Nuclear Weapons

Observations about Nuclear Weapons

- They release enormous amounts of energy
- They produce incredible temperatures
- They produce radioactive fallout
- They are relatively difficult to make
- They use chain reactions

3 Questions about Nuclear Weapons

- Where is nuclear energy stored in atoms?
- Why are some atomic nuclei unstable?
- How does a nuclear chain reaction work?

Question 1

- Where is nuclear energy stored in atoms?

Atomic Nuclei

- Atoms are usually electrically neutral
  - They must have as many + charges as – charges
  - Each electron must be matched by a + charge
- At the center of an atom is its nucleus
  - Extremely small (1/100,000th of atom's diameter)
  - Contains most of the atom's mass
  - Also contains most of the atom's potential energy
    - Evidence is related to: $E=mc^2$

Structure of Nucleus

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

Sodium nucleus
(11 protons, 12 neutrons)

Question 2

- Why are some atomic nuclei unstable?

Nuclear Stability

- The nucleons in a nucleus are in equilibrium
- To be classically stable, that equilibrium must be stable
- To be quantum-mechanically stable, that equilibrium must also be the overall potential energy minimum
- Quantum mechanics and the Heisenberg uncertainty principle allow the nucleons to "try out" arrangements that are quite different from their equilibrium positions
- If they find a path to a new, lower-potential-energy equilibrium, the nucleus may fall apart

Radioactivity

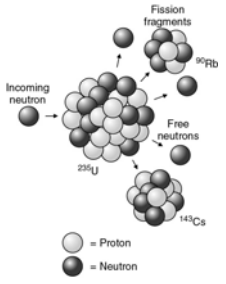
- Large nuclei have two possible problems:
  - Too many protons: too much electrostatic potential
  - Too many neutrons: isolated neutrons are unstable
- Balance between protons and neutrons is tricky
- Large nuclei tend to fall apart spontaneously
- These breakups are known as radioactive decay
  - and can include a splitting process called fission

Question 3

- How does a nuclear chain reaction work?

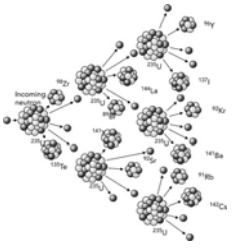
Induced Fission

- A large nucleus can break when struck hard
  - Collision knocks its nucleons out of stable equilibrium
  - Collision-altered nucleus may undergo induced fission
  - Since a neutron isn't repelled by nucleus, it makes an ideal projectile for inducing fission



Chain Reaction

- Since neutrons can induce fission
  - and induced fission releases neutrons,
  - this cycle can repeat, a chain reaction!
- Each fission releases energy
  - Many fissions release prodigious amounts of energy
  - Sudden energy release produces immense explosion

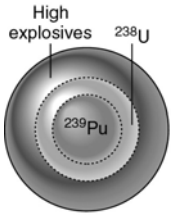


Requirement for a Bomb

- A fission bomb requires 4 things:
  - An initial neutron source
  - a fissionable material (undergoes induced fission)
  - each fission must release additional neutrons
  - material must use fissions efficiently (critical mass)
- ^{235}U and ^{239}Pu are both fissionable materials,
  - but ^{235}U is rare and must be separated from ^{238}U
  - and ^{239}Pu is made by exposing ^{238}U to neutrons.

The Gadget & Fat Man

- Each of these fission bombs started as a ^{239}Pu sphere below critical mass (6 kg)
- It was crushed explosively to supercritical mass
- and promptly underwent an explosive chain reaction.



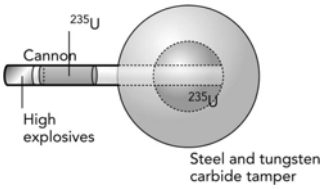
Introductory Question (revisited)

- Is it possible to have 100 tons of plutonium and not have it explode?

A. Yes
B. No

Little Boy

- This bomb started as a ^{235}U hollow sphere below critical mass (60 kg)
- A cannon fired a ^{235}U plug through that sphere so that it exceeded critical mass
- and it promptly underwent an explosive chain reaction.



Summary about Nuclear Weapons

- Nuclear energy is stored in atomic nuclei
- Nuclear fission released electrostatic potential
- Each fission releases an astonishing energy
- Induced fission permits a chain reaction
- Fission bombs explode via a chain reaction