

1. Important concepts

Important concepts

WORDS and PHRASES in Frisch & Peierls:

- fission
- neutrons
- isotopes - 235 and 238 Uranium - separation - thermal separation
- chain reaction - neutrons per fission ≈ 2.3
- scattering - elastic, inelastic
- capture
- cross section
- energy - 200 MeV per breakup of U
- critical radius (or mass) and mean free path

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2. Frisch & Peierls memorandum

Frisch & Peierls memorandum

- What is a chain reaction? Why is it important?
 - Exponential growth of energy release
 $\sim 2^{79} \times 200 \text{ MeV}$(see demos
<http://lectureonline.cl.msu.edu/~mmp/applist/chain/chain.htm>
<http://library.thinkquest.org/17940/texts/java/Reaction.html>)
- Why won't a chain reaction work to produce a "super" bomb in "ordinary Uranium" or ^{238}U ?
 - n's slowed by inelastic **scattering** to low E where absorption or **capture** dominates
 - much slower n's have higher fission probability or *cross section* σ
 - slowing down takes time & time to find U nucleus is 10^{-4} sec

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3.

Frisch & Peierls 2

Frisch & Peierls 2

- Combined with exponential growth time get explosive temp ~ 2-3000 degrees reached before chain reaction has gone far →
- ordinary chemical energy release & n's escape
- Note that using $^{238}\text{U} + \text{H}_2\text{O}$ slows n's further, to where fission is more likely (larger cross section), but n's too slow.
- More efficient slowing down with D_2O deuterium
- But liquid heats up rapidly (c.f reactor)

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4.

Frisch & Peierls 3

Frisch & Peierls 3

- How does ^{235}U overcome the problem of sustaining the chain reaction long enough to cause a "super" explosion?
 - ^{235}U (0.7%) has much greater fission probability.
 - Theoretically expect nearly 100% of collisions with n to yield fission AT ANY neutron energy.
 - Each fission yields an average of 2.3 neutrons.
 - Hence fast n's initiate chain reaction that progresses much faster than the time of expansion.
- How to separate? Thermal diffusion? No, actually gaseous diffusion. Enrichment process- large scale
 - Get 10 Kg out of how much U? ($M_U \times 0.007 = 10\text{Kg}$ so $M_U = 1400\text{ Kg}$)

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5. Frisch & Peierls 4

Frisch & Peierls 4

- What is *critical radius** (or mass) and *mean free path* (average distance from creation of n to next U nucleus)?
 - *Size of sphere where increase of n 's by fission = loss of n 's over surface
 - For high fission probability and metallic U density of 15 get mean free path of 2.6 cm and critical radius of 2.1 cm [actually larger because fission probability is $\sim 1/3$ of F&P's guess]
- n 's can have $v \sim 10^7$ m/sec leaving 2.6×10^{-9} sec between fissions \ll slow fission.
- $T \approx 10^{10}$ deg, $P \approx 10^{13}$ atm (rapid expansion!), E liberated \sim several kT's.
- Will there be protection from "super" explosions and radiation?
 - Radiation released in explosion \rightarrow equivalent to 100 tons of radium radiating. Effects on humans enormous, but many unknowns - warning system for entering aftermath - fallout

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6. More details

More details

- 10 nsec for 1 generation (1 nsec = 1 nanosec = 10^{-9} sec)
- With neutron speed 10^7 m/s that is over
 $d = 10^7 \text{m/s} \times 10^{-8} \text{sec} = 10^{-1} \text{m} = 10 \text{ cm or 4 inches}$
- ~ 1 microsec for 80 gens
or ~ 10 kT bomb
with critical mass ~ 10 Kg
- See copy of part of chapter on assembling the bomb

Models of U235 \rightarrow Hiroshima
"little boy"
and Pu239 bombs \rightarrow Nagasaki
"fat man"



Source: <http://www.fas.org/irp/keyhole/csis/corh/01/leboynsfatman.html>

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7.

Enrichment 1942-45

Enrichment 1942-45

Gaseous Diffusion

**Production of weapons grade U-235
Oak Ridge, TN - 1944-45**

fifty four-story buildings (2,000,000 square feet) in a U-shape measuring a half-mile long by 1,000 feet wide

- The small difference in effusion rates ($U(235)F_6$ vs. $U(238)F_6$) means that many effusion barriers (stages) are necessary for enrichment by passage of the enriched stream through successive stages. The K-25 gaseous diffusion plant at Oak Ridge required 4000 stages. This plant was one-half mile long and six stories high and covered 43 acres. The production of a suitable barrier was the key to successful separation. The holes must be microscopic (approximately one-millionth of an inch in diameter) and uniform in size. The porosity must always be high to sustain high flow rates and the barrier must not react with the highly corrosive hexafluoride. Nickel and aluminum oxide were best suited for barrier materials. Diffusion equipment is large and consumes significant amounts of energy. The entire system must be leak free; no air can be allowed in and no uranium hexafluoride can be allowed out.

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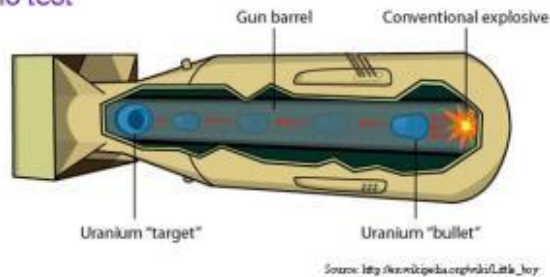
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8.

“Little boy”

“Little boy”

- Little boy ^{235}U
- Critical mass must be assembled in less time than spontaneous fission & minimize n loss
 - Sphere to minimize critical mass
 - Gun type trigger
 - Sure thing - no test



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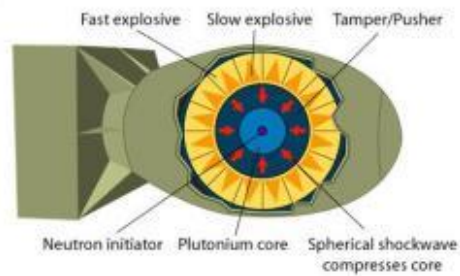
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9.

"Fat man"

"Fat man"

- Fat man ^{239}Pu from reactors (Hanford)
 $n + {}_{92}^{238}\text{U} \rightarrow {}_{92}^{239}\text{U} \rightarrow {}_{93}^{239}\text{Np} + e + \nu$
 ${}_{93}^{239}\text{Np} \rightarrow {}_{94}^{239}\text{Pu} + e + \nu$
- ^{239}Pu much faster spontaneous fission than ^{235}U
- Needs faster assembly to avoid fizzle
 - Implosion of sphere - subcritical with components
 - Compress to criticality, initiator, until internal P exceeds compression (80th gen) then disassembles



Source: http://www.kitp.ucla.edu/physics/Fat_man

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