NOTES: 25.2 – Nuclear Stability and Radioactive Decay

Why does the nucleus stay together?

STRONG NUCLEAR FORCE

- Short range, attractive force that acts among nuclear particles
- Nuclear particles attract one another
- Much stronger than electrical or gravitational force

STABLE NUCLEUS

- A nucleus that does NOT spontaneously decay
- MOST ATOMS ARE STABLE!!

Nuclides

- Different atomic forms of all elements
- Most small nuclides have equal # of protons and neutrons
- Some nuclides have “magic #’s” of protons and neutrons and are especially stable

The neutron-to-proton ratio determines the STABILITY of the nucleus

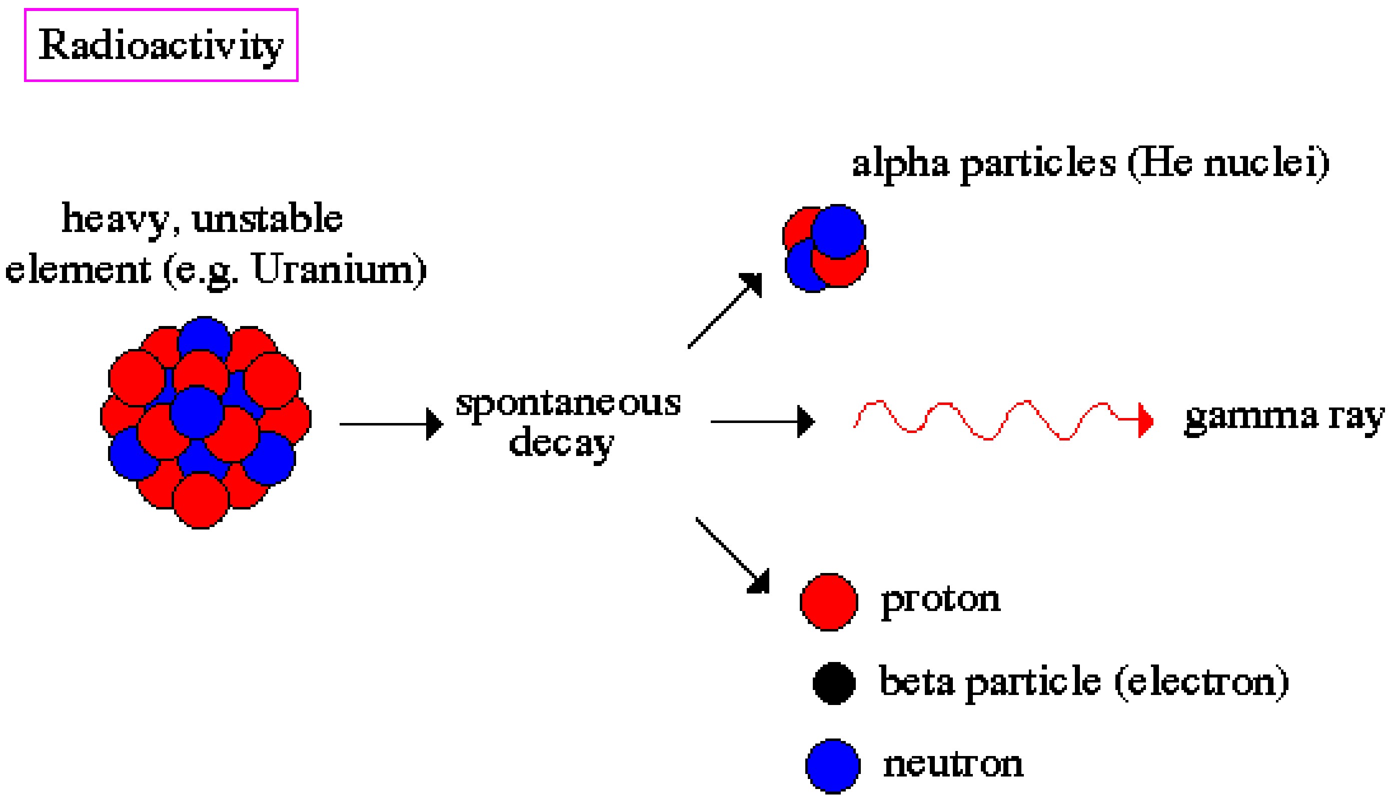
- For low atomic #'s:

Equal #'s of protons and neutrons

- Above atomic #20:

More neutrons than protons

Nuclei whose neutron-to-proton ratio is unstable undergo radioactive decay by emitting 1 or more particles and/or electromagnetic rays:



When is a nucleus STABLE?

- for nuclei below atomic #20, the stable nuclei have roughly equal numbers of protons and neutrons

- **EXAMPLES**: carbon-12: 6 pro, 6 neu

nitrogen-14: 7 pro, 7 neu

oxygen-16: 8 pro, 8 neu

When is a nucleus STABLE?

- for nuclei above atomic #20, the stable nuclei have more neutrons than protons;
- the "stable" neutron : proton ratio is **1.5**

- **EXAMPLE**:

lead-206: 82 protons, 124 neutrons

(ratio = 124 / 82 ≈ 1.5)

When is a nucleus UNSTABLE?

- too many neutrons relative to protons
- decay by turning a neutron into a proton and emitting a beta particle (an electron) – this results in an increase in # of protons and a decrease in # of neutrons:
- **EXAMPLE**:

$$^{12}_{5}B \rightarrow {}^{12}_{6}C + {}^{0}_{-1}e$$

When is a nucleus UNSTABLE?

- too many neutrons AND too many protons to be stable
- all nuclei with atomic # greater than 83 are radioactive and are especially heavy
- most of them emit alpha particles as they decay

- **EXAMPLE**:

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

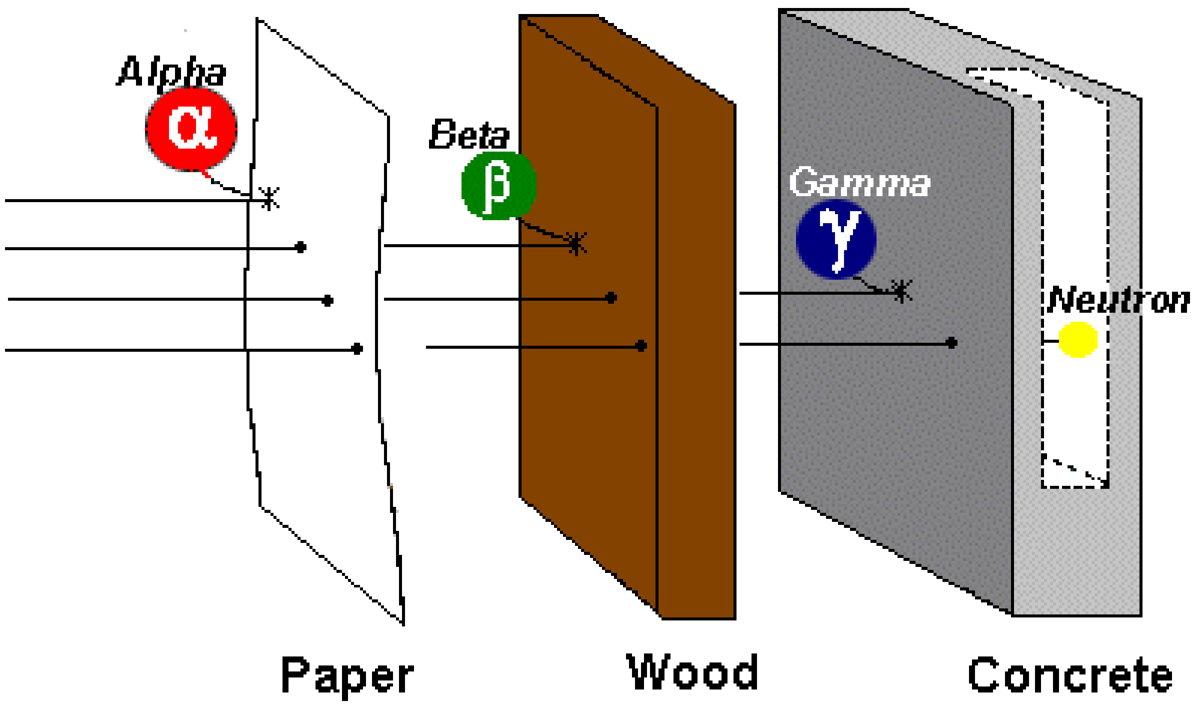
REVIEW: Radioactive Decay

- An unstable nucleus loses energy by emitting radiation
- Radiation = penetrating rays and particles emitted by a radioactive source
- Radioisotopes = unstable isotopes undergo change to become more stable

Nuclei whose neutron-to-proton ratio is unstable undergo radioactive decay by emitting 1 or more particles and/or electromagnetic rays:

Type/ symbol	Identity	Mass (amu)	Charge	Penetration
Alpha α or ${}^{4}_{2}He$	helium nucleus	4.0026	2+	low
Beta β or ${}^{0}_{-1}e$	electron	0.00055	1-	low-med
Gamma ${}^{0}_{0}\gamma$	high energy radiation	0	0	high
Proton ${}^{1}_{1}p$ or ${}^{1}_{1}H$	proton, H nucleus	1.0073	1+	low-med
Neutron ${}^{1}_{0}n$	neutron	1.0087	0	very high

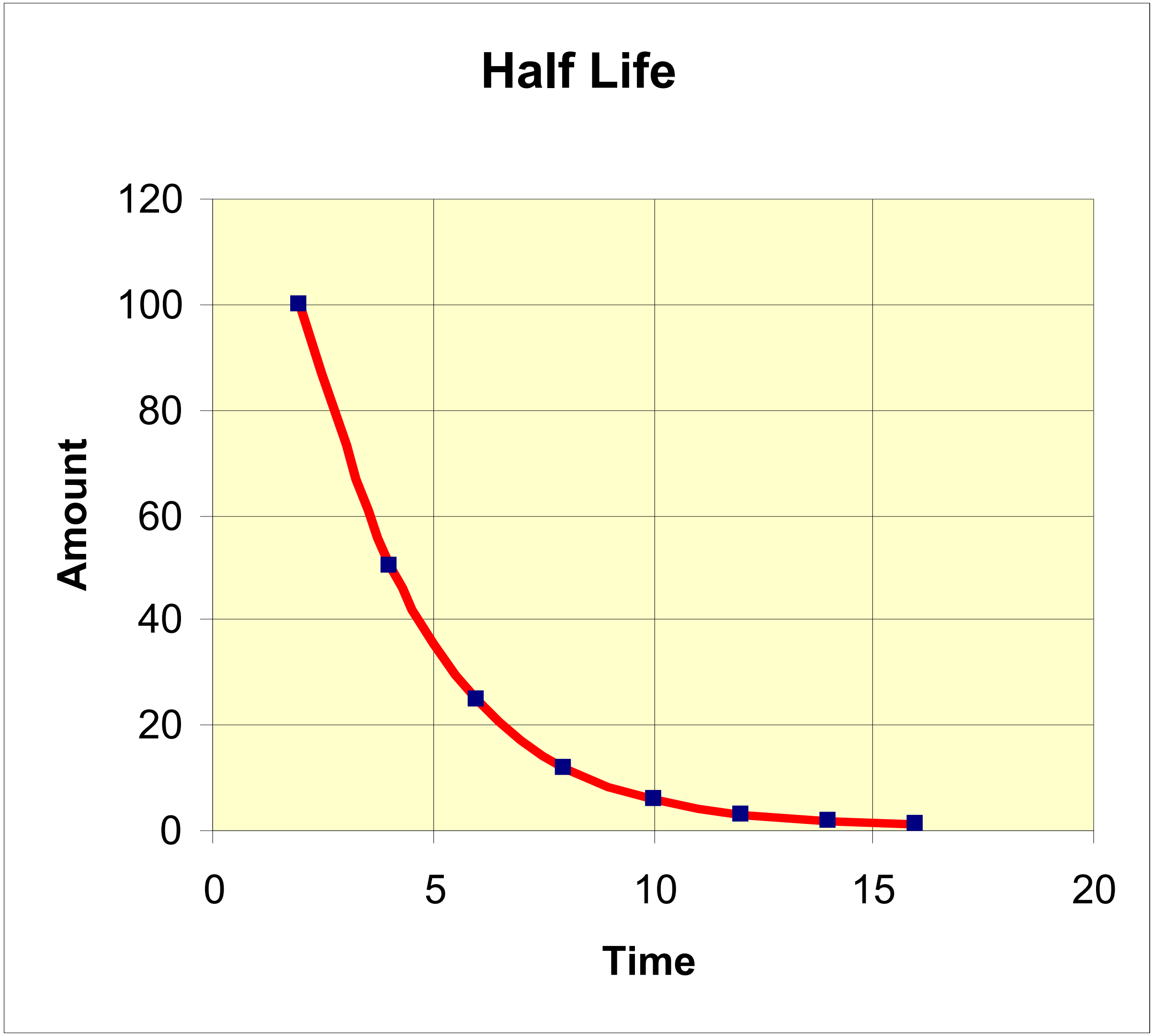
Comparing penetrating ability…

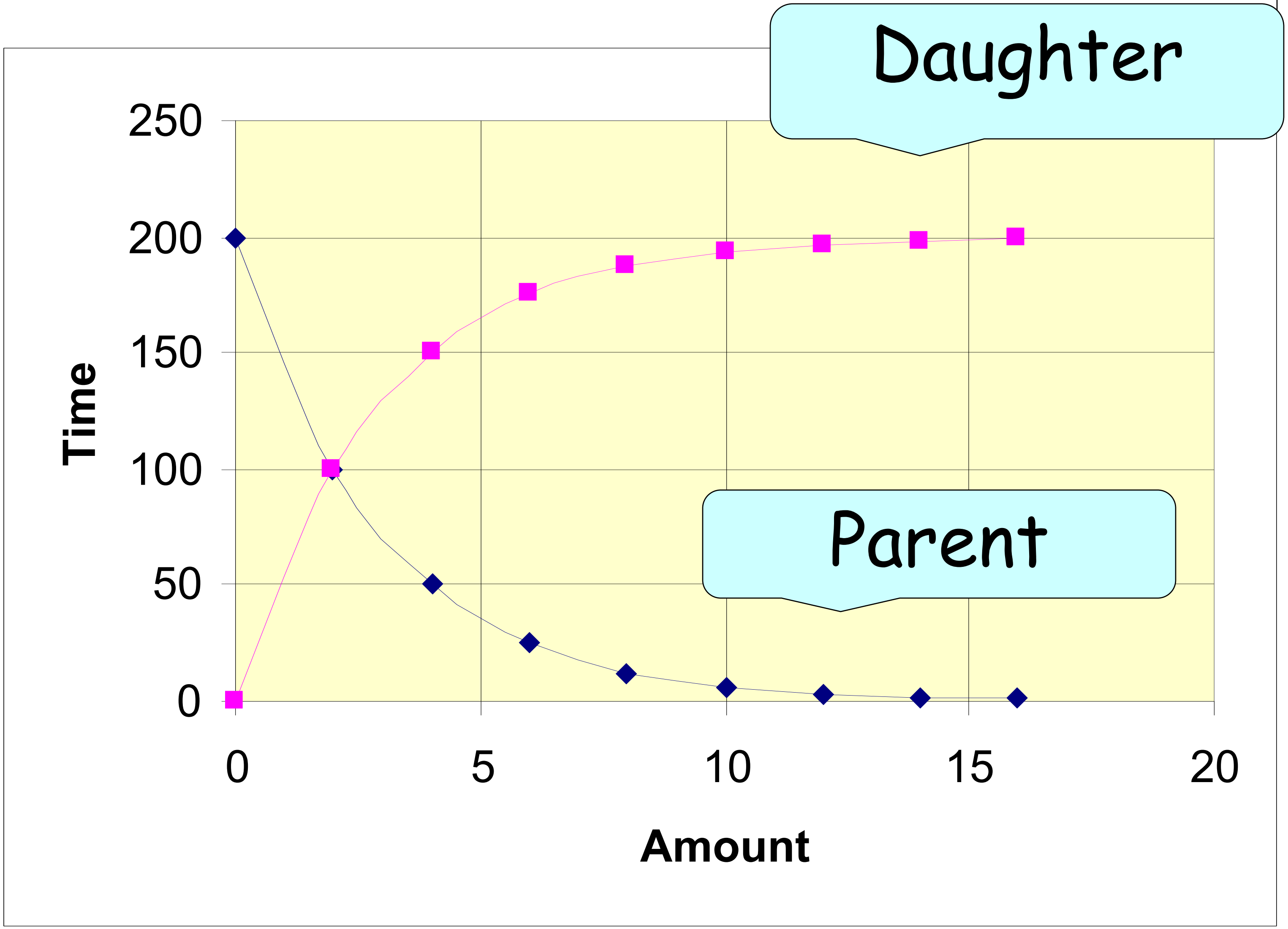


Half-Life:

- every radioactive isotope has a characteristic **RATE of decay** called the **HALF-LIFE**.
- **HALF-LIFE** = the amount of time required for ½ of the nuclei of a radioisotope sample to decay to its products
- Half-lives may be short (fraction of a second) or long (billions of years)

Half-Life




Daughter
Parent
Time
250
200
150
100
50
0
0
5
10
15
20
Amount

Uses of Radioactive Isotopes:

- **if there is a long half-life**: can be used to determine the age of ancient artifacts;
- **if there is a short half-life**: can be used in nuclear medicine (rapid decaying isotopes do not pose long-term radiation hazards to patient)

How is the decay rate of a radioactive substance expressed?

Equation: $\underline{\mathbf{A = A^{o} \times (1/2)^{n}}}$

A = amount remaining

A^{o} = initial amount

n = # of half-lives

(**to find n, calculate t/T, where t = time, and T = half-life, in the same time units as t), so you can rewrite the above equation as:

$$\underline{\mathbf{A = A^{o} \times (1/2)^{t/T}}}$$

½ Life Example #1:

- Nitrogen-13 emits beta radiation and decays to carbon-13 with $t_{1/2}$ = 10 minutes. Assume a starting mass of 2.00 g of N-13.

A) How long is three half-lives?

B) How many grams of the isotope will still be present at the end of three half-lives?

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- Nitrogen-13 emits beta radiation and decays to carbon-13 with $t_{1/2}$ = 10 minutes. Assume a starting mass of 2.00 g of N-13.

A) How long is three half-lives?

(3 half-lives) x (10 min. / h.l.) =

<u>30 minutes</u>

½ Life Example #1:

- Nitrogen-13 emits beta radiation and decays to carbon-13 with $t_{1/2}$ = 10 minutes. Assume a starting mass of 2.00 g of N-13.

B) How many grams of the isotope will still be present at the end of three half-lives?

2.00 g x ½ x ½ x ½ =0.25 g

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- Nitrogen-13 emits beta radiation and decays to carbon-13 with $t_{1/2}$ = 10 minutes. Assume a starting mass of 2.00 g of N-13.

B) How many grams of the isotope will still be present at the end of three half-lives?

$A = A^{o} \times (1/2)^{n}$

$A = (2.00\ g) \times (1/2)^{3}$

A = 0.25 g

½ Life Example #2:

- Mn-56 is a beta emitter with a half-life of 2.6 hr. What is the mass of Mn-56 in a 1.0 mg sample of the isotope at the end of 10.4 hr?

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A = ?n = t / T = 10.4 hr / 2.6 hr

A_0 = 1.0 mgn = 4 half-lives

A = (1.0 mg) x $(1/2)^4$ = 0.0625 mg

½ Life Example #3:

- Strontium-90 is a beta emitter with a half-life of 29 years. What is the mass of strontium-90 in a 5.0 g sample of the isotope at the end of 87 years?

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- Strontium-90 is a beta emitter with a half-life of 29 years. What is the mass of strontium-90 in a 5.0 g sample of the isotope at the end of 87 years?

A = ?n = t / T = 87 yrs / 29 yrs

A_0 = 5.0 gn = 3 half-lives

A = (5.0 g) x $(1/2)^3$

A = 0.625 g