Homework, Essay, Exam

HW10: Chap 16:- Conceptual # 7, 10 Problem # 1
Due Nov 29th
Essay outlines returned Monday.
Essay due Dec 8th

Hour Exam 3: Wednesday, November 29th

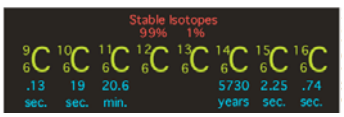
- In-class, Quantum Physics and Nuclear Physics
- Twenty multiple-choice questions
- Will cover: Chapters 13, 14, 15 and 16
  Lecture material
- You should bring
  - 1 page notes, written single sided
  - #2 Pencil and a Calculator
  - Review Monday November 27th
  - Review test will be available online on Monday

From the Last Time

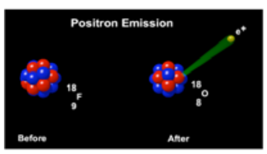
- Radioactive decay: alpha, beta, gamma
- Radioactive half-life
- Decay types understood in terms of number neutrons, protons and size of the nucleus.
- Beta decays due to the weak force

Today: Fission and Fusion

Other carbon decays



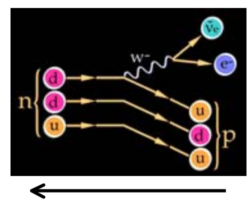
- Lightest isotopes of carbon are observed to emit a particle like an electron, but has a positive charge!

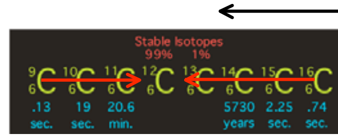


- This is the **antiparticle** of the electron.
- Called the **positron**.

What is going on?

- ^{14}C has more neutrons than the most stable form ^{12}C.
  - So it decays by electron emission, changing neutron into a proton.
- Other isotopes of carbon have fewer neutrons
  - Decays by emitting **positron**, changing proton into neutron.



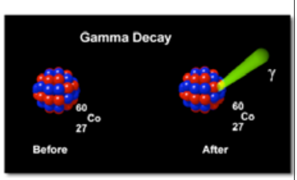


Gamma decay

- So far
  - Alpha decay: alpha particle emitted from nucleus
  - Beta decay: electron or positron emitted
- Both can leave the nucleus in excited state
  - Just like a hydrogen atom can be in an excited state
  - Hydrogen emits photon as it drops to lower state.

Nucleus also emits photon as it drops to ground state
This is gamma radiation

But energies much larger, so **extremely** high energy photons.



Turning lead into gold

Radioactive decay changes one element into another by changing the number of protons in a nucleus.

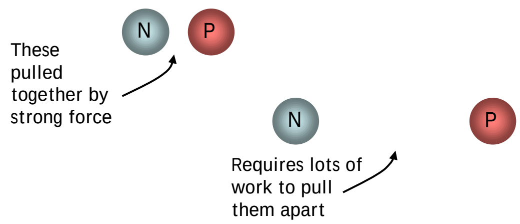
This can also be done artificially by neutron bombardment.

- The transmutation of platinum into gold accomplished by a sequence of two nuclear reactions
- first: ^{198}Pt + neutron --> ^{199}Pt
- second: ^{199}Pt --> ^{199}Au + subatomic particle

Radioactive decay summary

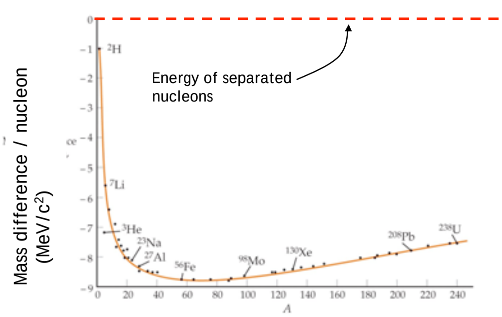
- *Alpha decay*
  - Nucleus emits alpha particle (2 neutrons + 2 protons)
  - Happens with heavy nuclei only
  - Caused by Coulomb repulsion
- *Beta decay*
  - Nucleus emits electron (beta-) or positron (beta+)
  - Internally,
    neutron changes to proton (beta-), *or*
    proton changes to neutron (beta+)
  - Caused by weak force
- *Gamma decay*
  - Nucleus starts in internal excited state
  - Emits photon and drops to lower energy state

Energy stored in the nucleus

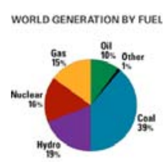


So energy of nucleus is LESS than that of isolated nucleons…
…and energy is released when nucleons bind together.

Binding energy of different nuclei



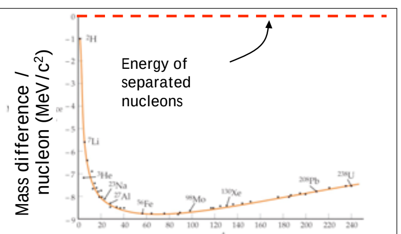
Energy Production



3.5 barrels of oil, or... 17,000 cubic feet of natural gas, or... 1,780 pounds of coal.

How can we release this energy?

Question

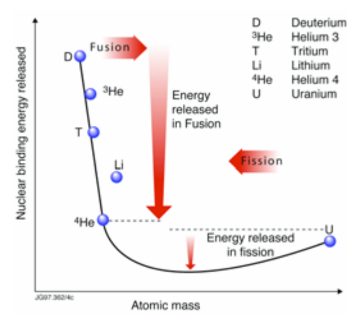


Suppose we could split the Iron (Fe) nucleus into two equal parts. In this process energy is

A. Released
B. Absorbed
C. Same before & after

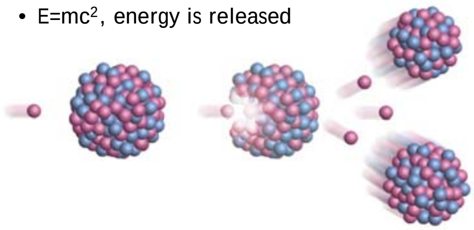
Differences between nuclei

- Schematic view of previous diagram
- ^{56}Fe is most stable
- Move toward lower energies by fission or fusion.
- Energy released related to difference in binding energy.



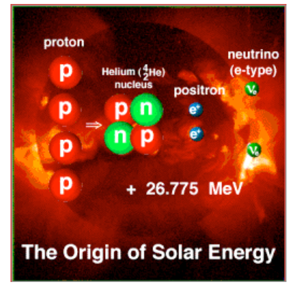
Nuclear fission

- A heavy nucleus is split apart into two smaller ones.
- Energy is released because the lighter nuclei are more tightly bound, less mass
- $E=mc^2$, energy is released



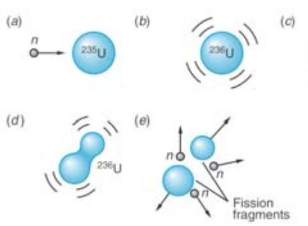
Nuclear Fusion

- 'Opposite' process also occurs, where nuclei are fused to produce a heavier nucleus.
- Final nucleus is more tightly bound (lower energy, less mass).
- Energy is released



Nuclear Fission: Neutron Capture

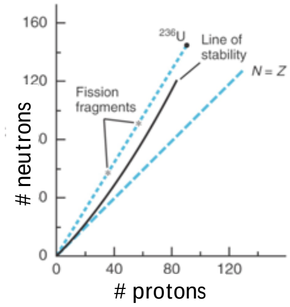
- Fission: heavy nucleus breaks apart into pieces.
- Not spontaneous, induced by capture of a neutron
- When neutron is captured, ^{235}U becomes ^{236}U
  - Only neutron # changes, same number of protons.



Nucleus distorts and oscillate, eventually breaking apart (fissioning)

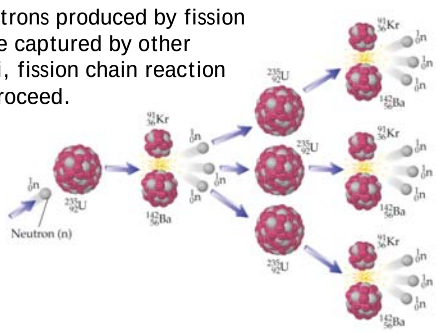
Neutron production

- Fission fragments have too many neutrons to be stable.
- So free neutrons are produced in addition to the large fission fragments.
- These neutrons can initiate more fission events



Chain reaction

- If neutrons produced by fission can be captured by other nuclei, fission chain reaction can proceed.



Neutrons

- Neutrons may be captured by nuclei that do not undergo fission
  - Most commonly, neutrons are captured by ^{238}U
  - The possibility of neutron capture by ^{238}U is lower for slow neutrons.
- The moderator helps minimize the capture of neutrons by ^{238}U by slowing them down, making more available to initiate fission in ^{235}U.

The critical mass

- An important detail is the probability of neutron capture by the ^{235}U.
- If the neutrons escape before being captured, the reaction will not be self-sustaining.
- Neutrons need to be slowed down to encourage capture by U nucleus
- The mass of fissionable material must be large enough, and the ^{235}U fraction high enough, to capture the neutrons before they escape.

The first chain reaction

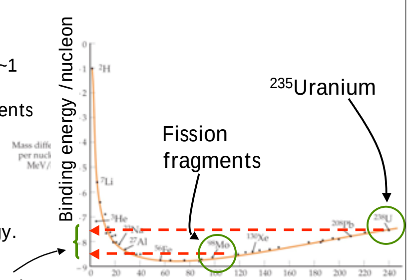
- Construction of CP-1, (Chicago Pile Number One) under the football stadium in an abandoned squash court.
- A 'pile' of graphite, uranium, and uranium oxides.
- Graphite = moderator, uranium for fission.
- On December 2, 1942: chain reaction produced 1/2 watt of power.

- 771,000 lbs graphite, 80,590 pounds of uranium oxide and 12,400 pounds of uranium metal,
- Cost ~ $1 million.
- Shape was flattened ellipsoid 25 feet wide and 20 feet high.

How much energy?

Binding energy/nucleon ~1 MeV less for fission fragments than for original nucleus

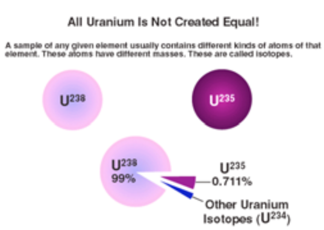
This difference appears as energy.



Energy released

- ^{235}U has 235 total nucleons, so ~240 MeV released in one fusion event.
- ^{235}U has molar mass of ~235 gm/mole
  - So 1 kg is ~ 4 moles = $4x(6x10^{24})=2.5x10^{25}$ particles
- Fission one kg of ^{235}U
  - Produce ~$6x10^{33}$ eV = 10^{15} Joules
  - 1 kilo-ton = 1,000 tons of TNT = $4.2x10^{12}$ Joules
  - This would release ~250 kilo-tons of energy!!!
- Chain reaction suggests all this could be released almost instantaneously.

Uranium isotopes



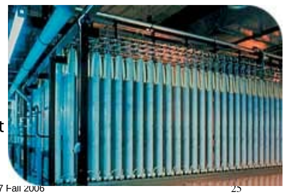
- Only the less abundant ^{235}U will fission.
- Natural abundance is less than 1%, most is ^{238}U
- Note: 3-5% enrichment ok for reactor.
- Bomb needs much higher fraction of ^{235}U
- Oppenheimer suggested needed as much as 90% ^{235}U vs ^{238}U

Where does uranium come from?

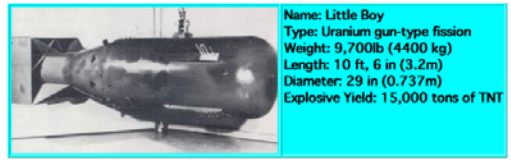
- Uranium is abundant, but in low concentration
- E.g. uranium is mixed with granite, covering 60% of the Earth's crust.
- But only four parts of uranium per million million parts of granite.

Gas centrifuge enrichment

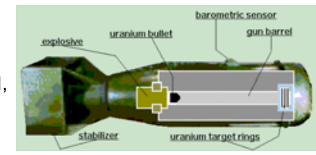
- Gaseous UF_6 is placed in a centrifuge.
- Rapid spinning flings heavier U-238 atoms to the outside of the centrifuge, leaving enriched UF_6 in the center
- Single centrifuge insufficient to obtain required U-235 enrichment.
- Many centrifuges connected in a 'cascade'.
- U-235 concentration gradually increased to 3 - 5% through many stages.
- Simplest method of enrichment which is why you hear about it on the news



Uranium fission bomb

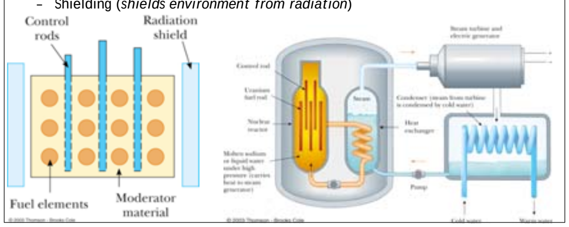


- Uranium 'bullet' fired into Uranium target
- Critical mass formed, resulting in uncontrolled fission chain reaction



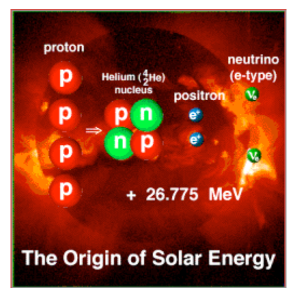
Controlled Nuclear Reactors

- The reactor in a nuclear power plant does the same thing that a boiler does in a fossil fuel plant - it produces heat.
- Basic parts of a reactor:
  - Core (*contains fissionable material*)
  - Moderator (*slows neutrons down to enhance capture*)
  - Control rods (*controllably absorb neutrons*)
  - Coolant (*carries heat away from core to produce power*)
  - Shielding (*shields environment from radiation*)



Nuclear Fusion

- Fusing together light nuclei releases energy
- Energy of 6.7MeV per nucleon.
- Remember U^{235} fission release 1MeV per nucleon
- Hard to reproduce the conditions of the sun. Use different process in fusion experiments



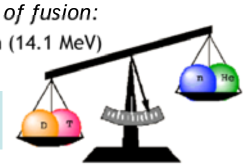
Terrestrial fusion reactions

- Deuterium = nucleus of (1 proton & 1 neutron)
- Tritium = nucleus of (1 proton & 2 neutrons)
- Two basic fusion reations:
  - deuterium + deuterium -> ^{3}He + n
  - deuterium + tritium -> ^{4}He + n

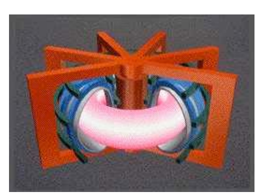
Energy is released as result of fusion:

D + T -> ^{4}He (3.5 MeV) + n (14.1 MeV)

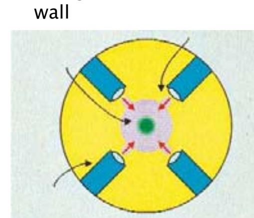
Energy determined by mass difference



Routes to fusion



Laser beams compress and heat the target; after implosion, the explosion carries the energy towards the wall



- Magnetic confinement in a torus (in this case a tokamak).
- The plasma is ring-shaped and is kept well away from the vessel wall.

Fusion reactors

Proposed ITER fusion test reactor

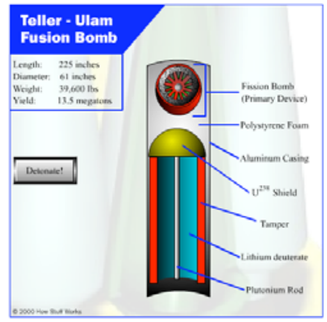
Superconducting magnet form a Plasma confinement torus

Nova

Fusion bombs

Fission bombs worked, but they weren't very efficient.

- Fusion bombs, have higher kiloton yields and efficiencies, But design complications
- Deuterium and tritium both gases, which are hard to store.
- Instead store lithium-deuterium compound which will fuse



Fission and Fusion

- Fission:
  - Heavy nucleus is broken apart
  - Total mass of pieces less than original nucleus
  - Missing mass appears as energy $E=mc^2$
  - Radioactive decay products left over
- Fusion
  - Light nuclei are fused together into heavier nuclei
  - Total mass of original nuclei greater than resulting nucleus
  - Missing mass appears as energy.