University of Virginia

Department of Physics

Physics 606: How Things Work II

Lecture #38 Slides:

Nuclear Weapons II

Structure of Nucleus

- Nucleus contains two kinds of nucleons
  - Protons are positively charged
  - Neutrons are neutral
- Two forces are active in a nucleus
  - Electrostatic repulsion between protons
  - Nuclear force attraction between touching nucleons
  - At short distances, nuclear force is stronger than electric
  - At long distances, electric force is stronger than nuclear

Sodium nucleus
(11 protons, 12 neutrons)

Nuclear Stability

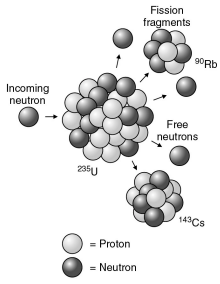
- In a nucleus, nucleons are in equilibrium
- To be classically stable, equilibrium must be stable
- To be quantum-mechanically stable, equilibrium must also be the potential energy minimum
- Quantum mechanics and the Heisenberg uncertainty principle allow the nucleons to try out arrangements outside their equilibrium positions
- If they find a path to a new equilibrium, they may take it and the nucleus may fall apart

Radioactivity

- Protons repel one another & neutrons are unstable
- Large nuclei have two problems:
  - Too many protons, then too much electrostatic potential
  - Too many neutrons, then neutrons are unstable
  - Delicate balance between protons and neutrons
- Large nuclei tend to fall apart spontaneously
- Such decay is called fission
- Fission is a type of radioactivity

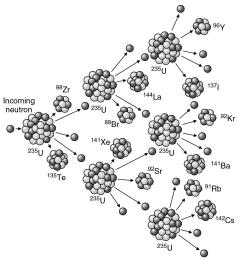
Induced Fission

- Large nuclei can break when struck
  - Collision knocks nucleons out of stable equilibrium
  - Hard collisions are best at inducing fission
  - Neutrons make ideal projectiles for inducing fission



Chain Reaction

- Neutrons can induce fission
- Induced fission releases neutrons
- This cycle can repeat – Chain reaction!
- Each fission releases energy
  - Many fissions release prodigious amounts of energy
  - Sudden energy release produces immense explosion



Requirement for a Bomb

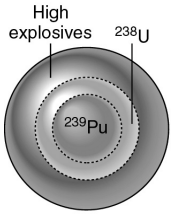
1. Initial neutron source
2. Fissionable material (allowing induced fission)
3. Fissions must release additional neutrons
4. Material must use fissions efficiently (critical mass)

Fissionable Materials

- ^{235}U and ^{239}Pu are fissionable materials
- ^{235}U is rare and must be separated from ^{238}U
- ^{239}Pu is made by exposing ^{238}U to neutrons

Gadget & Fat Man

- ^{239}Pu sphere below critical mass (6 kg)
- Crushed by explosives to above critical mass
- Shell of ^{238}U assisted implosion



Little Boy

- ^{235}U hollow sphere below critical mass (60 kg)
- Cannon fired plug through sphere to exceed critical mass
- Tungsten-carbide shell contained explosion initially