Phyx 320
Modern Physics

April 30, 2021

Reading: 42.5-42.7

Homework #12 Due Next Tuesday

Half-life

For unstable nuclei, after one half-life half the nuclei will turn into another element called daughter nuclei

Each radioactive isotope has its own half-life (${}^{14}C$: 5,730 years, ${}^{218}Pb$: 15 s)

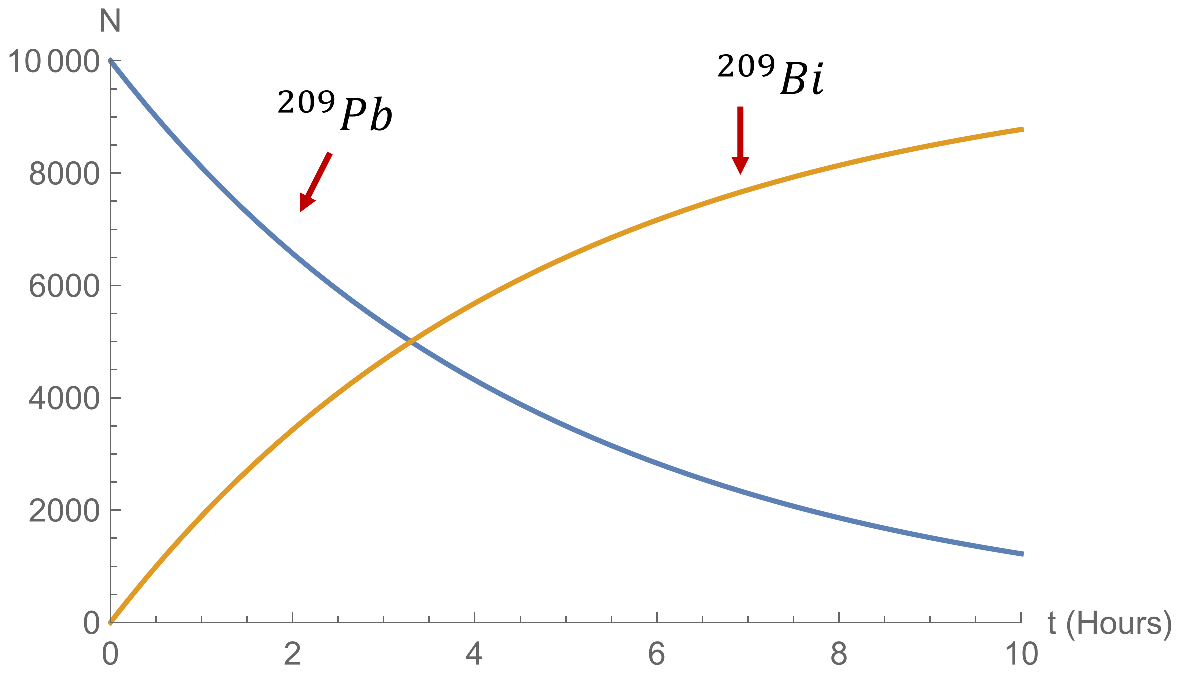
We can't know which nuclei will decay since the process is random

For example, if we have a sample of 10,000 ${}^{209}Pb$ nuclei after the half-life of 3.3 hours, we'd have 5,000 ${}^{209}Pb$ nuclei and 5,000 ${}^{209}Bi$ nuclei

After 6.6 hours, we'd have 2,500 ${}^{209}Pb$ nuclei and 7,500 ${}^{209}Bi$ nuclei

$$ {}^{209}Pb \rightarrow {}^{209}Bi + e^{-} + \bar{\nu}_e $$

$$ t_{\frac{1}{2}} = 3.3\ h $$



Alpha Decay

$$^{A}X_{Z} \rightarrow {}^{A-4}Y_{Z-2} + \alpha + energy$$

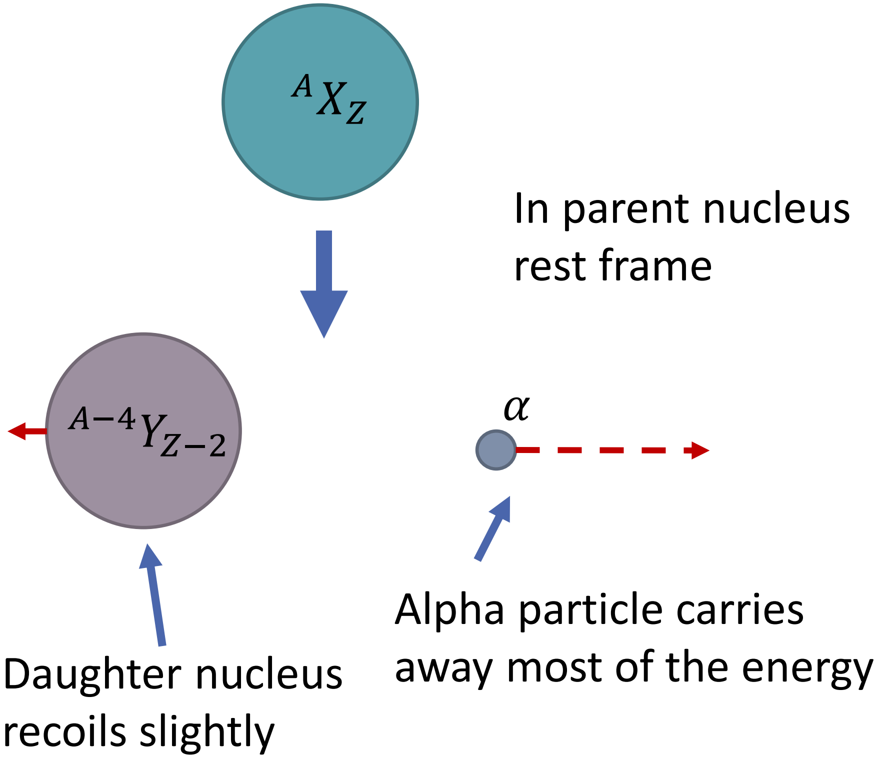
An alpha particle is a ^{4}He nucleus, 2 protons and 2 neutrons

When a nucleus of X element (parent nucleus) undergoes alpha decay, it turns into a nucleus of Y (daughter nucleus)

The mass number decreases by 4 and the atomic number decreases by 2

This can only happen if:

$$m_X > m_Y + m_\alpha$$



Alpha Decay

Alpha decay mainly happens in heavier elements ($Z > 52$)

The energy emitted is:

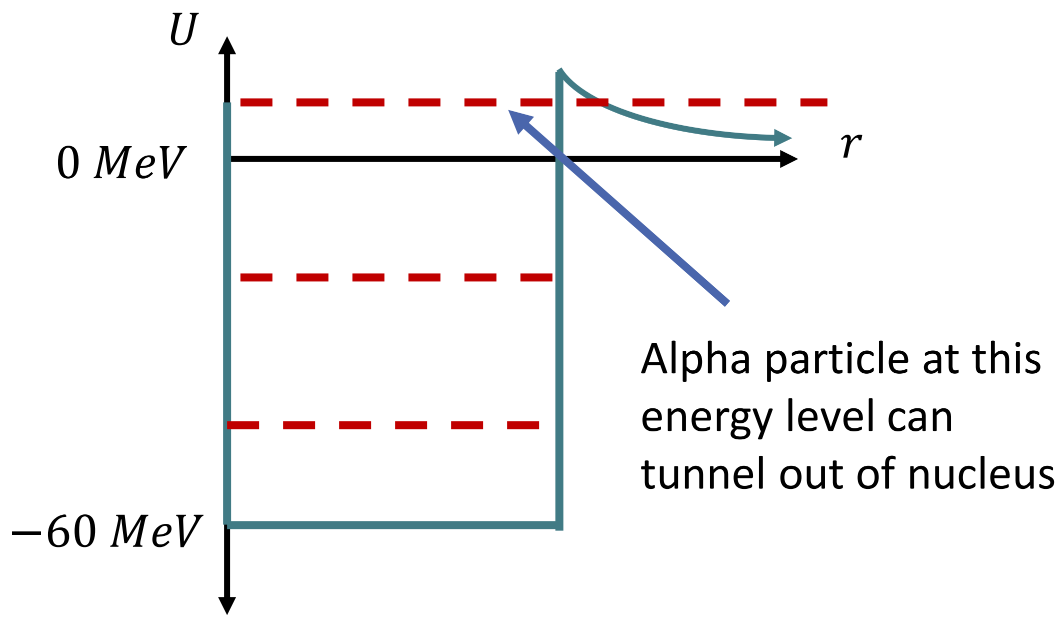
$$\Delta E \approx (m_X - m_Y - m_\alpha)c^2$$

We can think this large nuclei as many ^{4}He nuclei bound together

Decay happens when one of the alpha particles tunnels out of the potential

$$^{A}X_{Z} \rightarrow {}^{A-4}Y_{Z-2} + \alpha + energy$$

Potential for the alpha particle



Beta Decay

Beta decay happens when a either a proton turns into a neutrons or visa versa

Must satisfy a similar mass condition:

$$m_X > m_Y$$

More common than alpha decay and happens in small-Z nuclei

Interaction must conserve charge

Tries to balance the number of neutrons and protons

A proton can also absorb an electron in a process called electron capture

$$^{A}X_{Z} \rightarrow {}^{A}Y_{Z\pm1} + e^{\mp} + energy$$

Beta-minus: $n \rightarrow p + e^{-}$

Beta-plus: $p \rightarrow n + e^{+}$

Electron capture: $p + e^{-} \rightarrow n$

Orbital electron

Weak Force

So far, we've just said that protons and neutrons can turn into each other, but this is very strange

Additionally, beta-decay was found to not conserve either energy or momentum

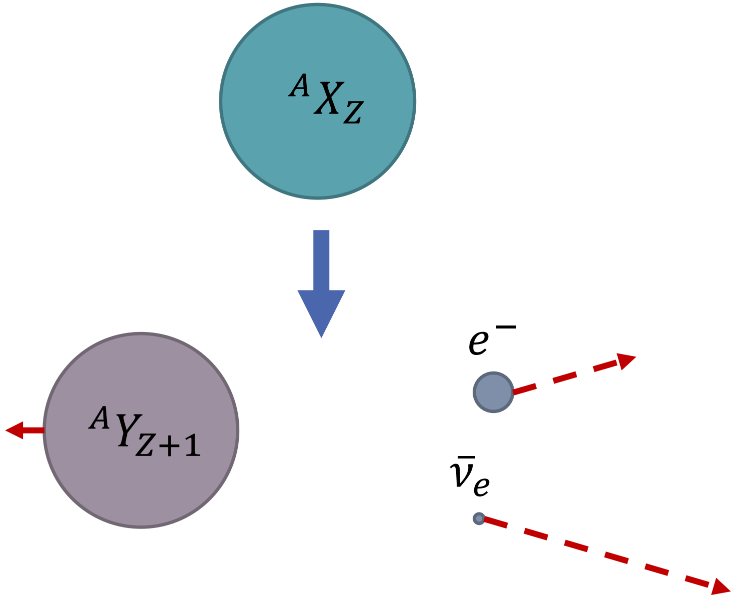
We must add a new fundamental force to called the weak force, to allow nucleons to turn into each other

We also have to include a new particle, the neutrino, which carries away the missing energy and momentum

Neutrinos originally thought to be massless but found to have small (still unknown) mass in the 1990s

Beta-minus: $n \rightarrow p + e^- + \bar{\nu}_e$

Beta-plus: $p \rightarrow n + e^+ + \nu_e$



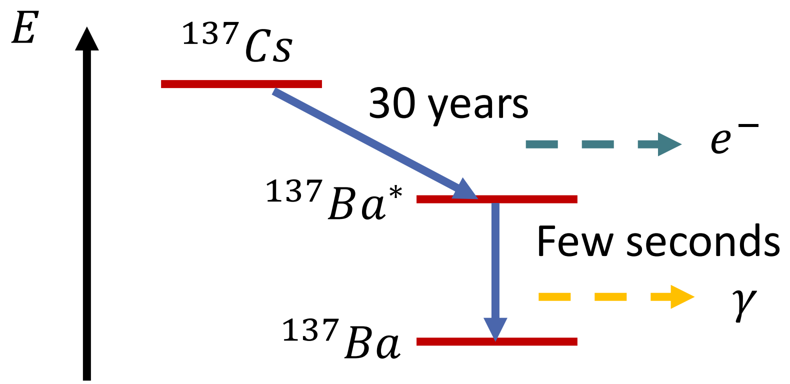
Gamma Decay

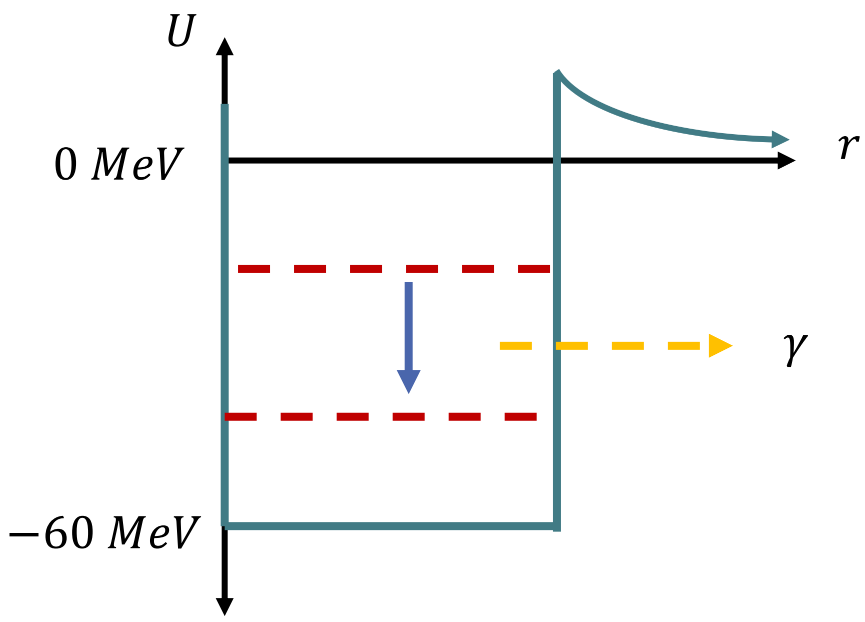
Gamma decay is identical to the decay of excited atomic states just for the nucleons instead of electrons

Nuclear states are separated by MeV of energy, so the photon is much higher energy than atomic transitions

Gamma decay usually happens when a nucleus undergoes either alpha or beta decay into an excited state

$$^{A}X_Z^{*} \rightarrow {}^{A}X_Z + \gamma$$





Decay Series

Many daughter nuclei are themselves radioactive and will decay into other elements

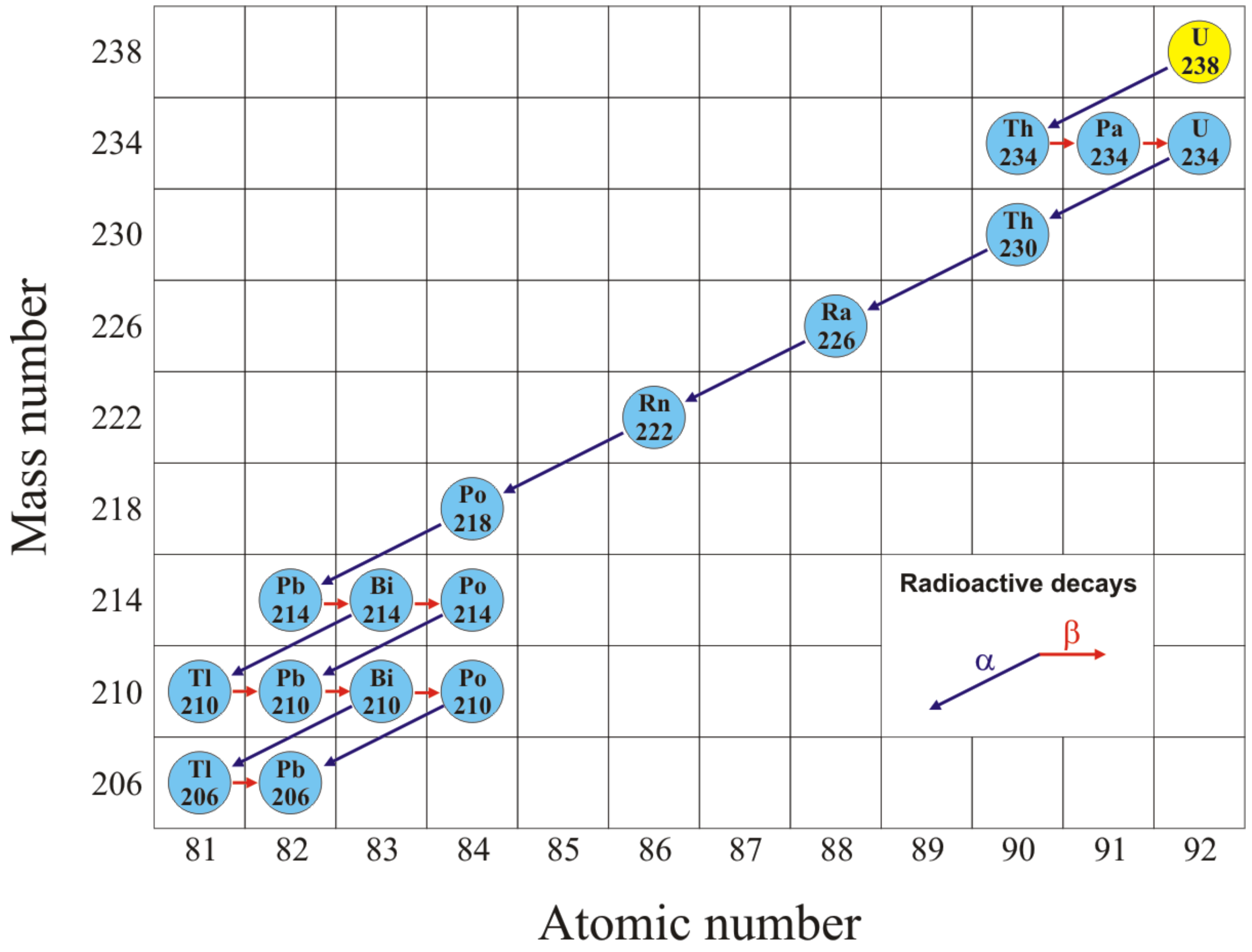
This then causes a given isotope to have a decay series

Nuclei will continue decaying until it gets to a stable isotope

This makes isotopes have a chemical signature as well as an energy signature

Can also mean elements can transition from metals to gases and back

For example, uranium eventual turns into radon (a noble gas) which can freely travel away from the sample



Radiation Health Effects

Ionizing radiation can damage cells in multiple ways

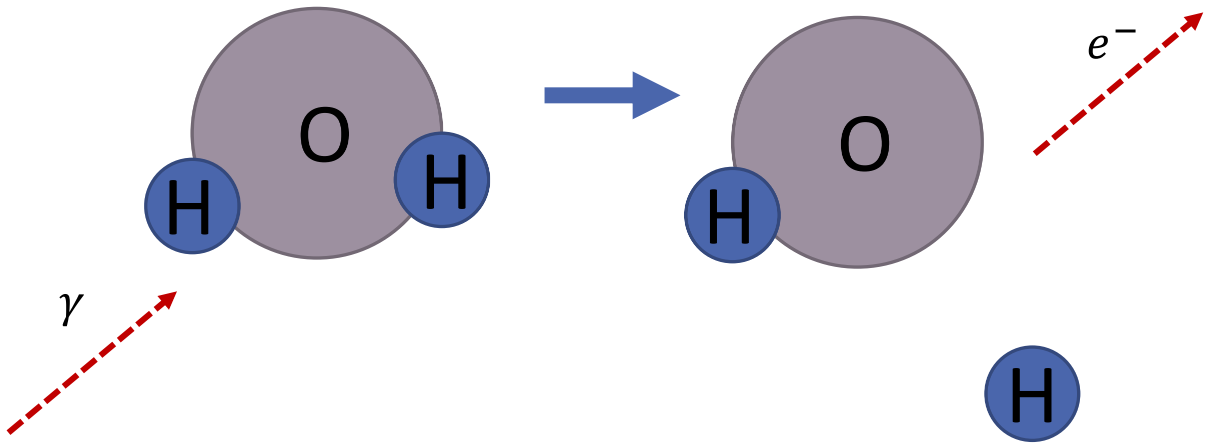
- Induce mutations – mutated cells are usually killed by immune system, but some can grow uncontrollably (cancer)
- Change chemistry of cells – can split water into OH and H which can cause cell death

Health effects depend strongly on amount, energy, and type of radiation exposure

Radiation affects cells types that have rapid reproduction rates more strongly

Strong effect: gastrointestinal system, blood forming, immune system

Weak effect: skin, muscle, nerve



Radiation Health Effects

Beta and gamma radiation can penetrate the human body while alpha radiation doesn’t

Beta and gamma can get to internal organs

Alpha interacts with skin or, if inhaled, lungs

The absorbed dose is the amount of energy absorbed per unit mass of tissue, unit: grays

$$1\ Gy = 1.00\ J/kg$$

The relative biological effectiveness (RBE) accounts for how types of radiation affects tissue

Dose equivalent, unit: sievert, is the product of these:

$$dose\ equiv\ (Sv) = absorbed\ dose\ (Gy) \times RBE$$

Rems is another unit $1\ rem = 0.01\ Sv$

Radiation Type	RBE
X-Rays	1
Gamma	1
Beta	1-2
Neutrons	5-20
Alpha	20

Radiation Source	Exposure
CT Scan	10 mSv
Natural background	3 mSv/year
Dental x-ray	0.03 mSv
Cross country flight	0.02 mSv
Living near nuclear power plant	0.0001 mSv/year
Trip to Mars	700 mSv
Fukushima Workers	12 mSv

Homework Questions

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