Fundamentals

Coulomb Force and Potential Energy

Coulomb's Law of electrostatic force (*i.e.*, the force between two charged bodies) is given by:

$$F(r) = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

where q_1 and q_2 are the charges on the two bodies; r is their distance of separation, and ε_0 is the *permittivity of the vacuum*, which has the numerical value (in SI units) $8.854 \times 10^{-12}\ C^2J^{-1}m^{-1}$.

Because the mutual potential energy, V, of such a pair of charges is generated by the electrostatic force acting over a distance, the energy is obtained by integrating the above expression over the separation distance, r:

$$V(r) = -\int_{r_1}^{r_2} \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}\,dr = \frac{q_1 q_2}{4\pi\varepsilon_0}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

If the two charged bodies are an electron and an atomic nucleus, then if r_1 is very large (*i.e.*, the electron is at an infinite distance from the nucleus), the above expression becomes

$$V(r) = \frac{q_1 q_2}{4\pi\varepsilon_0 r}$$

In SI units, the charge is given in coulombs, in which $e^- = p^+ = 1.602 \times 10^{-19}$ C.

Thus, if the two charged bodies are an electron and a proton at a separation of 1 Å (1×10^{-8} cm),

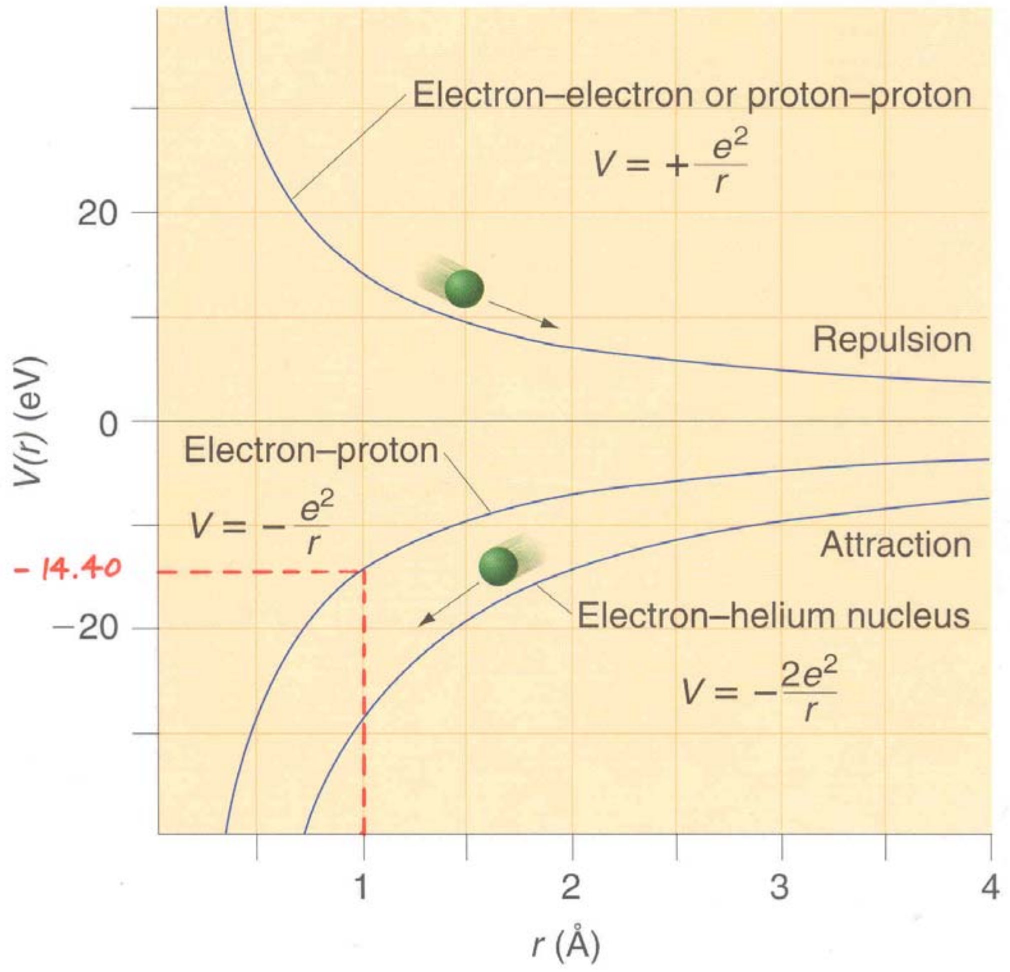
$$V(1A^{\circ}) = \frac{-(1.602 \times 10^{-19}\,C)^2}{4\pi(8.854 \times 10^{-12}\,C^2J^{-1}m^{-1})(1 \times 10^{-10}\,m)}$$
$$= -2.307 \times 10^{-18}\,J$$

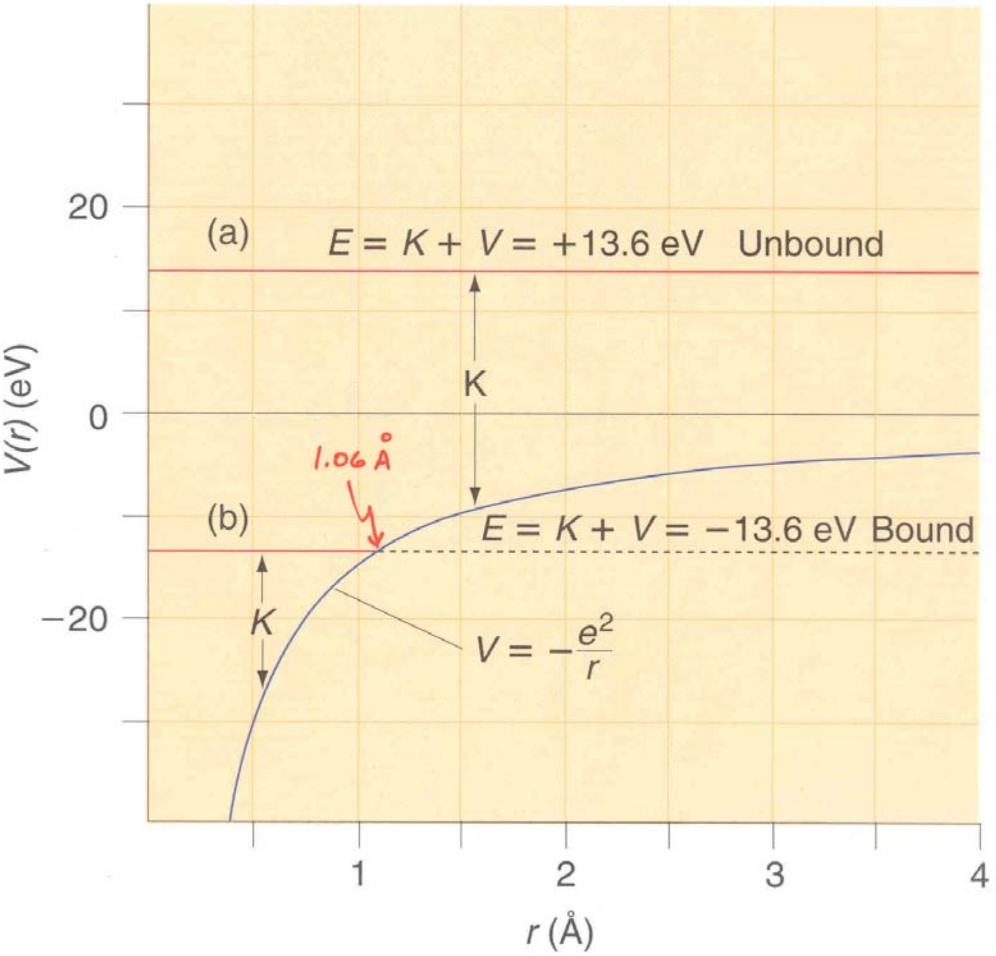
A more convenient unit for expressing electronic energies in atoms is the electron-volt, eV, which is the kinetic energy gained by an electron in falling through a potential difference (voltage) of 1 volt. Since 1 V = 1 J/C, then

$$1\ eV = 1\ V \times (1.602 \times 10^{-19}\ C) = 1.602 \times 10^{-19}\ J$$
$$= 96.47\ kJ/mol$$

Therefore, for the above case of an electron-proton interaction at a distance of 1Å,

$$V = \frac{-2.307 \times 10^{-18}\,J}{1.602 \times 10^{-19}\,J/eV} = -14.40\ eV$$




20
0
−20
V(r) (eV)
(a)
E = K + V = +13.6 eV Unbound
K
1.06 Å
(b)
E = K + V = −13.6 eV Bound
K
V = −e²/r
1
2
3
4
r (Å)

Stoichiometry and the Atomic Theory of Matter

Composition of Matter

- Mixtures
- Substances
- Compounds
- Elements

Atomic Theory of Matter

Conservation of Mass (Lavoisier)

Mass is neither created nor destroyed.

Definite Proportions (Proust)

A given compound always contains exactly the same proportion of elements by mass.

Multiple Proportions (Dalton)

When two elements form a series of compounds, the ratios of the masses of the second element that combine with a given mass of the first element can always be reduced to small whole numbers.

Atomic Theory (Dalton)

Elements are composed of tiny, identical individual particles called atoms.

Combining Volumes (Gay-Lussac)

At the same temperature and pressure, the ratios of volumes of gases that react with each other are small whole numbers.

Avogadro's Hypothesis (Avogadro)

At the same temperature and pressure, equal volumes of different gases contains the same number of particles.

Cannizzaro's Interpretation (Cannizzaro)

Compiled relative masses of atoms and molecules to confirm correct molecular formulas.

Weighing and Counting Molecules

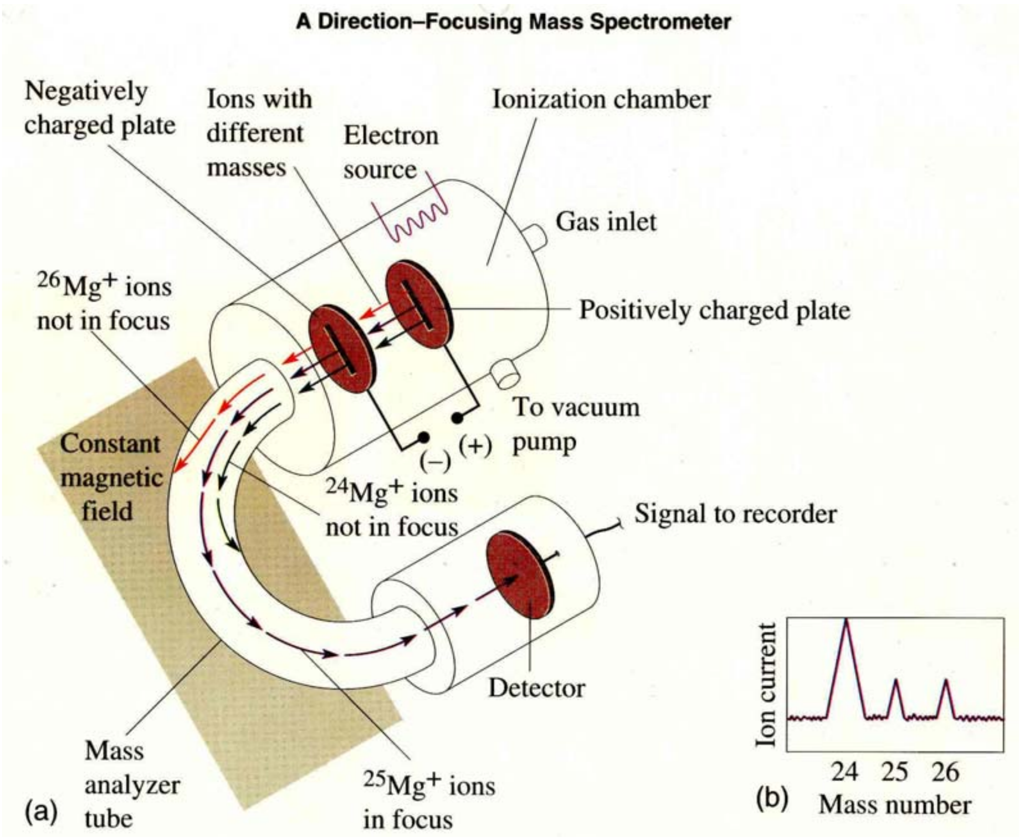
Atomic Weights
Avogadro's Number
The Mole

Chemical Formulas and Chemical Equations

Empirical Formulas
Molecular Formulas
Percentage Composition
Balanced Chemical Equations

Mass Relationships in Chemical Reactions

Conservation of Mass
Limiting Reagent
Percentage Yield


A Direction–Focusing Mass Spectrometer
Negatively charged plate
Ions with different masses
Electron source
Ionization chamber
Gas inlet
Positively charged plate
$^{26}Mg^+$ ions not in focus
To vacuum pump
(−)
(+)
Constant magnetic field
$^{24}Mg^+$ ions not in focus
Signal to recorder
Detector
Mass analyzer tube
$^{25}Mg^+$ ions in focus
(a)
Ion current
24
25
26
(b)
Mass number

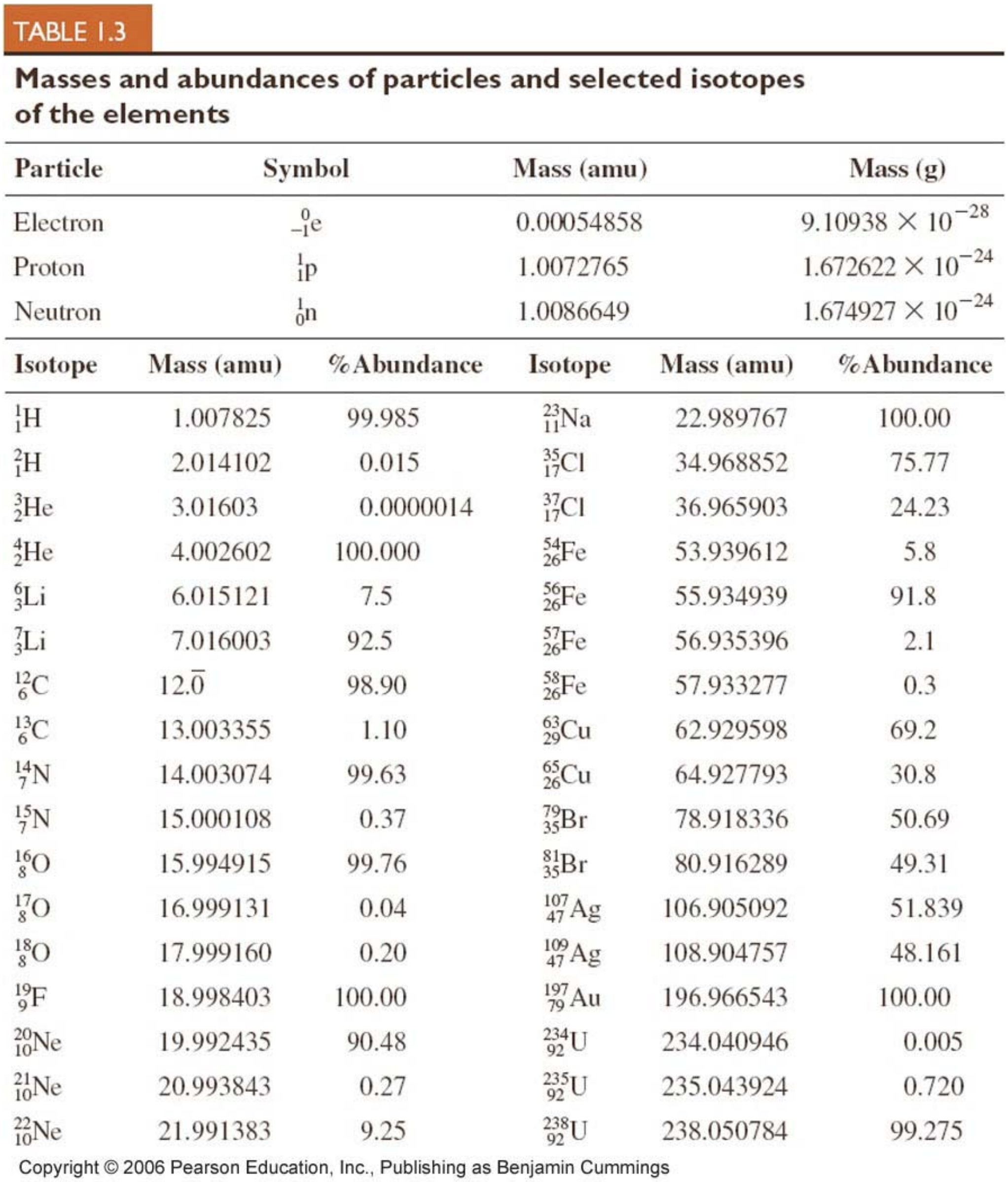


TABLE 1.3

Masses and abundances of particles and selected isotopes of the elements

Particle	Symbol	Mass (amu)	Mass (g)
Electron	${}_{-1}^{0}e$	0.00054858	9.10938×10^{-28}
Proton	${}_{1}^{1}p$	1.0072765	1.672622×10^{-24}
Neutron	${}_{0}^{1}n$	1.0086649	1.674927×10^{-24}

Isotope	Mass (amu)	%Abundance	Isotope	Mass (amu)	%Abundance
${}_{1}^{1}H$	1.007825	99.985	${}_{11}^{23}Na$	22.989767	100.00
${}_{1}^{2}H$	2.014102	0.015	${}_{17}^{35}Cl$	34.968852	75.77
${}_{2}^{3}He$	3.01603	0.0000014	${}_{17}^{37}Cl$	36.965903	24.23
${}_{2}^{4}He$	4.002602	100.000	${}_{26}^{54}Fe$	53.939612	5.8
${}_{3}^{6}Li$	6.015121	7.5	${}_{26}^{56}Fe$	55.934939	91.8
${}_{3}^{7}Li$	7.016003	92.5	${}_{26}^{57}Fe$	56.935396	2.1
${}_{6}^{12}C$	$12.\overline{0}$	98.90	${}_{26}^{58}Fe$	57.933277	0.3
${}_{6}^{13}C$	13.003355	1.10	${}_{29}^{63}Cu$	62.929598	69.2
${}_{7}^{14}N$	14.003074	99.63	${}_{26}^{65}Cu$	64.927793	30.8
${}_{7}^{15}N$	15.000108	0.37	${}_{35}^{79}Br$	78.918336	50.69
${}_{8}^{16}O$	15.994915	99.76	${}_{35}^{81}Br$	80.916289	49.31
${}_{8}^{17}O$	16.999131	0.04	${}_{47}^{107}Ag$	106.905092	51.839
${}_{8}^{18}O$	17.999160	0.20	${}_{47}^{109}Ag$	108.904757	48.161
${}_{9}^{19}F$	18.998403	100.00	${}_{79}^{197}Au$	196.966543	100.00
${}_{10}^{20}Ne$	19.992435	90.48	${}_{92}^{234}U$	234.040946	0.005
${}_{10}^{21}Ne$	20.993843	0.27	${}_{92}^{235}U$	235.043924	0.720
${}_{10}^{22}Ne$	21.991383	9.25	${}_{92}^{238}U$	238.050784	99.275

TABLE 21.1 Number of Stable Nuclides Related to Numbers of Protons and Neutrons

Number of Protons	Number of Neutrons	Number of Stable Nuclides	Examples
Even	Even	168	${}^{12}_{6}\mathrm{C}$, ${}^{16}_{8}\mathrm{O}$
Even	Odd	57	${}^{13}_{6}\mathrm{C}$, ${}^{47}_{22}\mathrm{Ti}$
Odd	Even	50	${}^{19}_{9}\mathrm{F}$, ${}^{23}_{11}\mathrm{Na}$
Odd	Odd	4	${}^{2}_{1}\mathrm{H}$, ${}^{6}_{3}\mathrm{Li}$

Note: Even numbers of protons and neutrons seem to favor stability.

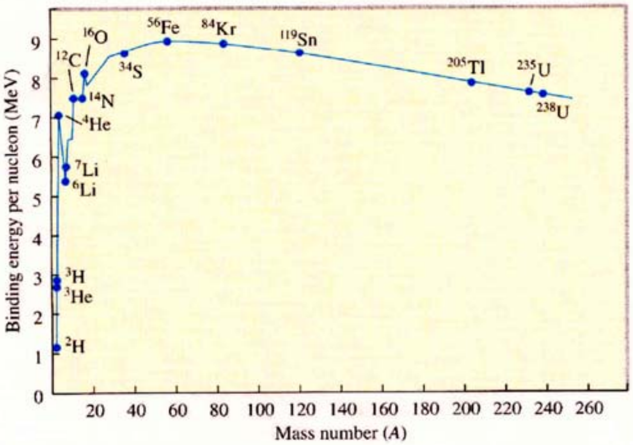
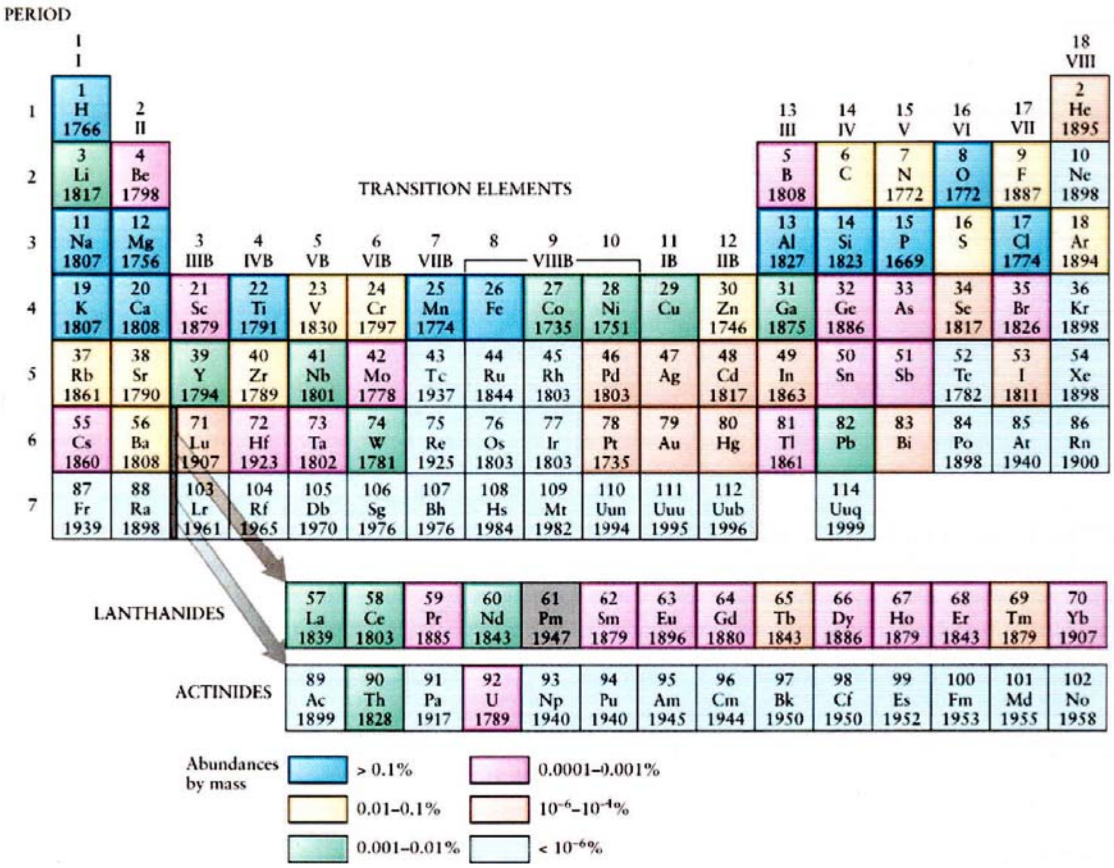


FIGURE 21.9

The binding energy per nucleon as a function of mass number. The most stable nuclei are at the top of the curve. The most stable nucleus is ${}^{56}_{26}\mathrm{Fe}$.



TRANSITION ELEMENTS

PERIOD	1 I	2 II	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 III	14 IV	15 V	16 VI	17 VII	18 VIII
1	1 H 1766																	2 He 1895
2	3 Li 1817	4 Be 1798											5 B 1808	6 C	7 N 1772	8 O 1772	9 F 1887	10 Ne 1898
3	11 Na 1807	12 Mg 1756											13 Al 1827	14 Si 1823	15 P 1669	16 S	17 Cl 1774	18 Ar 1894
4	19 K 1807	20 Ca 1808	21 Sc 1879	22 Ti 1791	23 V 1830	24 Cr 1797	25 Mn 1774	26 Fe	27 Co 1735	28 Ni 1751	29 Cu	30 Zn 1746	31 Ga 1875	32 Ge 1886	33 As	34 Se 1817	35 Br 1826	36 Kr 1898
5	37 Rb 1861	38 Sr 1790	39 Y 1794	40 Zr 1789	41 Nb 1801	42 Mo 1778	43 Tc 1937	44 Ru 1844	45 Rh 1803	46 Pd 1803	47 Ag	48 Cd 1817	49 In 1863	50 Sn	51 Sb	52 Te 1782	53 I 1811	54 Xe 1898
6	55 Cs 1860	56 Ba 1808	71 Lu 1907	72 Hf 1923	73 Ta 1802	74 W 1781	75 Re 1925	76 Os 1803	77 Ir 1803	78 Pt 1735	79 Au	80 Hg	81 Tl 1861	82 Pb	83 Bi	84 Po 1898	85 At 1940	86 Rn 1900
7	87 Fr 1939	88 Ra 1898	103 Lr 1961	104 Rf 1965	105 Db 1970	106 Sg 1976	107 Bh 1976	108 Hs 1984	109 Mt 1982	110 Uun 1994	111 Uuu 1995	112 Uub 1996		114 Uuq 1999				

LANTHANIDES	57 La 1839	58 Ce 1803	59 Pr 1885	60 Nd 1843	61 Pm 1947	62 Sm 1879	63 Eu 1896	64 Gd 1880	65 Tb 1843	66 Dy 1886	67 Ho 1879	68 Er 1843	69 Tm 1879	70 Yb 1907
ACTINIDES	89 Ac 1899	90 Th 1828	91 Pa 1917	92 U 1789	93 Np 1940	94 Pu 1940	95 Am 1945	96 Cm 1944	97 Bk 1950	98 Cf 1950	99 Es 1952	100 Fm 1953	101 Md 1955	102 No 1958

Abundances by mass

> 0.1%	0.0001–0.001%
0.01–0.1%	10^{-6}–10^{-4}%
0.001–0.01%	< 10^{-6}%

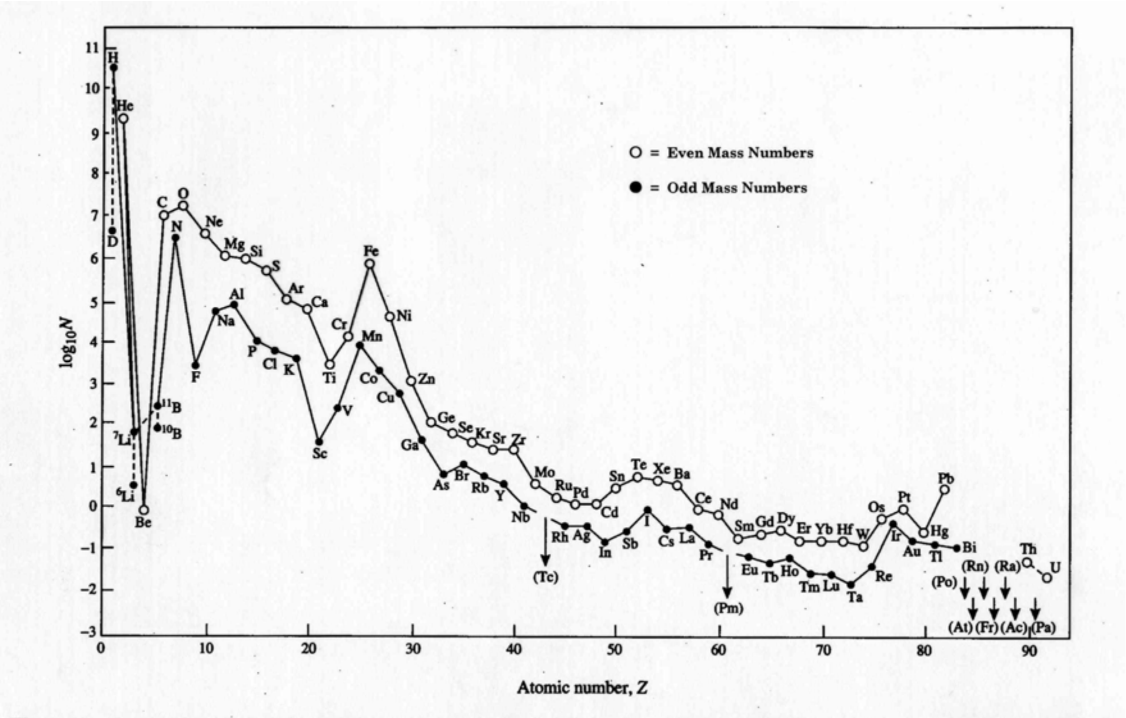


Figure 1.1 Cosmic abundances of the elements as a function of atomic number Z. Abundances are expressed as numbers of atoms per 10^6 atoms of Si and are plotted on a logarithmic scale. (From A. G. W. Cameron, *Space Sci. Rev.* **15**, 121–46 (1973), with some updating.)