Nuclear Chemistry

Chem 36

Spring 2002

Nuclear Review

- Some chemical reactions can involve changes in *nuclear* structure
- Nuclear Properties
  - ✓ **Small Size:** radius $\approx 10^{-13}$ cm
  - ✓ **High Density:** 1.6×10^{14} g/cm^3
  - ✓ **HUGE Energies:** 10^{11} J/mol

10 million times smaller than atomic radius

2.5 billion ton golf ball

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Nuclear Reactions

- Recall Notation:

Protons + Neutrons → $^{12}_{6}C$ ← Atomic Number (= #protons)

Isotopes differ in # of neutrons:

^{12}C, ^{13}C, ^{14}C

Example: *Radioactive Decay*

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

Alpha Particle (→ $^{4}_{2}He$)

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More Decay

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

Beta Particle

- **How do we get an e^- from a nucleus?**

$$^{1}_{0}n \rightarrow {}^{1}_{1}H + {}^{0}_{-1}e$$

Positron

Another one:

$$^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + {}^{0}_{+1}e$$

$$^{1}_{1}H \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e$$

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Still *More* Decay!

- There can be more than one possible decay route:

b decay: $$^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{-1}e$$

e^- capture: $$^{40}_{19}K + {}^{0}_{-1}e \rightarrow {}^{40}_{18}Ar$$

from an inner orbital

origin of Ar in atmosphere

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Kinetics of Nuclear Decay

- Radioactive decay is a *first-order* process:

$$\mathbf{Ln(N/N_0) = -kt}$$

So the half-life of the decay is:

$$\mathbf{t_{½} = 0.693/k}$$

- If we know the *half-life* for a radionuclide, then we know the rate constant (k) and, with a measurement of the current radioactive decay rate, we can determine for ***how long*** the nuclide has been decaying.

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Radiodating

- The Uranium-Lead Method
  - for inorganic materials (e.g., rocks)
  - Based on the decay of ^{238}U:

$$^{238}_{92}U \rightarrow {}^{206}_{82}Pb + 8\,{}^{4}_{2}He + 6\,{}^{0}_{-1}e$$

✓Assume: all ^{206}Pb is from ^{238}U decay

✓Measure: ^{206}Pb and ^{238}U

✓$N_0 = {}^{206}Pb + {}^{238}U$

✓$N = {}^{238}U$

Calculate t, using k
(get from $t_{½} = 4.51 \times 10^9$ years)

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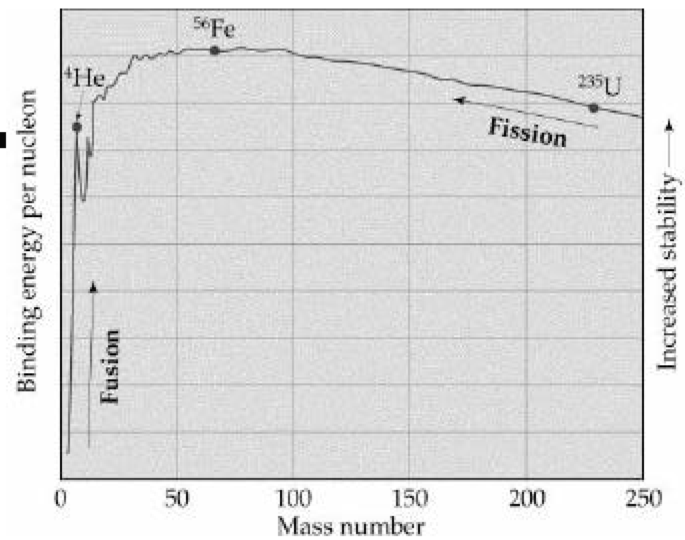
Energy



- Energy stored in nucleus can be released by either:
  - breaking apart big nuclei (*Fission)*
  - combining small nuclei *(Fusion)*

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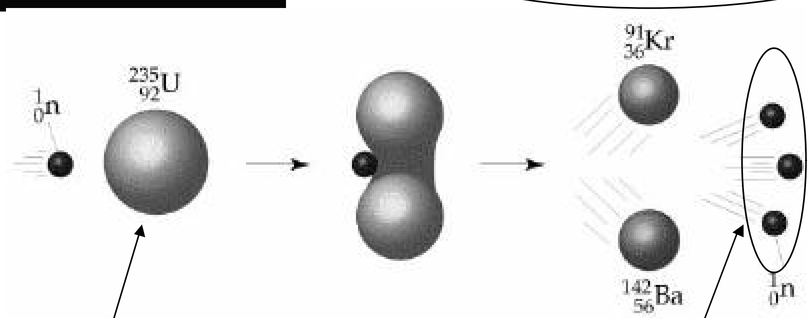
Fission

+ 2.1 x 10^{13} J/mol ^{235}U



~0.7% in natural ore

Can split more ^{235}U - self sustaining reaction if at least 3% ^{235}U (critical mass)

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Fusion

- Fuels the stars and made the elements!

Example: **D-D Fusion**

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n$$

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$$

$+ 2.9 \times 10^{11}$ J/mol

The Challenge: nuclei must be within ~10^{-15} m before they will fuse

(requires a temperature of 10-100 million K!)

Quantifying Nuclear Energy Changes

1. **Calculate Dm for process**

Δm = mass of nucleus - mass of nucleons

mass of nucleons = proton mass + neutron mass

proton mass: 1.00727647 u/proton

neutron mass: 1.00866490 u/neutron

mass of nucleus = atomic mass - electron mass

electron mass: 0.0005485799 u/electron

$E = mc^2$

2. <u>Convert Dm to energy</u>

$$DE = (Dm)c^2$$

✓<u>To get *energy* in Joules:</u>

mass (kg) x velocity^2 (m^2/s^2)

✓To convert atomic mass units (u) to kg:

1 u = 1.660540 x 10^{-27} kg

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