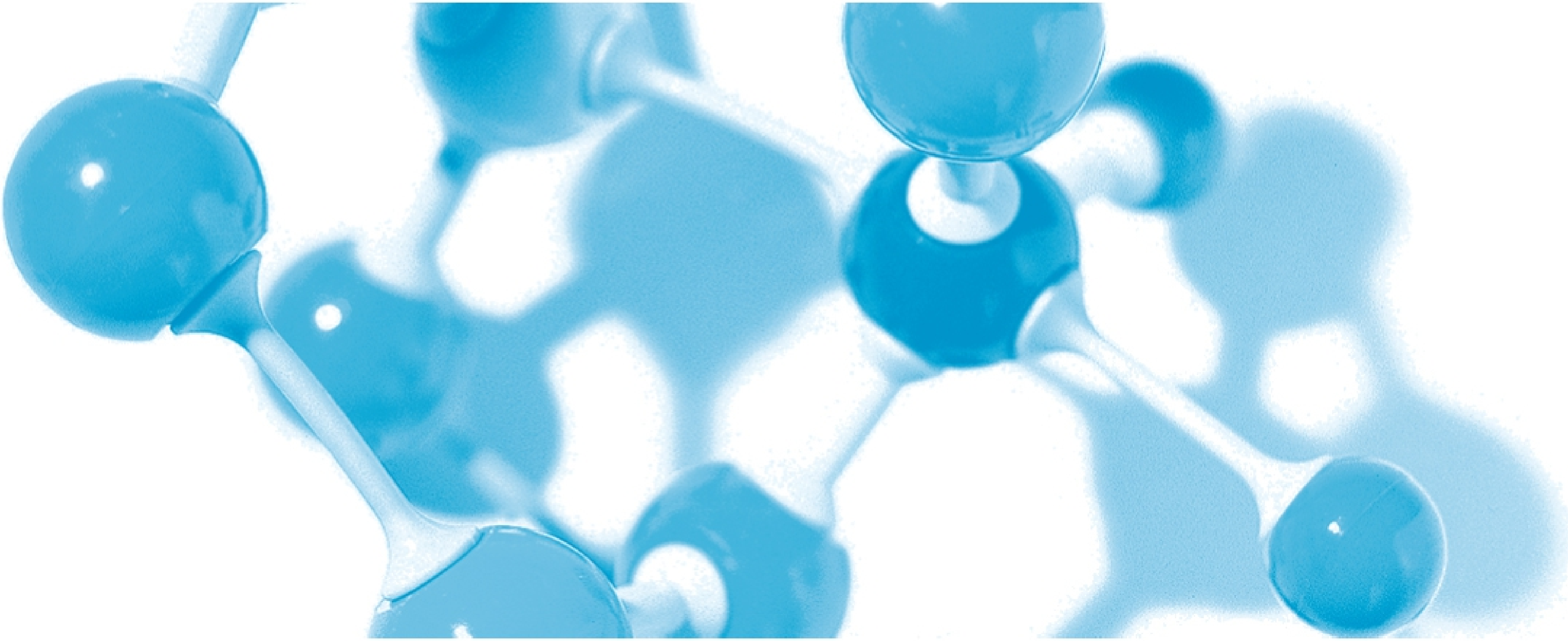
Chapter 5



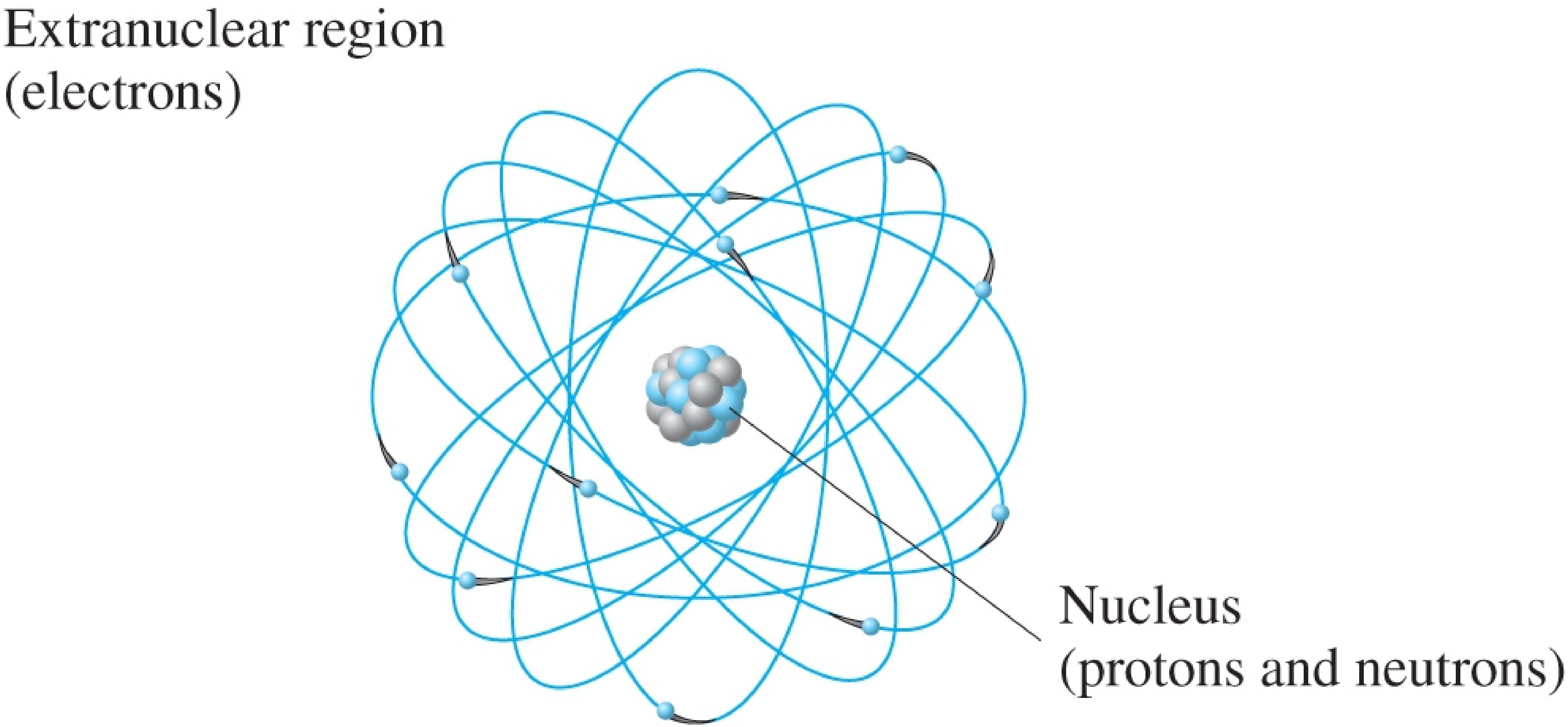
Atoms

Atoms are the smallest particle of at element that have the properties of that element.

Atoms are too small to be seen with even the most powerful optical microscope.

The three major particles that make up an atom are:

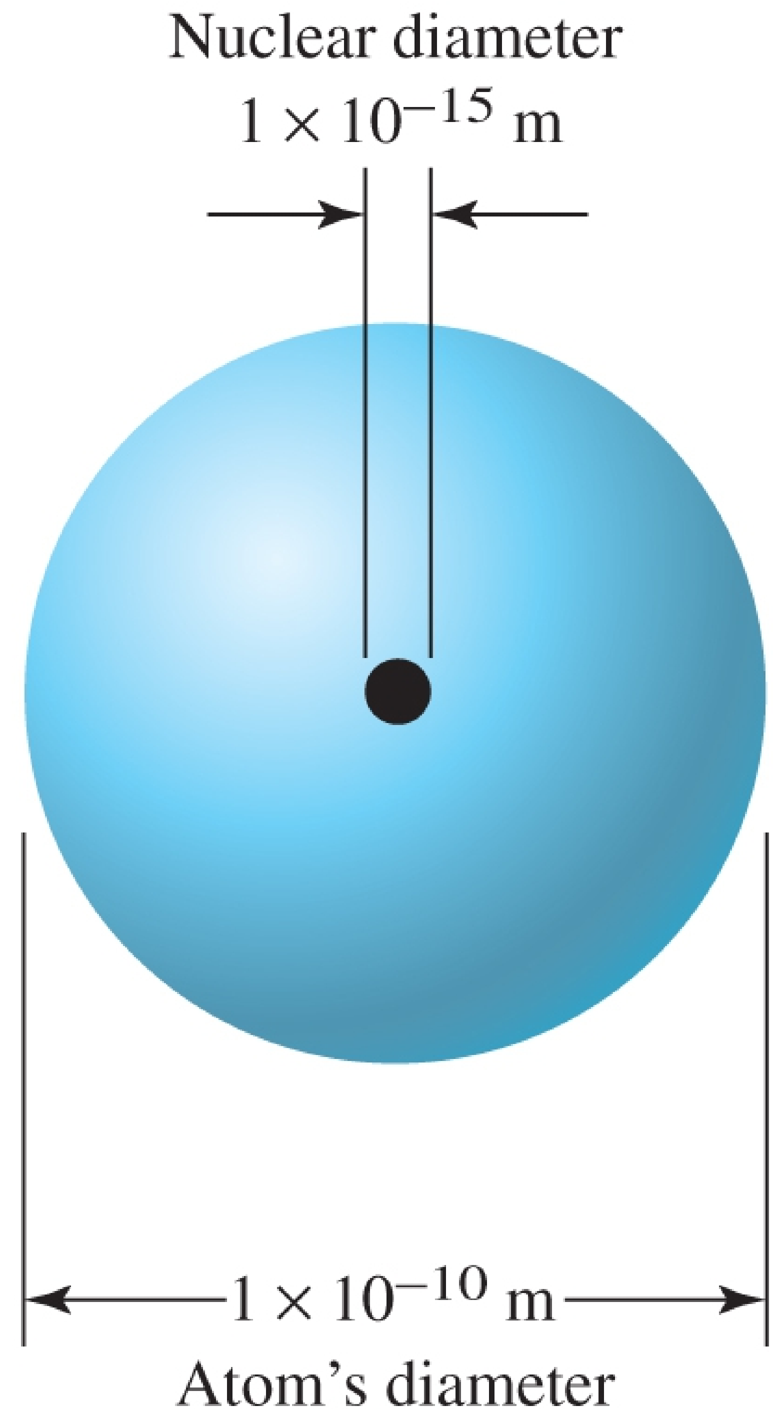
Protons, neutrons, and electrons


Extranuclear region
(electrons)
Nucleus
(protons and neutrons)

Particle	electrical charge	mass (g)	mass (amu)	Location
Proton	+1	1.66E-24	1	nucleus
Neutron	0	1.66E-24	1	nucleus
Electron	-1	9.03E-28	1/1839	electron cloud (orbitals)

- amu = atomic mass unit

- Most of the mass of an atom is in the small, dense nucleus.
- The radius of an atom is about 100,000 times larger than the radius of the nucleus.
- Electrons are located around the nucleus in orbitals.
- Orbitals – not distinct like planetary orbits, but 3-D regions where electrons can probably be found ("electron clouds").
- The position of the outermost electrons determines the radius of the atom.
- Most of an atom is empty space



Nuclear diameter
1×10^{-15} m
1×10^{-10} m
Atom's diameter

- An element is defined by the number of protons in its nucleus:
  This is called the atomic number (Z)

- The periodic table is arranged by atomic number, starting with #1 in the upper left and increasing across each period.

- Most of the mass of an atom is in the nucleus
  mass number (A) = protons (p) + neutrons (n)

- Atoms of elements are electrically neutral, so:
  # of electrons (e^-)= # of protons (p)

24 — Atomic number
Cr
52.00 — Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (269)	109 **Mt** (268)	110	111	112	(113)	(114)	(115)	(116)	(117)	(118)

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Metals

Metalloids

Nonmetals

The 1–18 group designation has been recommended by the International Union of Pure and Applied Chemistry (IUPAC) but is not yet in wide use. In this text we use the standard U.S. notation for group numbers (1A–8A and 1B–8B). No names have been assigned for elements 110–112. Elements 113–118 have not yet been synthesized.

Source: Raymond Chang, *General Chemistry: The Essential Concepts*, Third Edition, Copyright 2003 The McGraw-Hill Companies, New York, NY.

- All atoms of an element have the same atomic number.

- All atoms of an element will therefore have the same number of electrons.

- All atoms of an element may not have the same number of neutrons, so may also have different mass numbers.

- Atoms of an element with different numbers of neutrons are called isotopes.

Isotope Notation

- Z = atomic # = # of protons = p
- A = mass # = p + n
- Isotopes are denoted using the chemical symbol, X, or the element name:

  $_{Z}^{A}X$ = ^{A}X = X-A = element name-A

  So a carbon isotope with 6 neutrons could be written as:

  $_{6}^{12}C$ = ^{12}C = C-12 = Carbon-12

Most of the mass of an atom is in the nucleus, but the actual atomic mass is not exactly the sum of the masses of the nucleons (p + n).

- The electrons do have a small mass.
- Some mass is gained/lost in the energy binding nucleons together ($E = m c^2$)

The periodic table shows the average atomic masses, in amu.

These masses are the weighted averages of the masses of all of the naturally occurring isotopes.

Average atomic mass = sum over all isotopes of the mass of each isotope times its fractional abundance (percentage/100):

$$\text{Avg. at. mass} = \Sigma \frac{(atomic\ mass)(percent\ abundance)}{100\%}$$

where "Σ" means to sum over all isotopes present

For example:
Lithium has two naturally occurring isotopes:

Li-6 6.015 amu 7.42 % abundance
Li-7 7.016 amu 92.58% abundance

So, for a standard sample of lithium:

avg. at. mass =

$$\frac{(6.015\ \text{amu})(7.42\,\%)}{100\,\%} + \frac{(7.016\ \text{amu})(92.58\,\%)}{100\,\%}$$

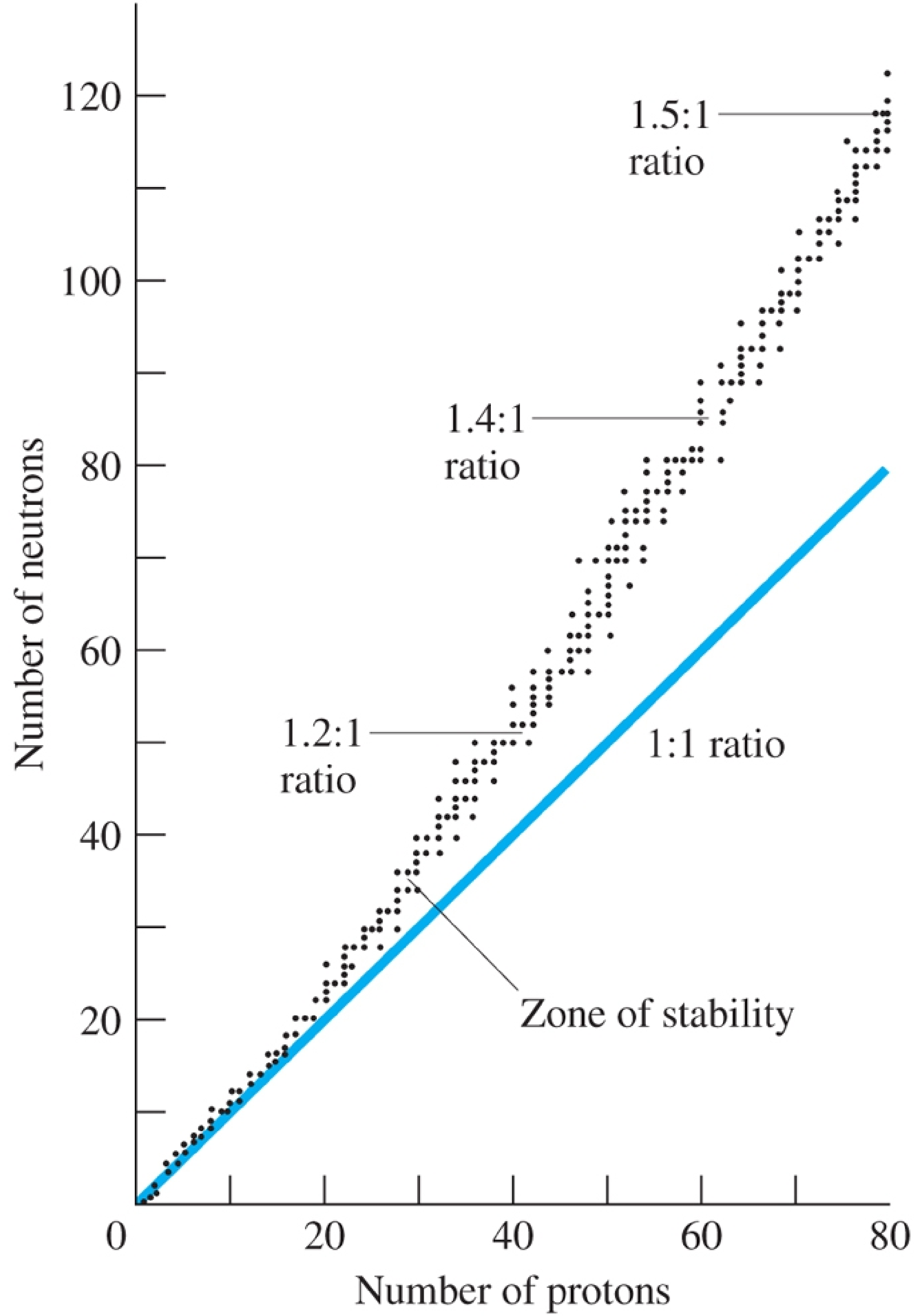
= 0.446 amu + 6.50 amu
= 6.94 amu

TABLE 5.2 Isotopic Data for Elements with Atomic Numbers 1 through 12. Information given for each isotope includes mass number, isotopic mass in amu, and percent abundance.

Atomic number	Element	Isotope	Isotopic mass	Percent abundance
1	Hydrogen	$^{1}_{1}H$	1.008 amu	99.985%
		$^{2}_{1}H$	2.014 amu	0.015%
		$^{3}_{1}H$	3.016 amu	trace
2	Helium	$^{3}_{2}He$	3.016 amu	trace
		$^{4}_{2}He$	4.003 amu	100%
3	Lithium	$^{6}_{3}Li$	6.015 amu	7.42%
		$^{7}_{3}Li$	7.016 amu	92.58%
4	Beryllium	$^{9}_{4}Be$	9.012 amu	100%
5	Boron	$^{10}_{5}B$	10.013 amu	19.6%
		$^{11}_{5}B$	11.009 amu	80.4%
6	Carbon	$^{12}_{6}C$	12.000 amu	98.89%
		$^{13}_{6}C$	13.003 amu	1.11%
		$^{14}_{6}C$	14.003 amu	trace
7	Nitrogen	$^{14}_{7}N$	14.003 amu	99.63%
		$^{15}_{7}N$	15.000 amu	0.37%
8	Oxygen	$^{16}_{8}O$	15.995 amu	99.759%
		$^{17}_{8}O$	16.999 amu	0.037%
		$^{18}_{8}O$	17.999 amu	0.204%
9	Fluorine	$^{19}_{9}F$	18.998 amu	100%
10	Neon	$^{20}_{10}Ne$	19.992 amu	90.92%
		$^{21}_{10}Ne$	20.994 amu	0.26%
		$^{22}_{10}Ne$	21.991 amu	8.82%
11	Sodium	$^{23}_{11}Na$	22.990 amu	100%
12	Magnesium	$^{24}_{12}Mg$	23.985 amu	78.70%
		$^{25}_{12}Mg$	24.986 amu	10.13%
		$^{26}_{12}Mg$	25.983 amu	11.17%

Radioactivity – spontaneous emission of radiation

- Unstable atoms – not all atoms are radioactive
- Radioactivity depends on number of protons and n/p ratio.
- Larger atomic # are more likely to be radioactive – all actinides are radioactive
- Stable nuclei have n/p close to 1 (so # n = # p)
- The n/p ratio increases for larger atomic #s



Number of neutrons
120
100
80
60
40
20
1.5:1 ratio
1.4:1 ratio
1.2:1 ratio
1:1 ratio
Zone of stability
0
20
40
60
80
Number of protons

There are three main types of radiation:

1) Alpha particles (α)

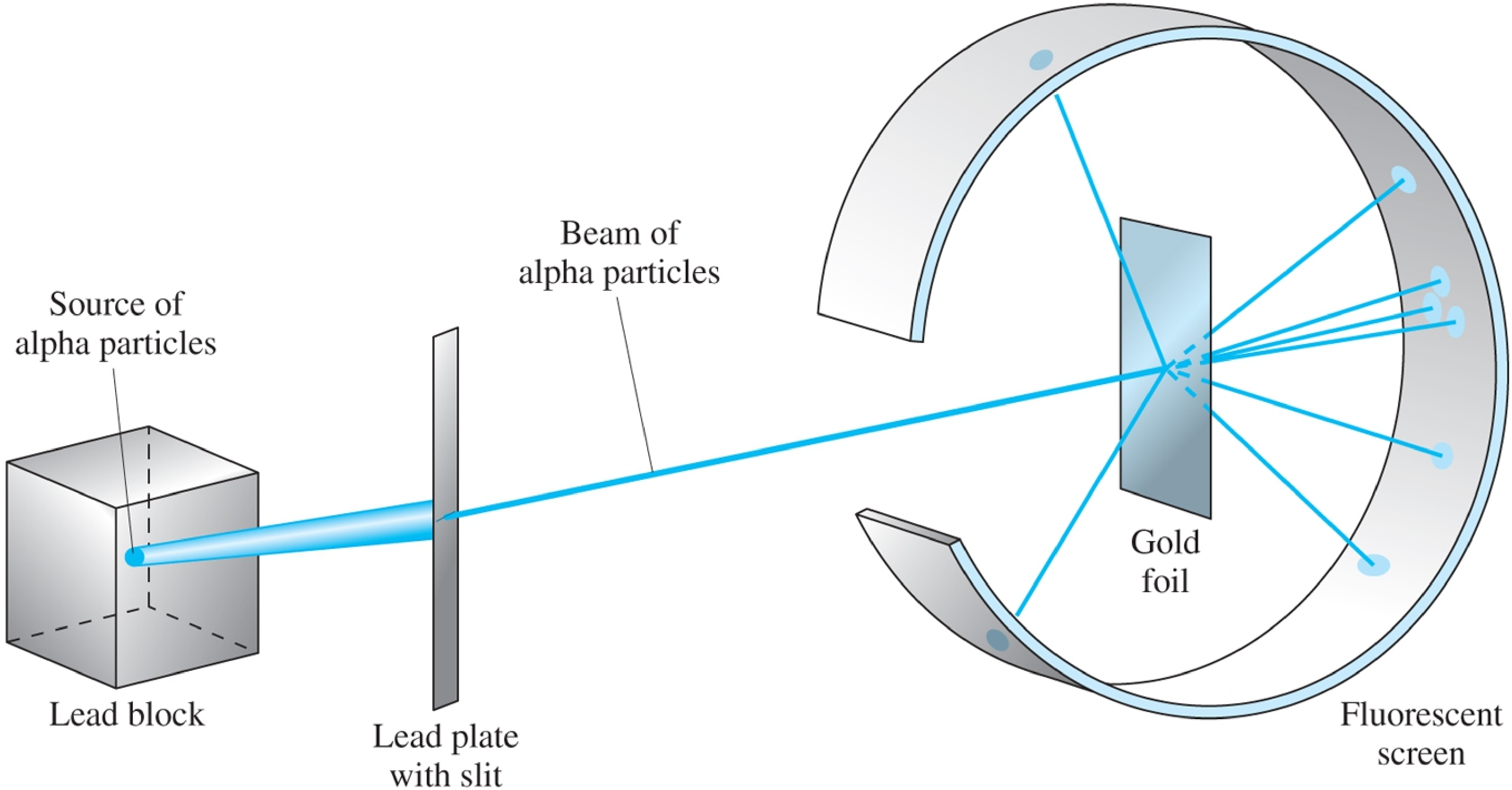
- Helium nuclei → 2 protons + 2 neutrons
- $\alpha = {}_{2}^{4}\alpha$
- Least dangerous – stopped by paper or skin
- Dangerous if inhaled/ingested

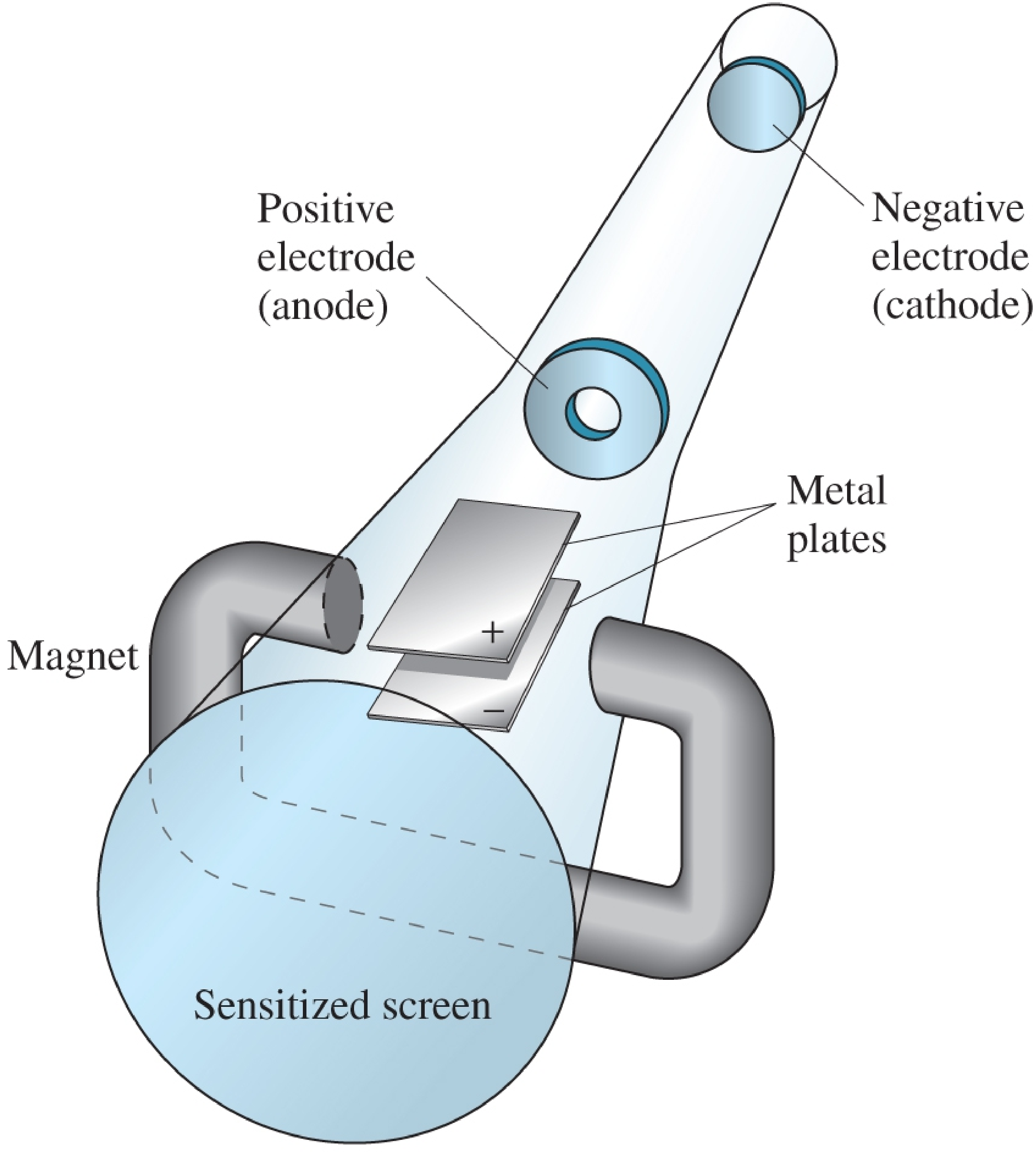
2) Beta particles (β)

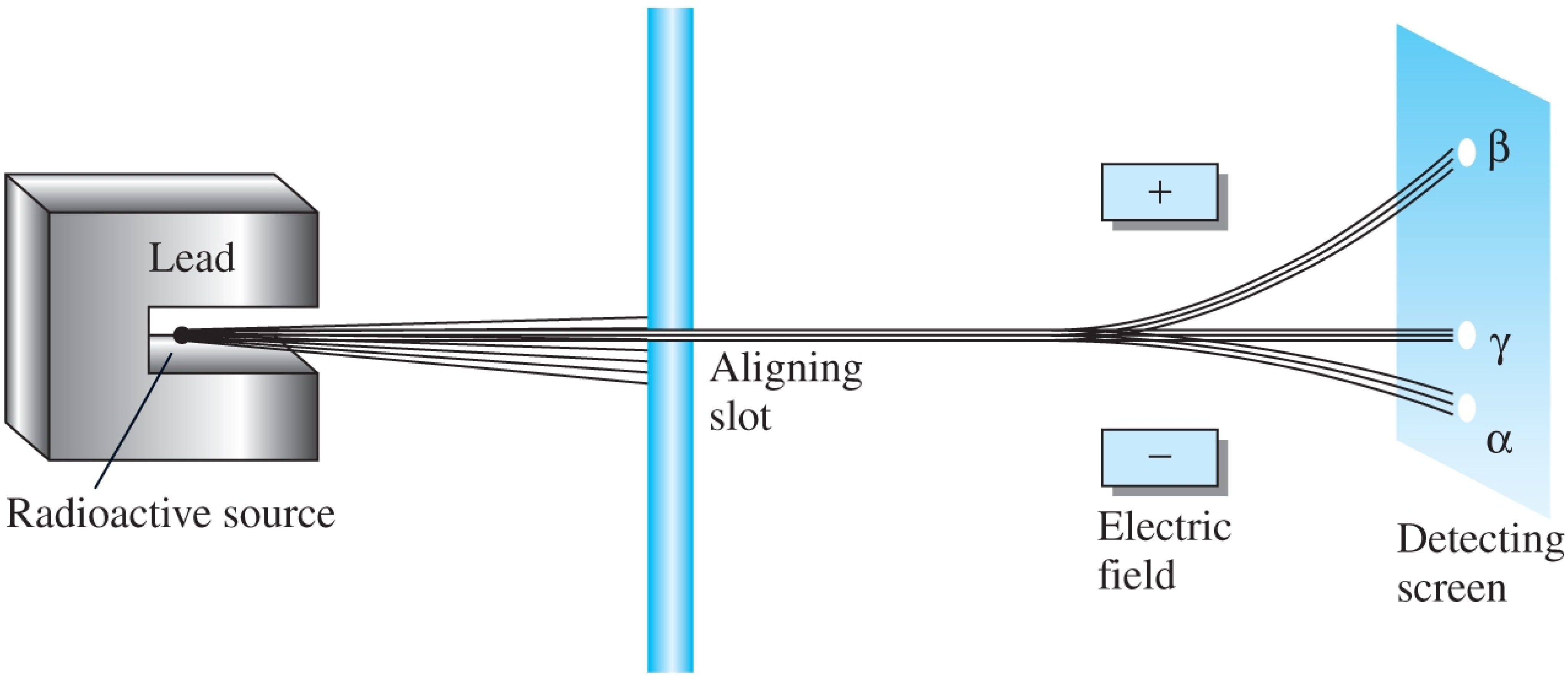
- High speed electron
- $\beta = {}_{-1}^{0}\beta$
- More dangerous – stopped by aluminum foil, usually stopped by skin
- Dangerous if inhaled/ingested

3) Gamma rays (γ)

- High energy electromagnetic radiation – more energetic than x-rays
- No rest mass or charge
- More dangerous than other radiation – may take several feet of concrete/lead to stop
- Breaks chemical bonds, damages DNA
- Gamma radiation accompanies other radioactive emissions.


Source of
alpha particles
Beam of
alpha particles
Lead block
Lead plate
with slit
Gold
foil
Fluorescent
screen


Positive
electrode
(anode)
Negative
electrode
(cathode)
Metal
plates
+
−
Magnet
Sensitized screen


Lead
Radioactive source
Aligning slot
+
−
Electric field
β
γ
α
Detecting screen

Radioactive Decay Series

- When unstable nuclei emit radiation, they change into other isotopes/elements.

- The new isotope(s) formed may also be radioactive.

- This process continues until stable isotopes are formed.

- The Decay Series is all of the isotopes formed as a radioactive element decays into stable isotopes.

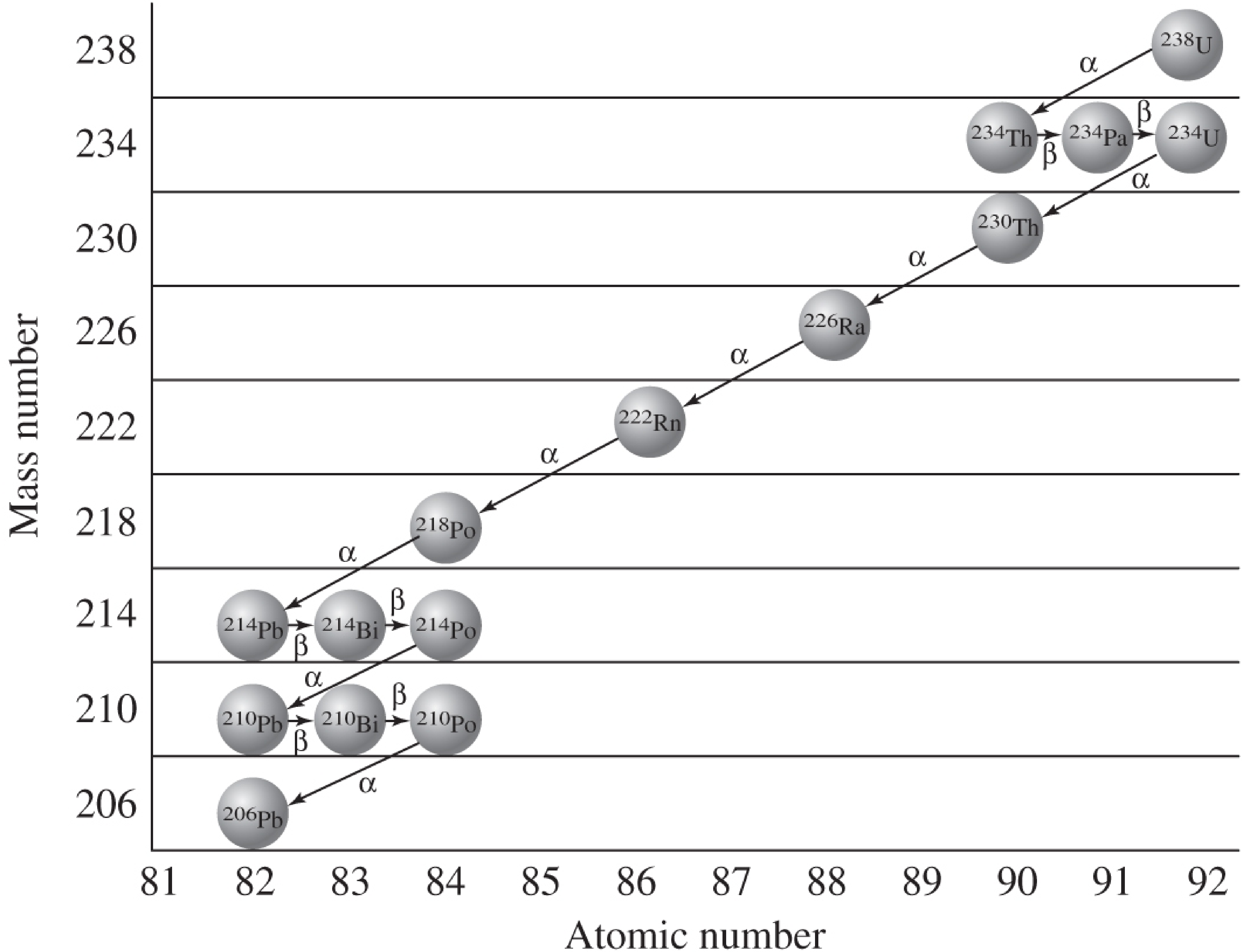

238
234
230
226
222
218
214
210
206
Mass number
238U
234Th
234Pa
234U
230Th
226Ra
222Rn
218Po
214Pb
214Bi
214Po
210Pb
210Bi
210Po
206Pb
α
β
81
82
83
84
85
86
87
88
89
90
91
92
Atomic number

TABLE 5.5 The Four Known Radioactive Decay Series

Parent	Number of Decay Steps	Final Product of Series
Uranium-238	14	lead-206
Thorium-232	10	lead-208
Uranium-235	11	lead-207
Plutonium-241	13	bismuth-209

When an isotope undergoes a decay process:

- A very small amount of mass is lost as energy.
- But the overall mass # is conserved.
- And the nuclear charge is conserved.

In other words:

- The mass number of the isotope should equal the sum of mass numbers of the products.
- The atomic number of the isotope should equal the sum of atomic numbers of the products.

Alpha Decay – emission of an alpha particle:

$${}_{92}^{238}U \rightarrow {}_{2}^{4}\alpha + {}_{90}^{234}Th$$

Beta Decay – emission of a beta particle:

$${}_{4}^{10}Be \rightarrow {}_{-1}^{0}\beta + {}_{5}^{10}B$$

Gamma rays accompany radioactive decay.

Neutrons may also be emitted:

$${}_{0}^{1}n \rightarrow {}_{-1}^{0}\beta + {}_{1}^{1}p$$

24 — Atomic number
Cr
52.00 — Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
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Metalloids

Nonmetals

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- The half life of an isotope is the time required for half of a sample to undergo radioactive decay.

- Half lives may range from fractions of a second to millions of years.

- After one half life, half of the sample decays, after two half lives, 3/4 has decayed,

- mass of isotope remaining = (initial mass)/2^x where x is the number of half lives

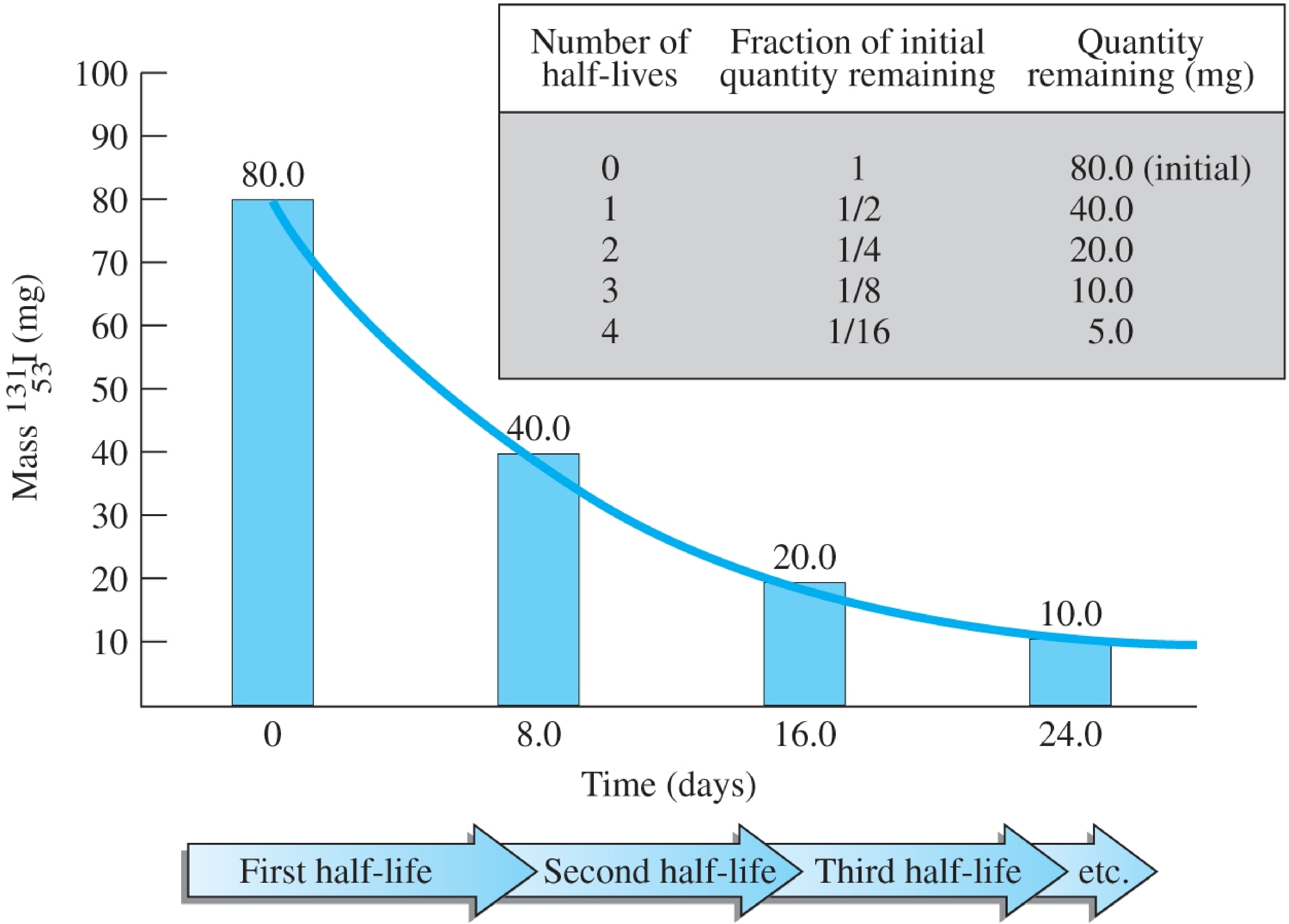
- Remember that, after a radioactive isotope has decayed, the new isotopes may also be radioactive.

TABLE 5.3 Range of Half-Lives Found for Naturally Occurring Radionuclides

Element	Half-life
Vanadium-50	6×10^{15} yr
Platinum-190	6.9×10^{11} yr
Uranium-238	4.5×10^{9} yr
Uranium-235	7.1×10^{8} yr
Thorium-230	7.5×10^{4} yr
Lead-210	22 yr
Bismuth-214	19.7 min
Polonium-212	3.0×10^{-7} sec

TABLE 5.4 Stability Characteristics of Transuranium Elements

Name	Symbol	Atomic Number	Mass Number of Most Stable Nuclide	Half-Life of Most Stable Nuclide	Discovery Year of First Isotope
Neptunium	Np	93	237	2.14×10^6 yr	1940
Plutonium	Pu	94	244	7.6×10^7 yr	1940
Americium	Am	95	243	8.0×10^3 yr	1944
Curium	Cm	96	247	1.6×10^7 yr	1944
Berkelium	Bk	97	247	1400 yr	1950
Californium	Cf	98	251	900 yr	1950
Einsteinium	Es	99	252	472 days	1952
Fermium	Fm	100	257	100 days	1953
Mendelevium	Md	101	258	52 days	1955
Nobelium	No	102	259	58 min	1958
Lawrencium	Lr	103	262	3.6 hr	1961
Rutherfordium	Rf	104	267	1.3 hr	1969
Dubnium	Db	105	268	1.2 days	1970
Seaborgium	Sg	106	271	1.9 min	1974
Bohrium	Bh	107	272	9.6 sec	1980
Hassium	Hs	108	270	3.6 sec	1984
Meitnerium	Mt	109	276	0.72 sec	1982
Darmstadtium	Ds	110	281	11.1 sec	1994
Roentgenium	Rg	111	280	3.6 sec	1994
Element 112	—	112	285	34 sec	1996
Element 113	—	113	284	0.48 sec	2004
Element 114	—	114	289	2.6 sec	1999
Element 115	—	115	288	87 msec	2004
Element 116	—	116	293	61 msec	2006
Element 118	—	118	294	0.89 msec	2006



Number of half-lives	Fraction of initial quantity remaining	Quantity remaining (mg)
0	1	80.0 (initial)
1	1/2	40.0
2	1/4	20.0
3	1/8	10.0
4	1/16	5.0