Nuclear Weapons

Introductory Question

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

A. Yes
B. No

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)

Clicker Question

- If you snipped the nucleus of a very massive atom in half, it would release energy stored in

A. the electrostatic repulsion between protons.
B. the nuclear attraction between nucleons.

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

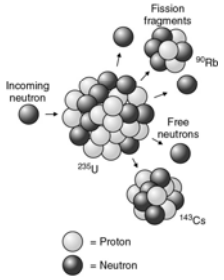
- Large nuclei have two possible problems:
  - Too many protons: too much electrostatic potential
  - Too many neutrons: isolated neutrons are unstable
- Balance between protons and neutrons is tricky
- Large nuclei tend to fall apart spontaneously
- These breakups are known as radioactive decay
  -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



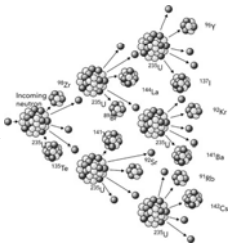
Clicker Question

- Fissioning nuclei may also release protons, but those fission-produced protons don't cause subsequent fissions because they

A. don't have enough mass to cause fissions.
B. collide too softly with nuclei to cause fissions.
C. don't have enough momentum to cause fissions.
D. don't collide with nuclei at all.

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

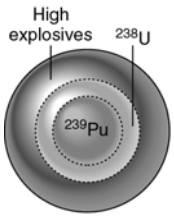


Requirement for a Bomb

- 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.



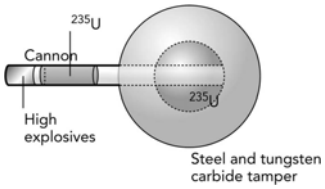
Introductory Question (revisited)

- 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.



Clicker Question

- A ^{235}U plug that is shot through a hollow ^{235}U sphere can initiate an explosive chain reaction even though it doesn't hit anything because

A. it only has to assemble a supercritical mass.
B. nuclei can collide even when the plug doesn't.
C. atoms can collide even when the plug doesn't.
D. a chain reaction doesn't involve any collisions.

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