Art 7/5/19.

How does Inertial Confinement Fusion work?

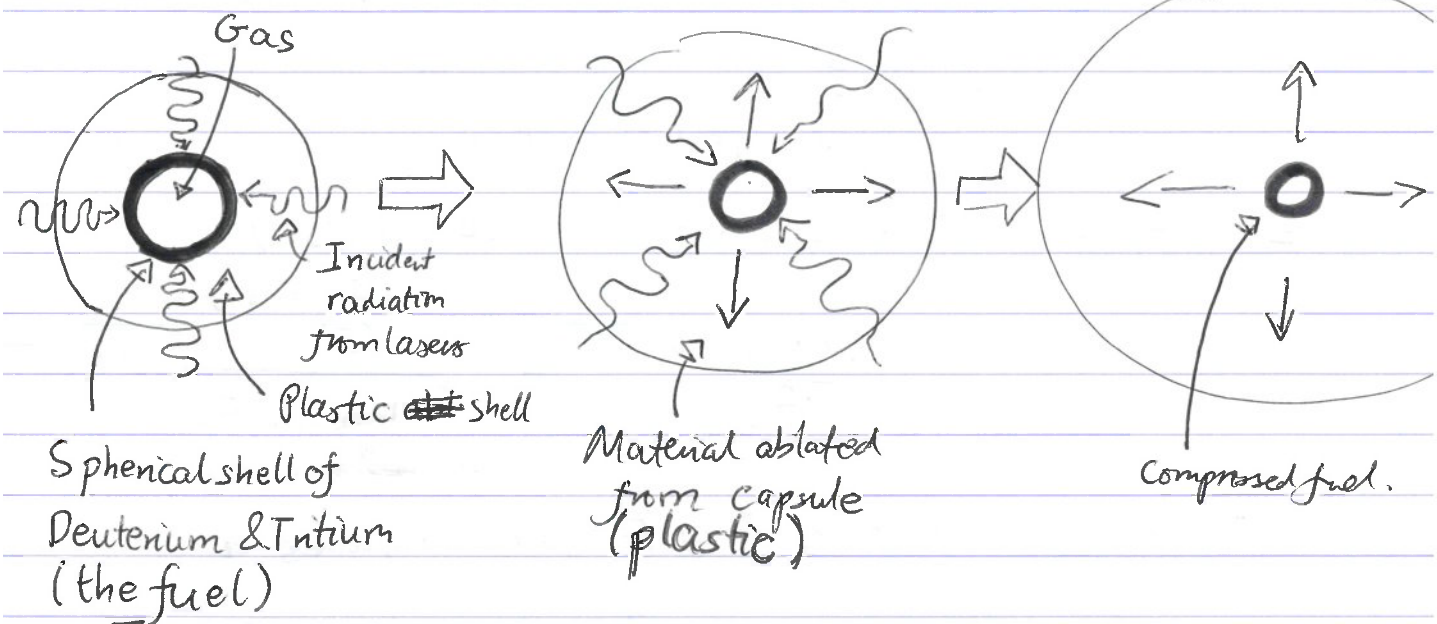

Fig. 1 How Inertial confinement works.

Aim: Fuse Deuterium (D) & Tritium (T) to ~~ma~~ release enough energy to sustain the reaction.

$$D + T \rightarrow {}^{4}He + n$$

$\quad\quad\quad\quad\quad\quad\quad\quad$ 3.5 MeV $\quad$ 14.1 MeV.

Why do we need high pressures?

Largest cross-section is @ 20 keV,

$$\sigma(E) = 4 \times 10^{-22} \, m^3 s^{-1}$$

Fraction of fuel burnt (not all of it is burnt!)

$$f = \tau \, n_D n_T \, \sigma(E) \,/\, (n_0/2)$$

confinement time; Number densities of deuterium & tritium; Overall number densities

Say, for the sake of argument, equal density of deuterium & tritium

$$\Rightarrow n_D = n_T = n_0/2 = \rho$$

If ~~the~~ a ball of fusion fuel expands at a constant speed for time

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particle density will fall to a half in time

$$\tau \approx \frac{R}{3c_s}$$ Initial radius. / Speed of expansion

$$\Rightarrow \quad f = \tau \times \tfrac{1}{2}n_0 \times \tfrac{1}{2}n_0 \times \sigma(E) \,/\, (\tfrac{1}{2}n_0)$$

In terms of mass densit

$$= \frac{R n_0 \sigma(E)}{6c_s} = \frac{\sigma(E)}{6M_{\cancel{nucle}\,atomic}\, c_s}\rho R$$

Total ~~Atom~~ Atomic mass $= 5 m_p$

To burn at least $\frac{1}{3}$rd of the fuel requires ~~a~~ .

$$\rho R \approx 30\,kg/m^2$$ (when we also add time dependance to the above calcul

Deuterium ice has a density $\sim 200 kg/m^3$

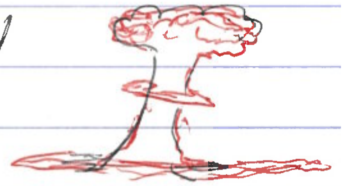
$$\Rightarrow R = 0.15\ m$$

To heat a 15cm radius ball of deuterium so each nucleon has a mass of ~20keV would require

$$\frac{\rho}{M_{atomic}} \times 20\,keV \times \frac{4}{3}\pi R^3 \approx 6.8 \times 10^{33}\,keV$$

$\frac{\rho}{M_{atomic}}$: $2.4 \times 10^{31}\ m^{-3}$

$$\approx 10^{12}\ J$$
$$\sim 1\ TJ$$



About the energy released by an atomic bomb

(Hiroshima "Little Boy" bomb ~ 6×1

Highest energy which can be delivered by a laser is ~ MJ

$\Rightarrow$ Need to compress fuel to very high pressures to reduce R.

radius of fuel capsule at ignition.

To achieve this we use a combination of lasers (providing pressure from the radiation) and ram pressure by ablating (vapourising) ~~the outside of the fuel sh~~ a shell containing the fuel. (fig. 1)

What are the limitations to inertial confinement fusion (ICF)?

The problem mainly is in keeping the shell of fuel compressed on all sides equally. Asymmetries due to the way ~~t~~ the fuel is heated or surface imperfections on the capsule grow exponentially in size as a result of the Rayleigh-Taylor instability

To reduce asymmetry in the way we heat the fuel (the drive) we use a gold tube (fig. 2)
The walls of the tube emit a smooth ~~emit~~ blackbody ~~radiation~~ spectrum with a peak in the X-ray spectrum.

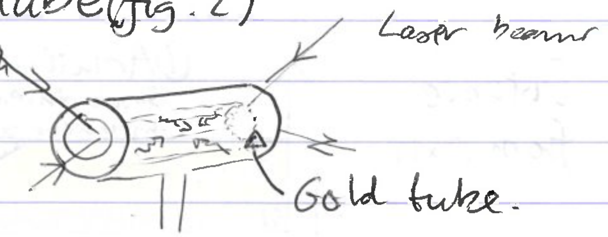


Fig. 2.

There are still asymmetries as a result of, for instance, the fuel injection point.

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There are two stages at which Rayleigh-Taylor instabilities can form (fig. 3)

1) During ablation: As the ablated (vapourized) plastic expands, it pushes back into the ~~solid plastic~~ more dense ~~material~~ ablated fluid closer to the surface of the capsule. Since there is a lower density fluid pushing into a higher density fluid, the interface between the two is unstable (in the Rayleigh-Taylor sense). Therefore need to have very smooth capsules.

2) When the implosion reaches the axis: The dense layer of D compresses a high temperature (& lower density) layer (the hotspot). The pressure forces the fuel against the lower density hotspot, which again means the interface is unstable.

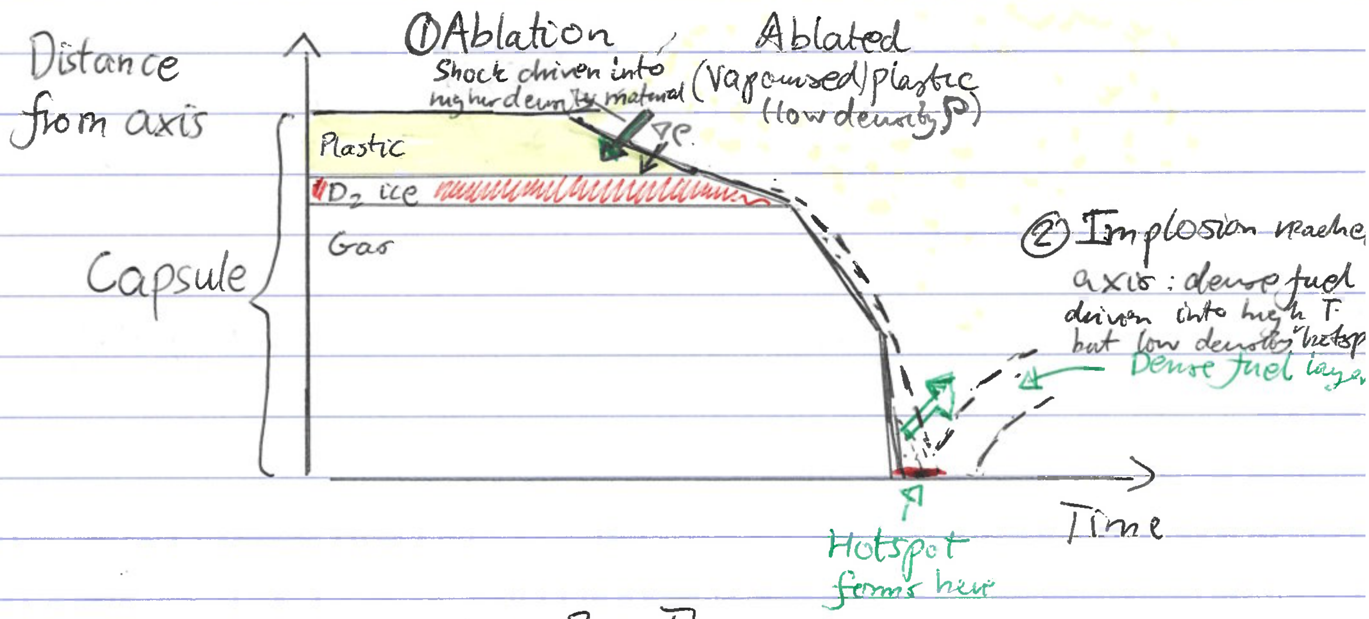

Fig. 3: The compression of a fuel capsule during ICF.