Unit 12 · Radioactivity

STUDY NOTES

Key terms

Radioactivity: breaking down of unstable nuclei by themselves, giving out radiation.

Nuclear radiation: the radiation that comes from the nucleus: alpha, beta, gamma.

Radioisotope: isotope with unstable nuclei (uranium-238, radium-226, carbon-14, cobalt-60).

Parent / daughter nucleus: the one that broke down / the one left.

Natural: uranium, thorium, radon, potassium-40. **Artificial**: made in reactors or accelerators (cobalt-60, technetium-99m, americium-241).

Penetrating power: how far it travels through matter before it is stopped.

Ionizing power: how many ions it makes along each cm of its path.

Tracer: tiny amount of radioactive substance collecting in an organ or leak.

Dose: energy left in the body and kind of radiation in one number; **sievert** (Sv); 1 mSv = 0.001 Sv; 1 μSv = 0.001 mSv.

Dosimeter: small badge that records the dose received.

Contamination: radioactive material on or in something.

Three features

- **by itself**: nothing starts or stops it
- **nothing outside the nucleus changes it**: heat, cold, pressure, compounds make no difference
- **the element changes** when a charged particle leaves

Nuclear equations

- ${}^{A}_{Z}\mathrm{X}$: Z protons; A protons + neutrons
- A **totals equal on both sides,** Z **totals equal**; find A, Z, then the element

Radiation	Leaves the nucleus	Z	A
alpha, ${}^{4}_{2}\mathrm{He}$	2 p + 2 n	− 2	− 4
beta, ${}^{0}_{-1}\mathrm{e}$	electron (a neutron became a proton)	+ 1	same
gamma, γ	energy only	same	same

- ${}^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$
- ${}^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$
- ${}^{60}_{27}\mathrm{Co} \longrightarrow {}^{60}_{28}\mathrm{Ni}^{*} + {}^{0}_{-1}\mathrm{e}$; ${}^{60}_{28}\mathrm{Ni}^{*} \longrightarrow {}^{60}_{28}\mathrm{Ni} + \gamma$ (* excited: spare energy leaves as gamma)
- beta: neutron → proton (stays) + electron (shot out) + antineutrino (shares the energy)

Counting a chain: only alpha changes A

- alphas = fall in $A \div 4$
- betas = final Z − (first Z − 2 × alphas)
- U-238 ($Z = 92$) → Pb-206 ($Z = 82$): $32 \div 4 = 8$ alpha; $92 - 16 = 76$; $82 - 76 = 6$ beta
- 1 alpha + 2 beta: Z same, $A - 4$: an isotope of the parent

The three compared

Property	Alpha (α)	Beta (β)	Gamma (γ)
What it is	helium nucleus: 2 p + 2 n	fast electron from the nucleus	electromagnetic wave
Charge	+2	−1	0
Mass	6.64×10^{-27} kg, about 4 u	9.11×10^{-31} kg, about 1/1836 u	0
Speed	about 1.5×10^{7} m/s, 5% of light's	up to 99% of light's	light's, 3×10^{8} m/s
Penetrating	**least**: 3–7 cm of air; stopped by paper, dead skin	**more**: a few m of air; a few mm of aluminium	**most**: only reduced by thick lead, concrete
Ionizing	**most**: tens of thousands of ion pairs per cm	**less**: about 100 per cm	**least**
Electric field	to − plate	to + plate, more	straight
Magnetic field	bends a little	other way, much more; spreads into a fan	straight

- **more ionizing** → **less penetrating**: every ion costs energy
- alpha ≈ 7,300 × beta's mass; twice the charge; heavy, so hard to turn → bends 35 to 150 times less in a magnet
- beta fan: beta has every speed up to a top one (shares energy with the antineutrino); alpha from one kind of nucleus, one sharp beam
- exam drawing: alpha and beta opposite, gamma straight, alpha to − plate; **say alpha bends less**
- gamma halved by 1.2 cm lead or 6.6 cm concrete (cobalt-60); no thickness stops every last ray; 4.8 cm lead: $(½)^4 = 1/16$
- experiment: source in lead block with a channel, thin beam between plates, **in a vacuum**, onto a screen; bends to − → positive; to + → negative; straight → no charge

Uses: chosen by penetrating and ionizing power

Use	Radiation	Why
radiotherapy (cobalt-60)	gamma	reaches a deep tumor; machine turns, beam stays on tumor
brachytherapy (iridium-192)	source beside tumor	through a thin tube, then back to its safe
gamma camera (technetium-99m)	gamma	gets out of the body; halves in 6 hours
overactive thyroid (iodine-131)	beta	about 2 mm at most; thyroid collects iodine
sterilizing syringes, gloves	gamma	through the packet; no heat
thickness of paper, plastic, foil	beta	thin sheet absorbs part; alpha all stopped, gamma almost unchanged
thick steel sheet, welds, castings	gamma	only it gets through thick metal; cracks show dark on film
leaks in buried pipes	gamma tracer	detected through the ground
smoke detector (americium-241)	alpha	ionizes air, ions carry current, smoke catches ions, current drops, alarm; stopped by air and case
food keeping, sterile insects, new crops	gamma	kills germs; sterile males; random DNA changes
dating	carbon-14; uranium, lead	how much is left; to about 50,000 years

- **LINAC**: X-rays from electricity; off = rays stop; no source. Cobalt-60 "off" = behind its shield
- **Nepal**: cobalt-60 radiotherapy from 1991 (Bir Hospital); around 2020, six centers, five LINACs, two cobalt-60 machines

Hazards

- ionization breaks molecules, above all **DNA**: cell repairs, dies, or lives changed (may become cancer)
- **short-term**, over about 1 Sv in a short time: radiation sickness (vomiting, tiredness, fewer white blood cells → infections, hair loss), burns; very large doses kill within weeks
- **long-term**: cancer (leukemia; thyroid, lung, bone), cataracts; more dose, more chance
- sex cells: **mutation** could pass to children (seen in animals, not clearly in people; organs shielded in X-rays)
- **outside the body: gamma** worst, to every organ; beta burns skin and eyes; alpha stopped by dead skin
- **inside: alpha** worst, all its energy in a few cells (radon in lungs; Radium Girls)
- **radon**: seeps from the ground, gathers in closed rooms; after smoking, commonest cause of lung cancer; open windows

Dose	What it is
0.02–0.1 mSv	chest X-ray
about 2.4 mSv a year	world average natural background
about 8 mSv	CT of abdomen
1 mSv a year	public limit, man-made sources
20 mSv a year (average)	radiation workers' limit
100 mSv	lowest dose with a rise in cancer seen
1,000 mSv, short time	radiation sickness
4,000–5,000 mSv, short time	kills about half, untreated, in two months

Safety

Time: half the time, half the dose.

Distance: gamma falls with the square: 2 × as far, ¼; 3 × as far, 1/9.

- 40 μSv per hour at 1 m → 10 at 2 m → 2.5 at 4 m

Shielding:

- paper or case for alpha
- few mm of aluminium or plastic for beta
- thick lead or concrete for gamma (cobalt-60 rooms: concrete over 1 m)

Handling:

- tongs, gloves, remote arms; never bare hands
- lab coat, gloves, dosimeter checked regularly
- no eating, drinking, make-up; wash and check hands
- lead bricks, lead glass, concrete
- at school: small, sealed, kept by the teacher

Storing:

- thick lead (concrete for strong ones), locked, away from people
- warning sign ☢ with what and when
- written record: where, who, how strong; never lost, sold as scrap, thrown away
- waste stored until harmless: technetium-99m in two days 1/256; long-lived sealed in steel and concrete, some deep underground
- **Nepal**: Radioactive Substances (Use and Regulation) Act, in force July 2020 (2077 BS): license needed
- **Goiânia** 1987: abandoned cesium-137 capsule opened for scrap; 4 dead, 249 contaminated

COMMON MISTAKES

✗ A beta particle is one of the atom's outer electrons.
✓ From the nucleus: a neutron turns into a proton.

✗ Beta: A and Z each fall by 1.
✓ $Z + 1$, A the same.

✗ Heating speeds up decay.
✓ No change: the nucleus doesn't notice.

✗ Lead stops gamma rays.
✓ Only reduces them.

✗ Alpha bends as much as beta in a magnet.
✓ Opposite way, far less.

✗ X-rayed people or sterilized food are radioactive.
✓ Not; only contamination spreads.