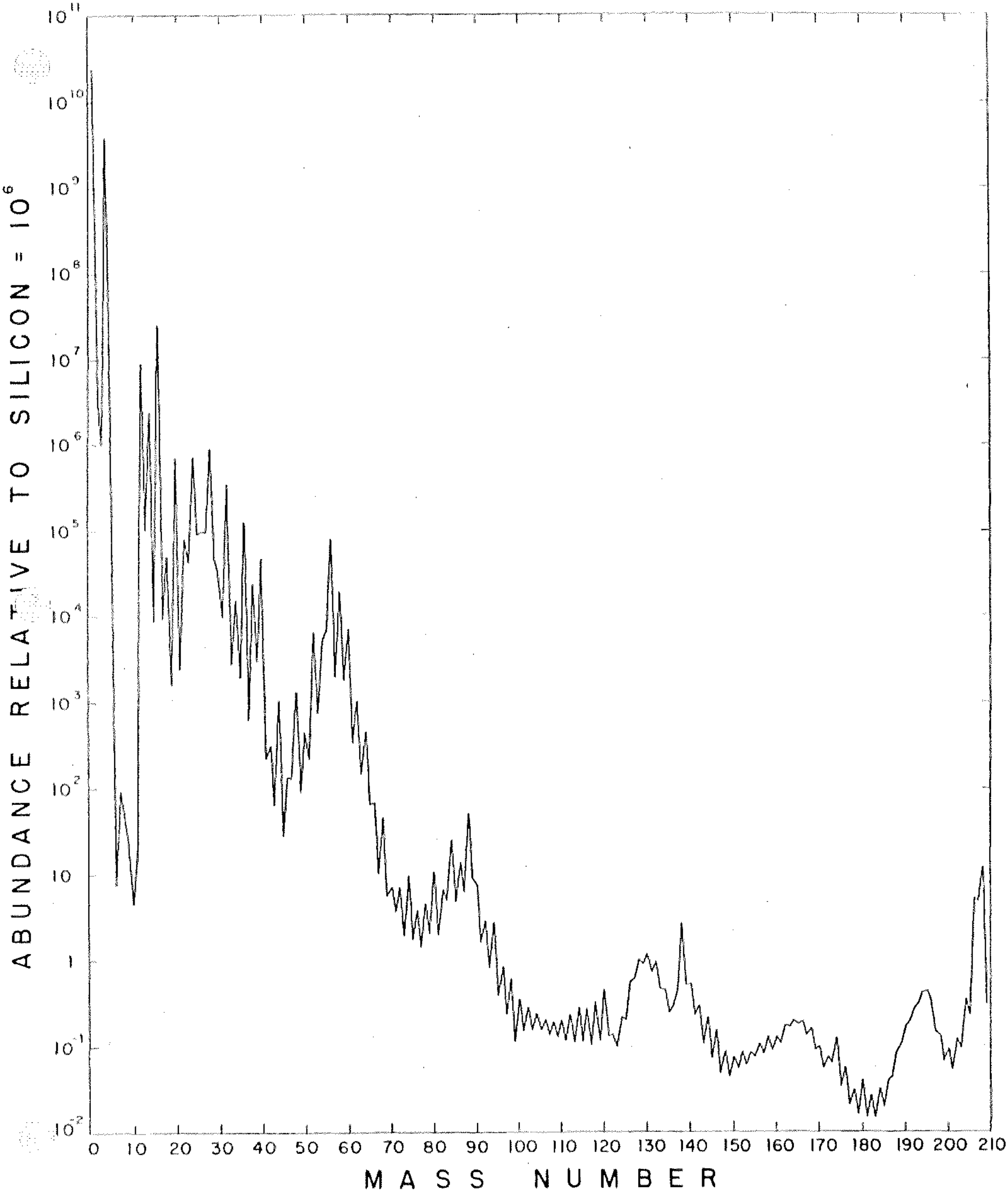
Cosmic (? prefer Standard) abundances

Urey suggested use of chondritic (common stony meteorites)
meteorites - few signs of differentiation
--> carbonaceous chondrites

Tables of cosmic abundances:Goldschmidt (1937); Urey 1952; Suess & Urey 1956;
Cameron 1959-1982; Anders & Ebihara 1982; Anders & Grevesee 1989;
Lodders 2003; Asplund et al. 2005-2010; Lodders, Palme & Gail 2009.

Meteoritic data has to be supplemented by
solar wind/corona, H II regions, stars ... for volatiles (noble gases etc)
early tables used interpolation for some nuclides
some tables used theoretical ideas for some nuclides

Meteoritic data has to be normalized to stellar abundances:
meteoritic abundances measured relative to Si
stellar (=astronomical) abundances - usually - measured relative to H
but meteorites have `no' H



ABUNDANCE RELATIVE TO SILICON = 10^6
10^{11}
10^{10}
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210
MASS NUMBER

METEORITES

ABUNDANCES OF THE ELEMENTS

`Cosmic' implied primordial origin of the elements
Suess & Urey speak of the table entries as
`representing the ash of a cosmic nuclear fire'

Now prefer `standard' or better yet `solar system' table of abundances

Table reflects several aspects of nuclear physics
Goeppert Mayer (1972) in her Nobel lecture said
`I stumbled over the magic numbers by examining the isotopic abundances.'

ORIGINS OF THE ELEMENTS

Alpher, Bethe & Gamow 1948 – The ylem hypothesis
- -- nucleosynthesis from a primordial ball of neutrons
- -- cosmic microwave background radiation!

Cosmic abundance curve crudely reproduced but major problems were pointed out:
- -- n-p equilibrium quickly converted n to p
- -- synthesis faces bottlenecks at A= 5 and 8 for which there are NO stable nuclides

See Alpher & Herman's 1953 Ann. Rev. Nuclear Science review

ORIGINS OF THE ELEMENTS

Key factors highlighting the need for stellar nucleosynthesis

1. Discovery of metal-poor stars by Chamberlain & Aller 1951 and confirmation by Baschek 1959

2. Detection of tehnectium in S stars by Merrill 1952

   `It was ironic that fate reserved so startling a discovery for someone as formally set in his ways as Merrill' and `Thereafter, however, he would listen to avant garde seminars more attentively than in former years'. Hoyle (1982)

3. Development of theoretical understanding of stellar evolution - red giant evolution and importance of He burning

   He burning - how to get around the A=8 bottleneck

   Triple- alpha --> C-12
     He-4 + He-4 --> Be-8
     Be-8 + He-4 --> C-12

   But C-12 was thought to go quickly to O-16

   Hoyle in 1953 predicted as resonance in C-12 so that the production of C-12 was greatly accelerated and C/O ratio was a reasonable value

4. Idea of Galactic chemical evolution for building up metal abundances with time