Introduction to Nuclear Chemistry II

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Our Very Existence

- There is a very important radioactive decay we have not discussed:

$$n \rightarrow p + e^{-} + \bar{\nu} + \text{Energy}$$

- These hydrogen atoms are fused into heavier elements by stars, releasing energy in the process.

- Neutrons alone cannot make atoms. If the reaction ran in the opposite direction then there would be *no elements*.

- You owe your existence to nuclear science!

Example

- Calculate the change in mass during the alpha decay of ^{232}Th:

$$^{232}Th \rightarrow {}^{228}Ra + {}^{4}He$$

- The masses are:
    - $m(^{232}Th)$ = 232.038060 amu
    - $m(^{228}Ra)$ = 228.031075 amu
    - $m(^{4}He)$ = 4.002603 amu

Example

$$^{232}Th \rightarrow {}^{228}Ra + {}^{4}He$$

- The change in mass (Δm) is

$$\Delta m = m(^{228}Ra) + m(^{4}He) - m(^{232}Th)$$

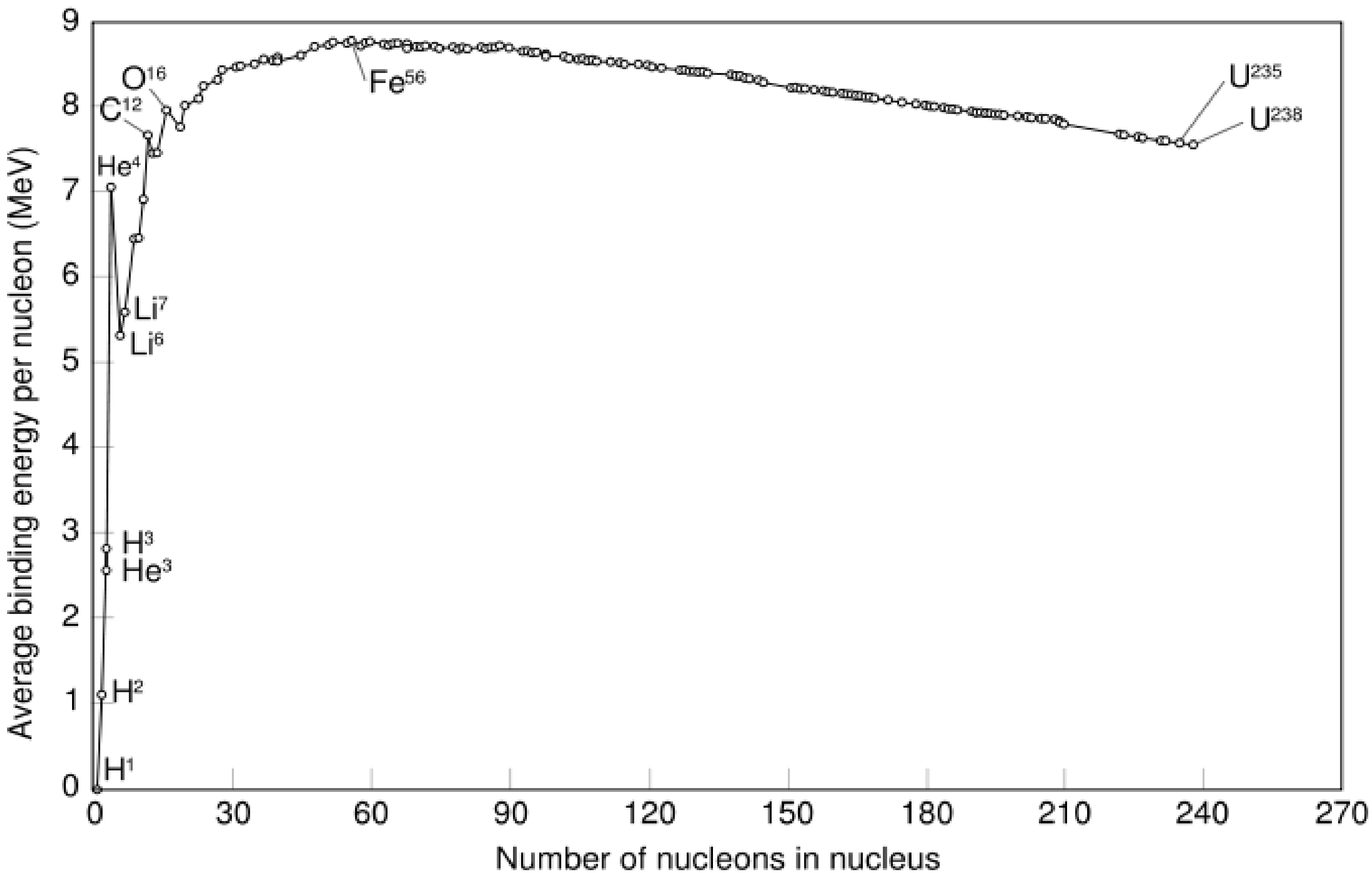
$$= 228.031075 \text{ amu} + 4.002603 \text{ amu} - 232.038060 \text{ amu}$$

$$= -0.004382 \text{ amu}$$

- That's not a lot, but 1 amu = 8.99×10^{10} kJ/mol!
- This reaction has $\Delta H = -3.94 \times 10^{8}$ kJ/mol!
- Nuclear reactions involve *much* more energy than chemical reactions.

Binding Energy per Nucleon

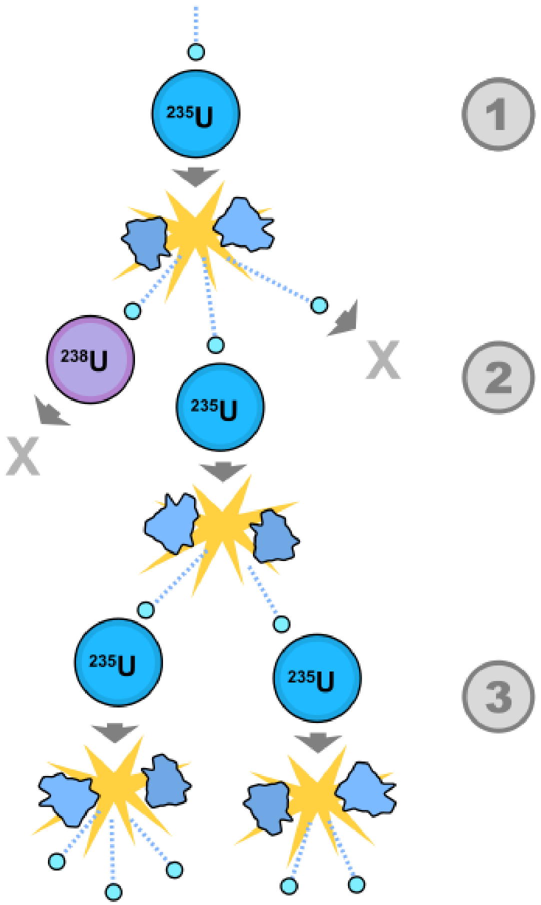
- Let's calculate the binding energy *per nucleon*:



Increasing Stability
Decreasing Energy

The Chain Reaction

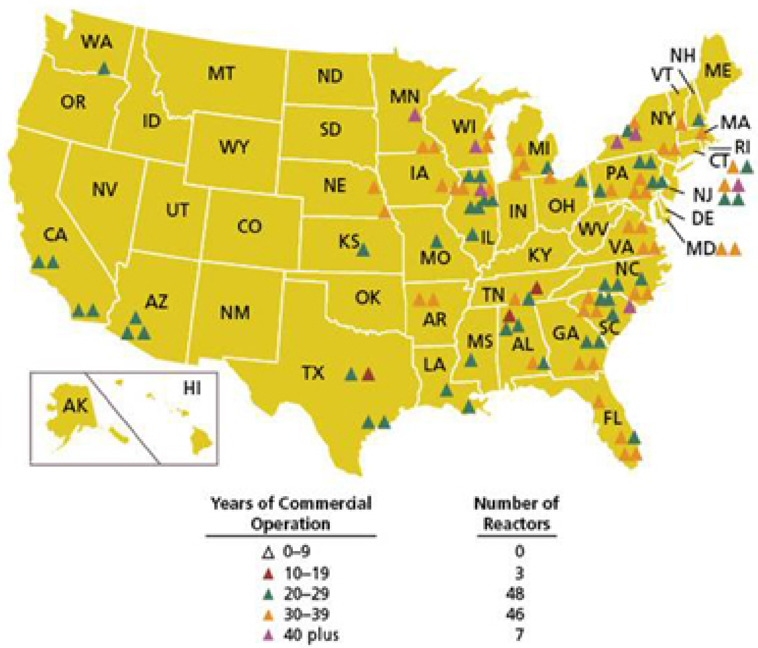
- Neutrons from one fission induce another fission in a different ^{235}U nucleus in a *chain reaction*.
- Not all neutrons lead to fission. Many different reactions are possible:
  - Neutron Capture in ^{235}U. This leads to the production of ^{236}U and other *minor actinides*.
  - Neutron Capture in ^{238}U. This leads to ^{239}U, which gives ^{239}Pu after two beta decays. ^{239}Pu is a by-product of most reactors.
  - Capture in surrounding construction materials. This creates *activation*.



Nuclear Power Plants in the USA

- There are 100 power reactors at 62 plants in 31 states.
- Texas has two plants, each with two reactors.
- Nuclear power provides ~20% of US electricity, and operates at 90.3% capacity factor.

U.S. Commercial Nuclear Power Reactors—
Years of Operation by the End of 2010



Note: Ages have been rounded up to the end of the year.

Source: U.S. Nuclear Regulatory Commission

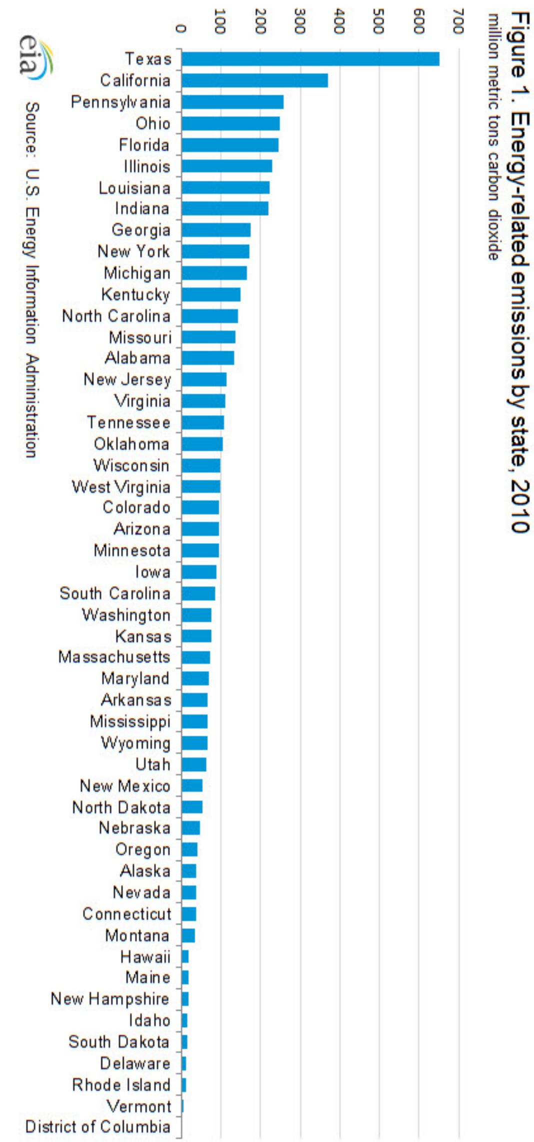
- Capacity increases ~0.3% per year, due to upgrades at existing plants.

Carbon Footprints

- Whether you support nuclear power depends partly on your opinion of climate change.
- Kilograms of CO_2 for various activities:
  - Producing 1 kWh of electricity (US average): 0.61
  - Producing 1 kWh of electricity (SW average): 0.69
  - Burning one gallon of gas: 8.8
  - Producing 1 kg of beef: 27
  - Producing 1 kg of lamb: 39
  - Producing 1 kg of cheese: 13
- Nuclear power is a more advanced technology than fossil fuels, but it also comes with risks.

Energy in Texas (2010)

- Texas produces slightly more electricity than it consumes.
- It leads the nation in total electricity production and CO_2 emissions.
- 10.0% of electricity in Texas is nuclear.
  - High: VT (72.2%), Low: IA (7.7%)
- 1999 CO_2 emissions:
  - Region: 0.694 kg/kWh
  - USA: 0.608 kg/kWh
  - Source: Energy Inform. Admin.
- Texas also leads the nation in developed wind energy capacity.



Capital Costs

- Nuclear power plants have a different cost structure than coal-fired power plants.
- Nuclear Power Plant
  - Very high up-front construction costs. This generally requires government loan guarantees and increased costs to the consumer.
  - Ongoing costs only include maintenance and infrequent refueling.
- Coal-Fired Power Plant
  - Moderate up-front construction costs.
  - High ongoing costs for purchasing coal daily (~10 million kg/day).

How to prioritize nuclear power?

- Prof. Folden's view on sources of energy:

1. Conservation. This is almost always the cheapest way to reduce carbon emissions.
2. Renewable Energy. This may require some carbon emissions but there is not the problem of nuclear waste.
3. Nuclear Power. Produces thousands of times less carbon dioxide, but nuclear waste in the process.
4. Fossil Power. Produces massive quantities of carbon dioxide (easily 10 million tons per year per plant).