Nuclear Weapons

Turn off all electronic devices

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

4 Questions about Nuclear Weapons

1. Where is nuclear energy stored in atoms?
2. Why are some atomic nuclei unstable?
3. How does a nuclear chain reaction work?
4. Why do nuclear explosions produce fallout?

Question 1

Q: Where is nuclear energy stored in atoms?
A: In each atom's central nugget, its nucleus.

Each atom has an ultra-dense core or nucleus
- Extremely small (1/100,000th of atom's diameter)
- Contains about 99.95% of the atom's mass
- 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

Q: Why are some atomic nuclei unstable?
A: They can release potential energy by breaking

In a stable nucleus, all objects remain in place
- For classical stability: stable equilibrium is required
- For quantum stability: potential energy minimum

Objects quantum-tunnel out of unstable nuclei

Quantum Tunneling

Each object in a nucleus is in equilibrium

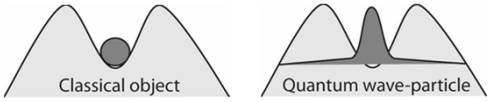
Classical object must climb potential hill to escape

- Without extra energy, object is trapped
- Classical nucleus would be stable

Quantum object can escape without climbing hill

- Heisenberg uncertainty principle makes position of wave-particle uncertain
- Particle-wave can "tunnel" through potential hill

Objects can tunnel out of unstable nuclei



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

- Known as radioactive decay
- Such decay is statistical, with a characteristic half-life
- May include a splitting process called fission

Question 3

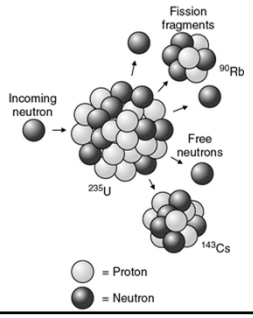
Q: How does a nuclear chain reaction work?
A: Decaying nuclei can shatter one another.

Radioactive decay releases tiny projectiles
Projectiles can collide with and agitate other nuclei
Agitated nuclei can decay, releasing new projectiles
and this can repeat, over and over again

Induced Fission

A large nucleus may break when struck

- Collision knocks its nucleons out of equilibrium
- Collision-altered nucleus may undergo induced fission
- Since a neutron isn't repelled by nucleus, it makes an ideal projectile for inducing fission



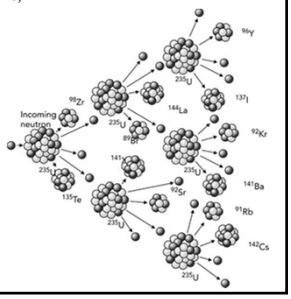
Chain Reaction

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:

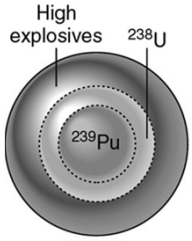
- An initial neutron source
- a fissionable material (undergoes induced fission)
- each fission must release additional neutrons
- material must use fissions efficiently (critical mass)

^{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.

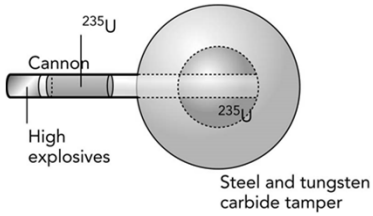
The Gadget & Fat Man

- 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.



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.



Question 4

Q: Why do nuclear explosions produce fallout?

A: Many fission-fragment nuclei are radioactive.

Large nuclei are neutron-rich
- High proportion of neutrons dilutes proton repulsion

Fragments of large nuclei are still neutron-rich
- They have too many neutrons for their size
- They tend to be radioactive

Radioactive Fallout

Fission-fragment nuclei gather electrons
- Electrons accumulate until neutral atoms form
- Atoms are chemically identical to ordinary atoms
- But atoms have unstable nuclei—too many neutrons

We incorporate those atoms into our bodies
- Iodine-131 (8-day half-life)
- Cesium-137 (30-year half-life)
- Strontium-90 (29-year half-life)

Radioactive atoms decay, damaging molecules

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

Fission fragment nuclei form radioactive atoms