Physics 107
Lec 33

Weak Interaction

Fourth and final force is weak force \(\ll\) strong force

\[\text{very short-range} \quad \text{at} \quad 10^{-18} \text{m} \]

\[= 10^{-14} \times \text{electric force at} \quad 3 \times 10^{-17} \text{m}\]

Unified with EM in 1968: "Electroweak force."

* Neutrinos only interact weakly \(\Rightarrow\) can not be detected directly

\(\Rightarrow\) Most pass right through Earth

Two important aspects of weak interaction based on neutron \(\leftrightarrow\) proton transitions

1. Beta decay

\[n \rightarrow p + e^- + \bar{\nu}_e \quad \text{slow}^{-1} \quad e^+ + e^- \quad (\beta)\]

\[\beta^+ \rightarrow e^+ + 2\gamma \rightarrow 2\gamma \]

FIGURE

2. "Solar fusion"

Core of stars like Sun, very slow normal fusion

\[p + p \rightarrow \text{D} + e^+ + \nu_e \quad (1)\]

\[D + p \rightarrow ^3\text{He} + \gamma \quad \times 2 \quad (2)\]

\[^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + p + p \quad (3)\]

\[|\text{net: } 6p + 2\bar{\nu}_e \rightarrow ^4\text{He} + 2p + \text{energy}|\]

Eddington 1932
Beck Bethe, '67 Nobel

Energy:

\[6p \; \text{mc}^2 = 5629.632 \text{ MeV} \]

\[2e^- \; \text{mc}^2 = 1.022 \text{ MeV} \]

\[^4\text{He} \; \text{mc}^2 = -3727.518 \text{ MeV} \]

\[2p \; \text{mc}^2 = -1876.544 \text{ MeV} \]

Net energy = 26.732 MeV

\[= 0.5\% \text{ of reactants} \]
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Nuclear Binding Energy = energy released per nucleus when assembled from protons and neutrons

**FIGURE**: Light nuclei release energy when fuse

- Sb is most tightly bound
- Heavy nuclei release energy when fission

Note: He is very strongly bound
  ➔ very plentiful in universe
  ➔ α particle detaches from α-unstable nuclei

Neutron discovery: \( ^{9}_{2} \text{Be} + ^{4}_{2} \text{He} \rightarrow ^{12}_{6} \text{C} + ^{2}_{0} \text{He} \)

1932 James Chadwick
(thought to be α earlier) from α-emitter like Po!

➔ shoot neutrons into things, see what happens

➔ 1932 Joliot-Curie \( n + ^{92}_{42} \text{U} \rightarrow ^{97}_{57} \text{La} + \text{stuff} \)???

**FIGURE**: Meitner/Frisch: Fission! Most kinetic energy

Example: \( n + ^{235}_{92} \text{U} \rightarrow ^{236}_{92} \text{U}^* \rightarrow ^{92}_{54} \text{Kr} + ^{134}_{54} \text{Ba} + 3 \text{n} + 1.8 \text{MeV} \)

➔ triples number of free neutrons!

Average is ~ 2 neutrons

\( ^{235}_{92} \text{U} \) is 0.72% of \( ^{238}_{92} \text{U} \)

But

\( n + ^{238}_{92} \text{U} \rightarrow ^{239}_{92} \text{U}^* \rightarrow ^{239}_{92} \text{Np} + ^{141}_{91} \text{Ce} \)

➔ Another

\( ^{239}_{92} \text{Np} \rightarrow ^{239}_{92} \text{Pu} + e^- \)

➔ artificially made, very fissile!

Easier to separate from \( ^{238}_{92} \text{U} \)

➔ very difficult to separate from \( ^{238}_{92} \text{U} \)

➔ 235U + n → 95Sr + 139Xe + 2n
  ➔ + 150 MeV

➔ artifically made, very fissile!

➔ Easier to separate from \( ^{238}_{92} \text{U} \)
Chain Reaction occurs if enough neutrons can hit more $^{235}$U or $^{239}$Pu before escaping.

Best shape = sphere (lowest area/volume)

$\Rightarrow$ critical mass = mass of sphere that will produce runaway chain reaction

$^{235}$U: 25 kg = size of cantaloupe

$^{239}$Pu: 8 kg = size of orange

$\Rightarrow$ fission bomb: slam > critical mass together fast to get rapid chain reaction

ENERGY: fission products ionize/slow $\rightarrow$ x-rays

challenges: (1) separate enough $^{235}$U from $U$ ore "Manhattan Project" or (2) manufacture enough $^{239}$Pu

$\Rightarrow$ also done in 1945

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(1) enough was separated for one bomb, no test!

- Hiroshima "Little Boy" bomb - live test 8/6/45

(2) enough $^{239}$Pu was made for a test of

- "The Gadget" at "Trinity" nuclear test July 16, 1945

- "Fat Man" bomb on Nagasaki 8/9/45

- "Urchin" Initiator: $^{210}$Po + Be

- $^{210}$Po $\rightarrow$ $^{206}$Pb + $^{4}$He + $^{α}$ + $^{α}$

- $^{α}$ + $^{9}$Be $\rightarrow$ $^{12}$C + $^{n}$ + $^{n}$

Fusion bomb - originally used fission bomb trigger

$n + ^{6}$Li $\rightarrow ^{4}$He + $^{3}$T

now - conventional explosive trigger

$^{n} + ^{7}$Li $\rightarrow ^{4}$He + $^{3}$T + n $\Rightarrow$ "small" fusion bombs, very difficult tech