Class 1

→ Story of Fusion Physics

→ 1 hr. / wk
P/NG
Participation

Focus: Physics of confinement, with historical background

→ 1 sheet: Name (opt.), anticipated major
Why took seminar?
1 thing you want to learn?

→ Materials:

~ F.F. Chen (*) "An Indispensable Truth"
1/2 fusion physics, 1/2 energy policy

opt.
ref: "Intro to Plasma Physics and Controlled Fusion", F. Chen. (Jnr/Senior)

~ Kenneth Ford, "Building the H-Bomb: A Personal History".

~ postings.

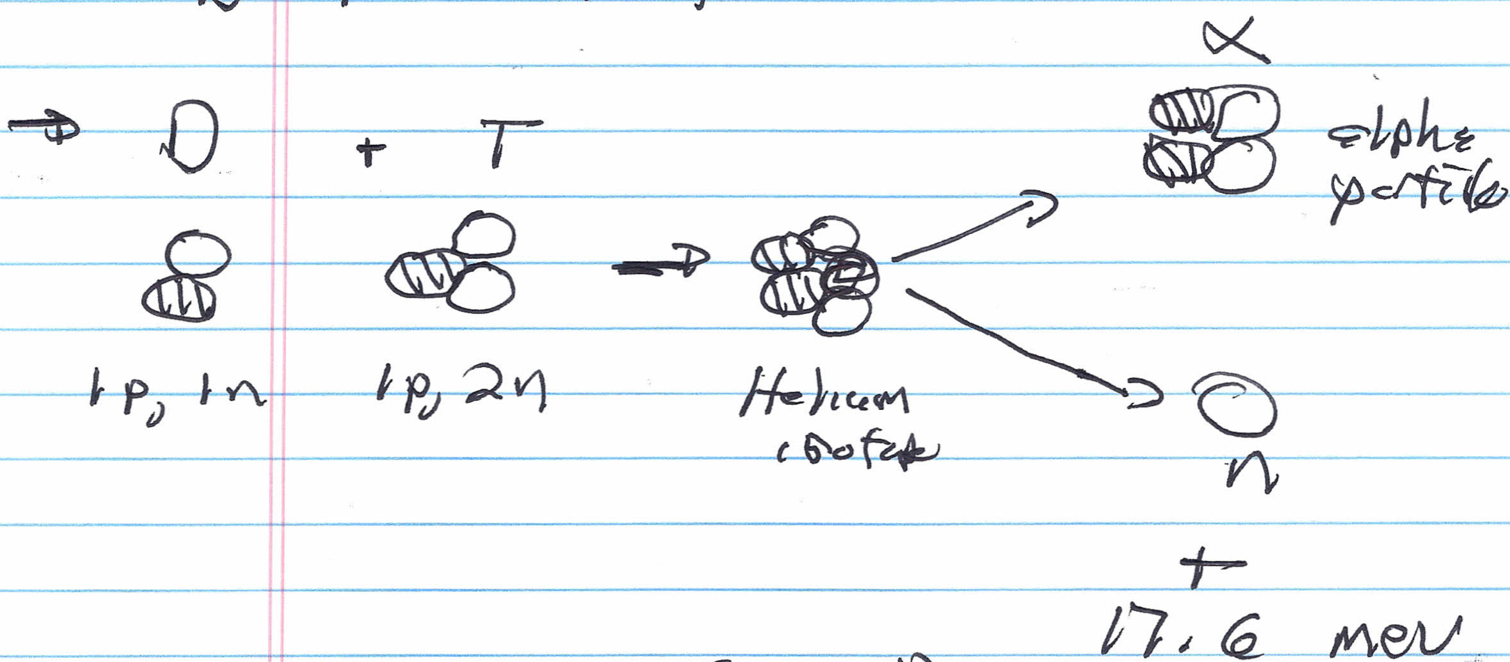
Next Week: Read → Meade article
→ Chapt. 4; Chen

→ What is Fusion

- nucleus p – ⊕
  n – o

- nuclear force between p, n etc.
  very strong ⇒ overcomes es repulsion

- D-T reaction:

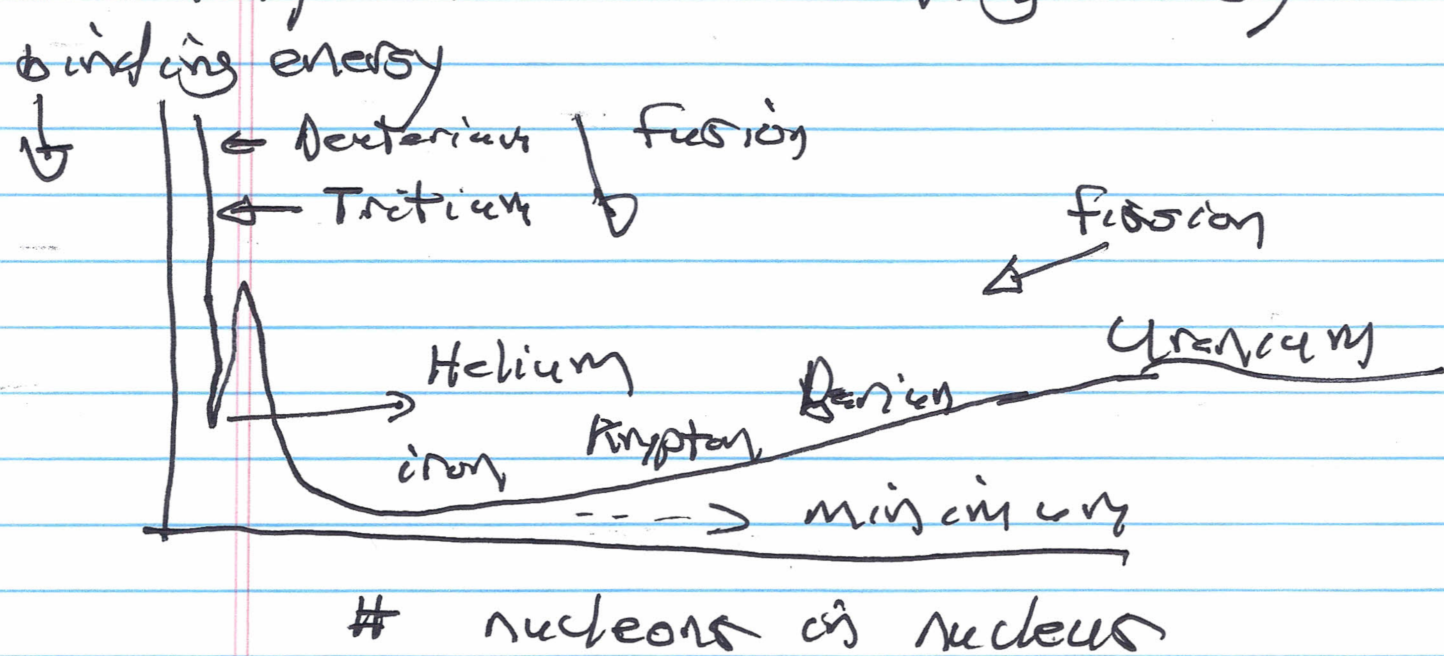


$17.6\ MeV = 17.6 \times 10^{6} \times 10^{-12}\ J$

but 1 mole fusing material → $\times 10^{23}$

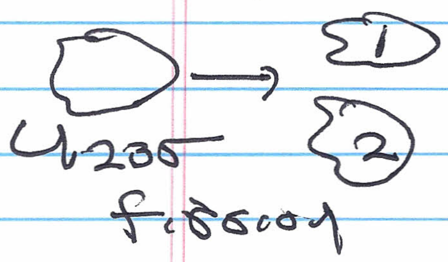
→ Deuterium — separate from water
tritium — make by nuclear reaction (blanket, in reactor).

→ Energy release — "binding energy"



"binding energy" → energy (nuclear) stored in assemblage of nucleus

→ energy release from binding energy (fission)



$M_U > M_1 + M_2$

mass defect $= M_U - (M_1 + M_2)$

$E = (md)c^2$ → energy release.

→ fusion : $M_{He} < M_D + M_T$

→ iron is minimum in curve of binding energy

→ # < $\#_{iron}$ ⇒ lower energy (release) by <u>fusion</u>

→ # > # iron ⇒ lower energy (release) by <u>fission</u>.

→ How facilitate a D + T reaction ?

– Point is electrostatic repulsion "wins" for most DT collisions!

– D (or T) must QM tunnel thru barrier of e.s. repulsion to fuse!

Fusion is inherently a QM process. (Bethe, 1939).

→ as fusion inherently inefficient, seek means to maintain energy of particles which don't fuse

⇒ hot plasma of D, T !

How confine ?

→ some Fusion History

1920's: Aston discovers mass of 4 hydrogen atoms (2P, 2N) exceeds mass 1 He.

1930's: Bethe – fusion pathway in stars

1940's: first Z pinch

1950's: start of fusion programs

Lawson criterion for fusion plasma.

→ What conditions are required for fusion: self-sustained state?

i.e. when is energy released from fusion events sufficient for continued fusion reaction?

$P_{released} > P_{lost}$

$P_{released}$ ↓ power released by fusion reaction

P_{lost} ↓ power loss from plasma

set by confinement physics.
↓

Define $\tau_E \equiv$ energy confinement time

then

$$1/\tau_E = \left(\frac{W}{P_{loss}}\right)^{-1}$$

W → energy content $3nk_BT$

P_{loss} → power loss.

⇒ [redacted]

$$P_{loss} = W/\tau_E$$

τ_E is where all the hard plasma physics is buried.

$$P_{released} > k_B n T / \tau_E$$

$$P_{released} = f \, E_{ch}$$

f → volume rate of fusion reactions

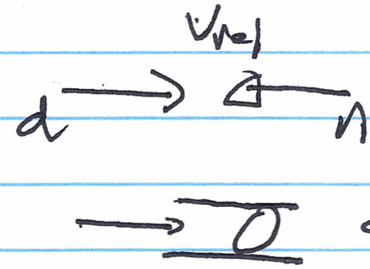
E_{ch} → energy of charged fusion products (3.5 MeV)

{neutrons don't heat plasma}

$$f = n_d n_t \langle \sigma v \rangle$$

σ → fusion cross section

v → $v_{rel.}$



area of interaction cylinder.

⇒

$$\boxed{n_d n_t \langle \sigma v \rangle E_{ch} > \frac{n T k_B}{\tau_E}}$$

and can re-arrange.

$$n \cancel{n} \langle \sigma v \rangle E_{ch} > \frac{\cancel{n} T k_b}{\tau_E}$$

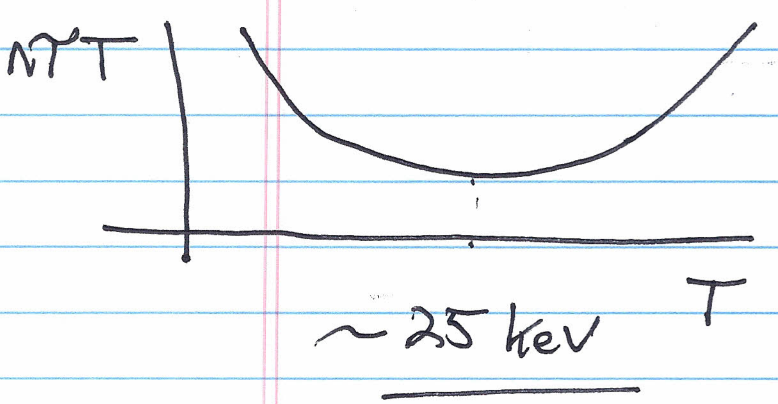
$$n\tau_E \geq 12 k_B T / \langle\sigma v\rangle E_{ch}$$

$$n\tau_E \geq 12\, k_B T / E_{ch}\langle\sigma v\rangle \rightarrow 1.5\times10^{20}\ \frac{s}{m^3}$$

and can extend to triple product:

$$\underbrace{n T \tau_E}_{\text{Lawson \#}} \geq 12 k_B T^2 / E_{ch}\langle\sigma v\rangle$$

$T^2/\langle\sigma v\rangle$ has absolute minimum.



so working from minimum:

<u>need</u>

$$n T \tau_E > 3 \times 10^{21} \text{ keV s/m}^3$$

→ TFTR, JET "close"

→ need achieve requisite n, T, τ_E simultaneously

→ key is confinement!