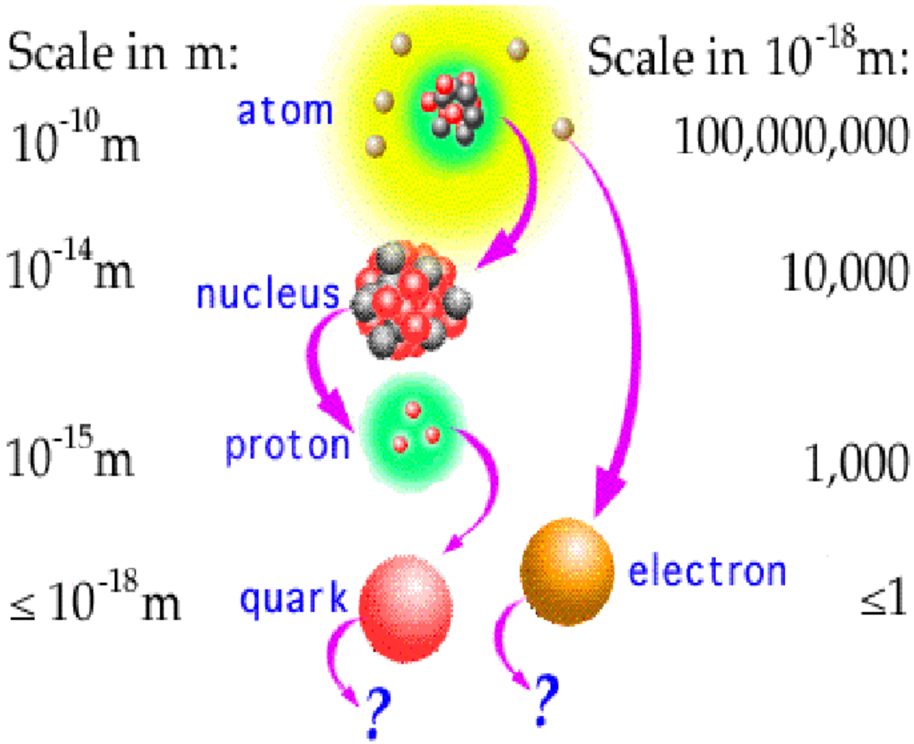
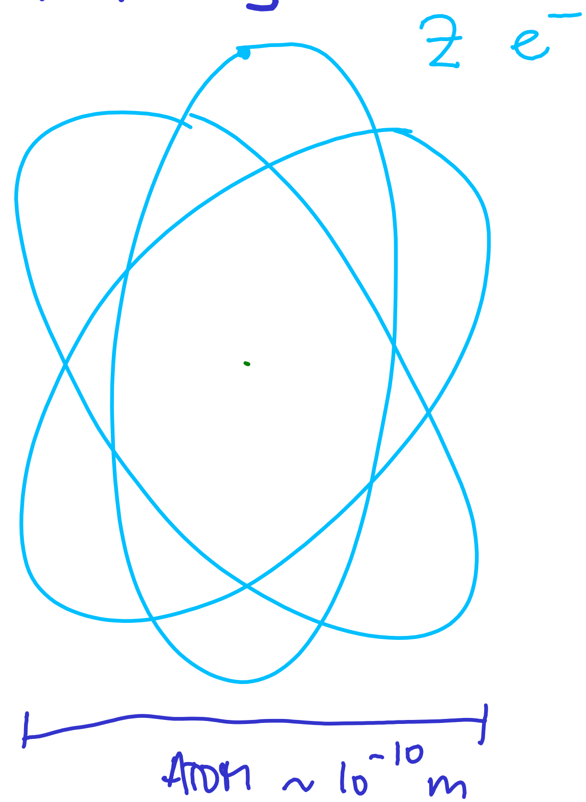
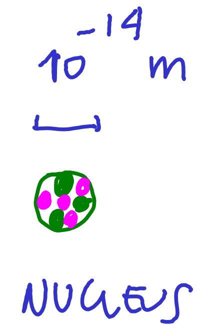
LECTURE 14

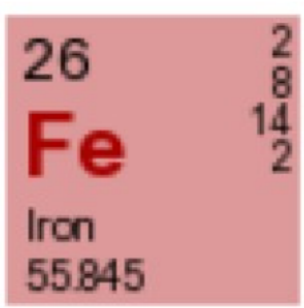
PHY 100. BINDING ENERGY, CHAIN REACTIONS

NUCLEAR PHYSICS









26 = # protons (Z)

Fe = Atomic element symbol

Iron = Element name

55.845 = Average atomic mass per atom

2 8 14 2 = Electron orbital configuration

AMU = ATOMIC MASS UNIT
~ 938 MeV/c^2
~ mass of one proton

AVERAGE OVER ISOTOPES : DIFFERENT NUMBER OF NEUTRONS IN NUCLEUS

DIFFERENT ISOTOPES CAN BE FOUND IN NATURE

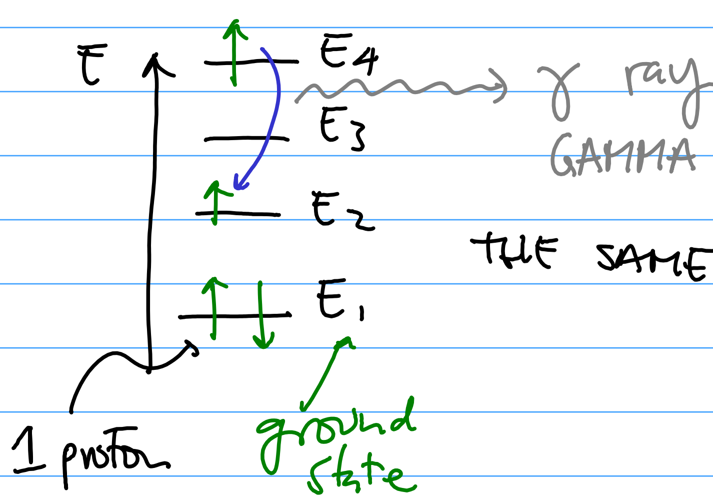
WHAT HOLDS THE NUCLEUS TOGETHER:

STRONG NUCLEAR FORCE

- MUCH STRONGER THAN E.M. AND GRAVITY
- LIMITED TO SHORT RANGES: 10^{-15} m

POP THIS NEW FORCE INTO SCHRÖDINGER EQ.

THE SOLUTIONS ARE DISCRETE ENERGY LEVELS FOR THE NUCLEONS (PROTONS & NEUTRONS)
VERY SIMILAR TO ORBITALS FOR e^- IN ATOM:

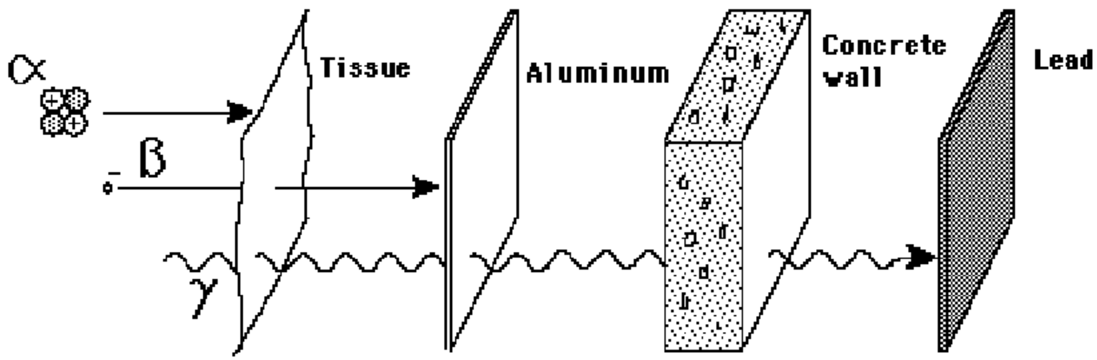


$E_4 - E_2 = hf \sim 10^6$ eV

THE SAME FOR NEUTRONS

THE STRONG FORCE KEEPS PROTONS GLUED TO EACH OTHER INSIDE NUCLEUS.
BUT E.M. REPULSION STILL EXISTS.

MOST NUCLEI ARE STABLE:
SOME ARE UNSTABLE: THEY NATURALLY DECAY (SPONTANEOUSLY)
THROUGH α, β, γ radiation.



β : e^-

${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X'$

$e^- \equiv \beta$

INSIDE X :

$n \longrightarrow p + e^-$

CAUSED BY WEAK FORCE
(A NEW KIND OF FORCE)

α · He nucleus

${}^{A}_{Z}X' \longrightarrow {}^{A-4}_{Z-2}X$

$\alpha \equiv$  2p 2n

TIME OF DECAY IS CHARACTERIZED BY <u>HALF-LIFE</u> $T_{1/2}$

TIME IT TAKES FOR 50% OF NUCLEI IN A GIVEN SAMPLE TO DECAY.

$$N = N_0 \, 2^{-\left(\frac{t}{T_{1/2}}\right)}$$

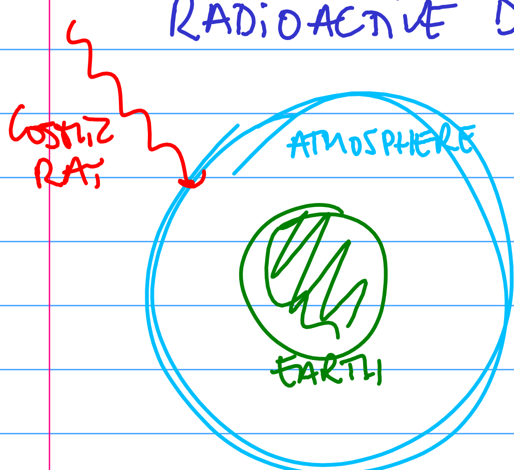
$2^{-\left(\frac{t}{T_{1/2}}\right)} \rightarrow$ less than 1

N: # of nuclei at time t

N_0: # of nuclei at time 0 (initial)

DON'T WORRY ABOUT THE FORMULA!

RADIOACTIVE DATING



NORMAL CARBON IN ATM: ${}^{12}_{6}C$

WHEN COSMIC RAYS HIT ATM.: ${}^{14}_{6}C$

${}^{14}C$ IS A NATURALLY RADIOACTIVE β EMITTER

$T_{1/2}$ = 6000 years

${}^{14}C$ INCORPORATED INTO LIVING TISSUE

WHEN YOU DIE $\rightarrow$ ${}^{14}C$ BEGINS DECAYING, ${}^{12}C$ REMAINS CONSTANT

$^{14}C/^{12}C$ RATIO GIVES AN ESTIMATE OF TIME OF DEATH.

$$\frac{N_{14C}}{N_{14C}(alive)} = 2^{-\frac{t}{T_{1/2}}} \Rightarrow t = T_{1/2} \times \log_2\left(\frac{N_{14C}}{N_{14C}(alive)}\right)$$

WE DON'T KNOW $N_{14C}(alive)$: WE USE $^{14}C/^{12}C$ IN THE FORMULA

WE KNOW $^{14}C/^{12}C$ FROM CALIBRATIONS WITH TREE RINGS, ...

EXAMPLE: WHAT IS THE AGE OF A BONE FOUND IN AN ARCHEOLOGICAL DIG IF THE MEASURED ^{14}C IS 1/4 OF THE NORMAL (IN A LIVING MATERIAL).

1 HALFTIME = INITIAL AMOUNT DROPS TO 1/2

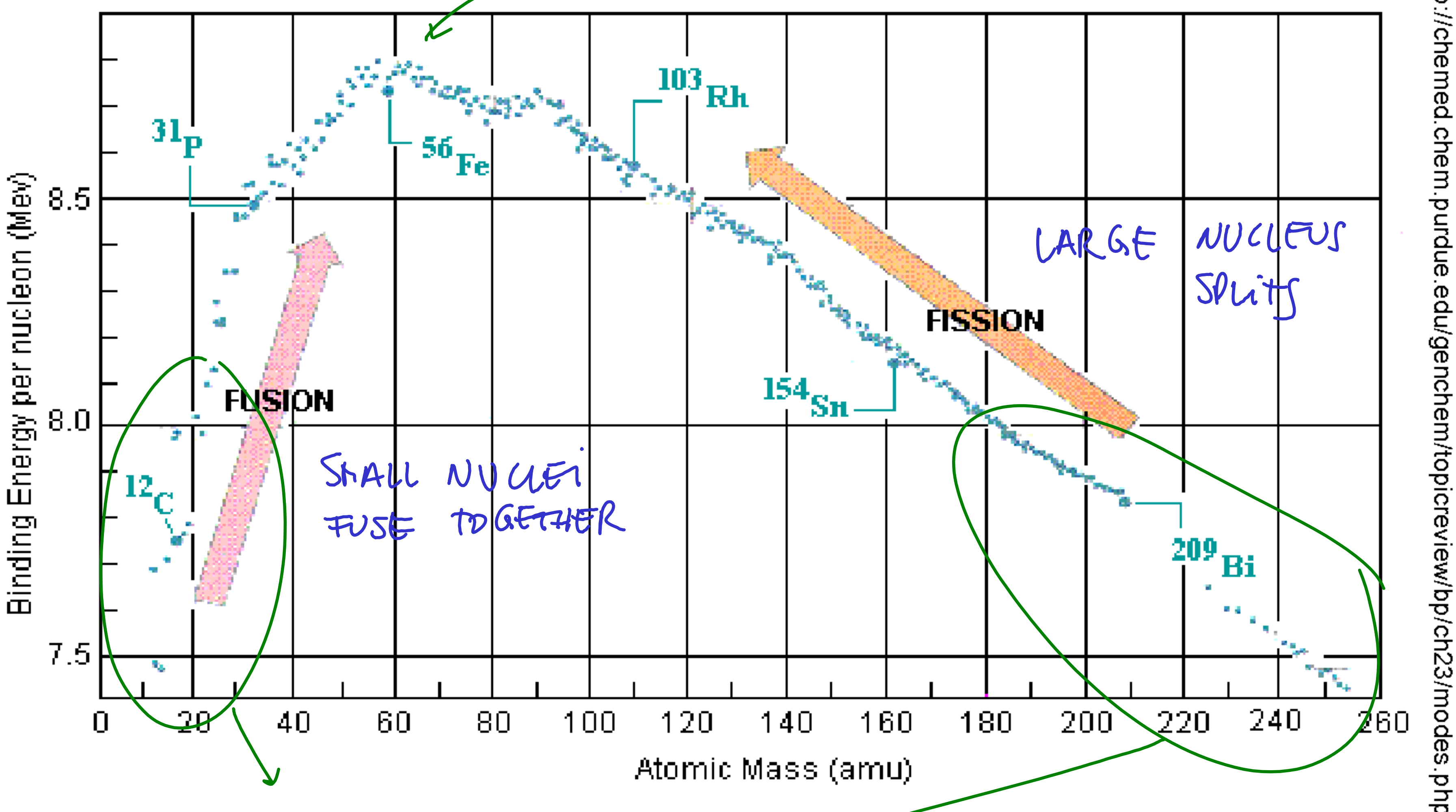
2 HALFTIMES = " " " " 1/4 (1/2 × 1/2)

⋮

$t = 2 \times 6{,}000$ years $= 12{,}000$ years.

BINDING ENERGY

MOST STABLE NUCLEI.



LESS STABLE NUCLEI

BINDING ENERGY PER NUCLEON IS THE ENERGY NEEDED TO BREAK FREE ONE NUCLEON FROM THE NUCLEUS : IT IS A MEASURE OF HOW EASY IT IS TO BREAK UP THE NUCLEUS.

EXAMPLE OF FISSION PROCESS:

$$\underbrace{{}^{235}_{92}U + n}_{\substack{\Sigma \text{masses} \\ \parallel \\ m_i}} \xrightarrow[\text{NUCLEAR FISSION}]{} \underbrace{{}^{93}_{37}Rb + {}^{140}_{58}Cs + 2n}_{\Sigma \text{masses} = m_f} + E$$

$$m_f - m_i > 0 \Rightarrow E = mc^2$$

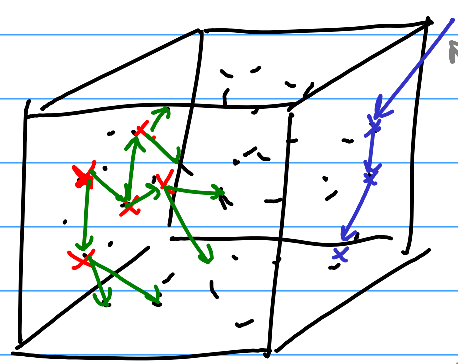
$${}^{235}_{92}U + n \Rightarrow \dots$$

...
...
...

THE RESULTING 2n PRODUCE A CASCADE OF THE SAME REACTION.

FOR EACH n IN THE INITIAL STATE, YOU GET TWO IN THE FINAL STATE.

CHAIN REACTION

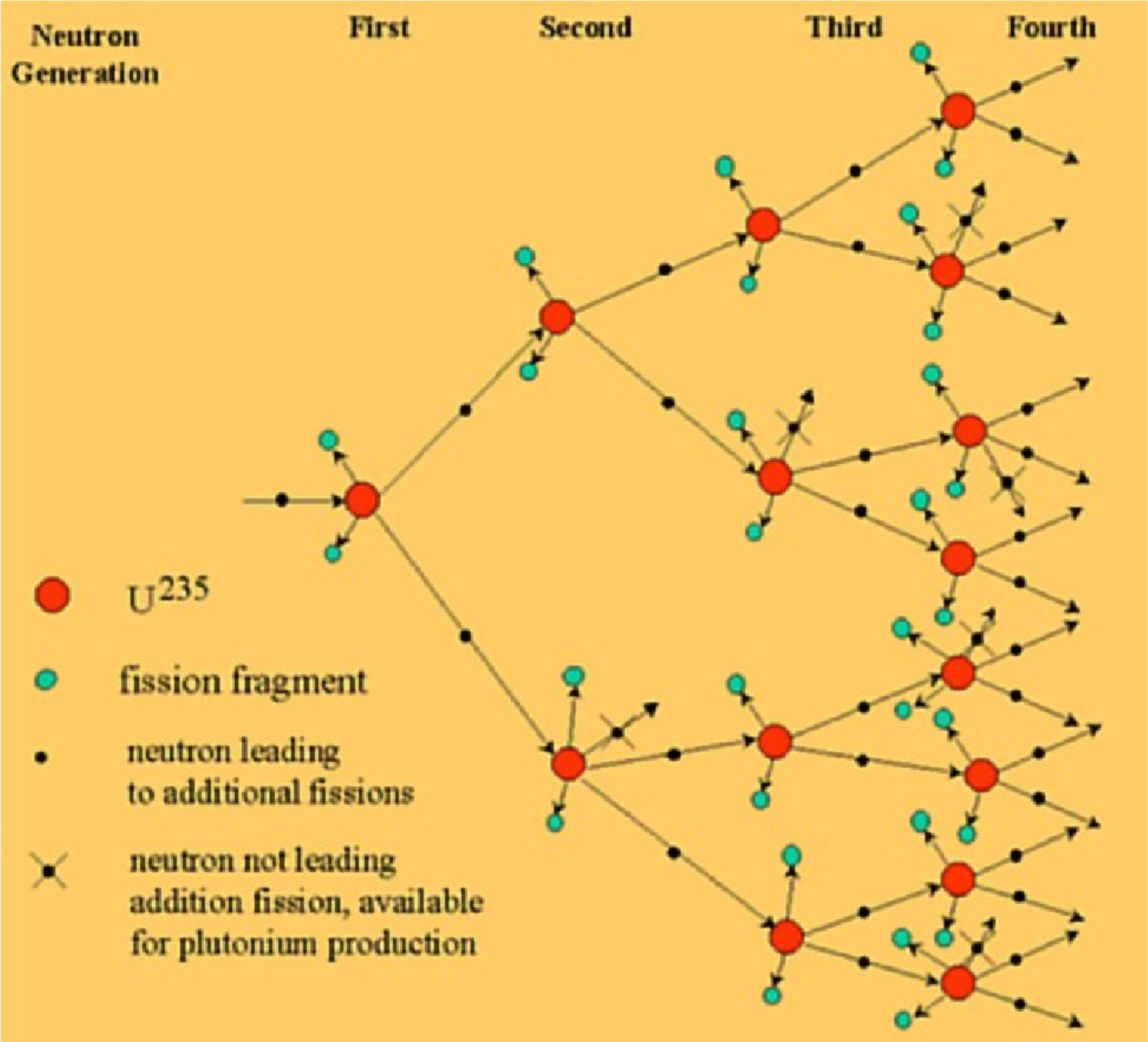


CRITICAL: 1 SPLIT PER SPLIT

SUBCRITICAL: < 1 " " "

SUPERCRITICAL: > 1 " " "

DEMONSTRATED IN 1942 (FERMI)



$^{235}U \sim 0.7\%$

$^{238}U \sim 99.3\%$

} NATURALLY OCCURING

IT IS HARD TO DISTILL ^{235}U FROM NATURE. ISOTOPES SHARE CHEMICAL CHARACT.

BUT:

$$^{238}U + n \longrightarrow {}^{239}U \longrightarrow \underbrace{{}^{239}Np}_{} + e^- + \bar{\nu}$$

NEPTUNIUM

neutrino

$\hookrightarrow$ ^{239}Pu ≡ PLUTONIUM

^{239}Pu CAN BE USED AS NUCLEAR FUEL BECAUSE IT ALSO PRODUCES A CHAIN REACTION

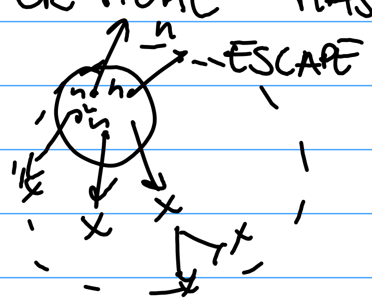
WEAPONS:

URANIUM: NEEDS TO BE ENRICHED: $90\%\ {}^{235}U + 10\%\ {}^{238}U$

$\rightarrow$ CENTRIFUGES

PLUTONIUM: EASY TO MAKE IN REACTORS $\quad {}^{238}U + n \rightarrow {}^{239}Pu$

CRITICAL MASS: IN ORDER TO SUSTAIN A CHAIN REACTION, THERE HAS TO BE ENOUGH FISSIBLE MATERIAL SO THAT THE n ACTUALLY ARE EFFICIENT.

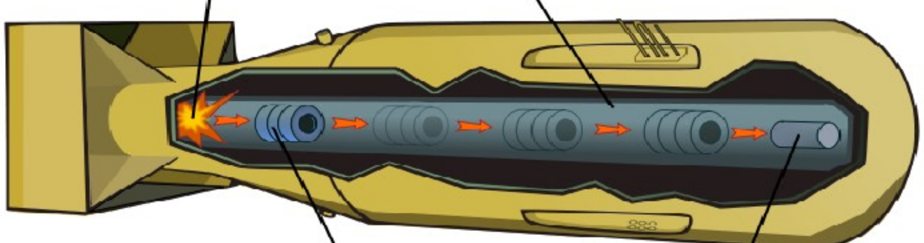


^{235}U BOMB: 40 kg (BASKETBALL)

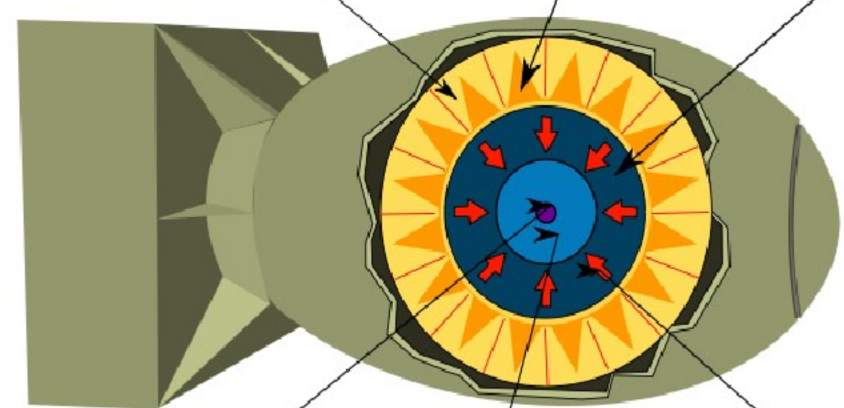
^{239}Pu BOMB: 5 kg (ORANGE)

DECEMBER 1945

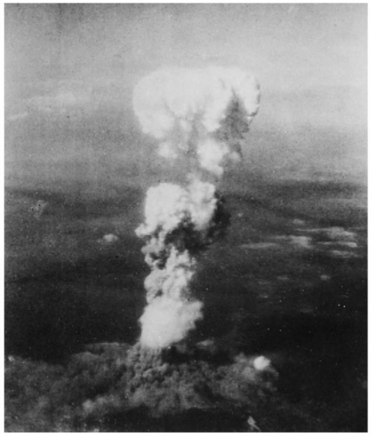
HIROSHIMA (U)



NAGASAKI (Pu)

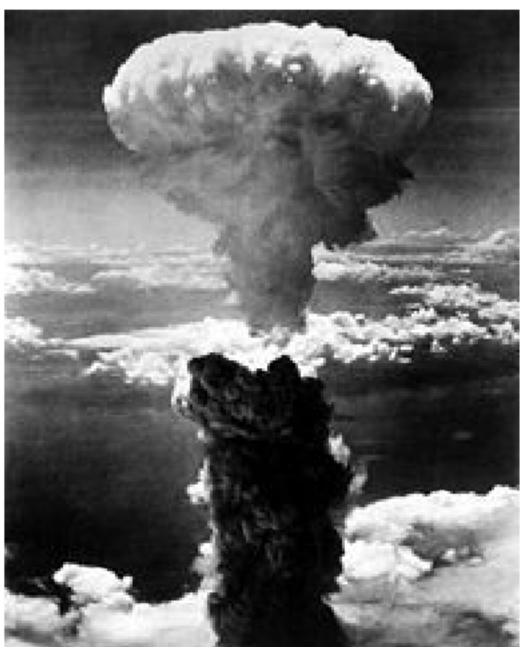


HIROSHIMA



12 kilotons

NAGASAKI



22 kilotons