Focus Fusion: p-$B^1$1 Fusion with DPF

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Outline of Presentation

1. Introduction - p-B^{11} Fusion
2. Theoretical Advances by LPPFusion Researchers

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p-B^{11} as Fusion Fuel

Advantages:

- No neutrons are produced in this reaction, $p+B^{11} \rightarrow 3He^4$.
- Released energy is carried only by charged particles.
- No need to use heat-exchanger, charged particles create electricity directly.
- Only tiny amount of neutrons is produced in secondary reaction, $He^4+B^{11} \rightarrow N^{14}+n$.
- No radioactive waste.

Challenges:

- Requires average ion energies above 100keV. (DT fusion requires 40keV).
- Plasma density-confinement product $n\tau$ requirement is 15 times higher than DT fusion.
- Boron ions lead far greater amounts of X-ray energy than DT fusion.

Dense Plasma Focus (DPF)

Advantages:

- Extremely compact.
- Simple in construction.
- No need for external magnets nor lasers.
- Utilize the instabilities of plasma rather than fighting them.

Challenges:

- Very bad fusion yield, efficiency 1.25×10^{-5}.

Fusion Yield

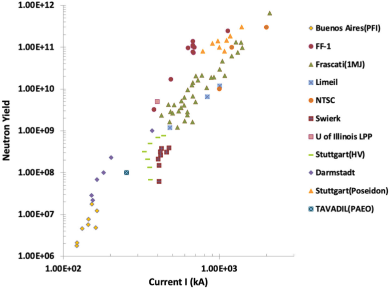

Figure 1: Up to peak currents of 1MA, DPF fusion yield rises sharply with increasing current, but plateaus above 1MA. At lower currents, FF-1's performance exceeds those of other DPFs, but was comparable to other best results at 1MA. [5]

E. J. Lerner, S. M. Hassan, I. Karamitsos-Zivkovic, and R. Fritsch. Focus Fusion: Overview of Progress Towards p-B11 Fusion with the Dense Plasma Focus.

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Quantitative Model of DPF Functioning

$$r_c = 1.32 \times 10^{-3} (\mu \cdot z)^{-2/3} r \tag{1}$$

$$B_c = 4z \left(\frac{\mu M}{m} \right) B \tag{2}$$

$$n_c = 3.7 \times 10^{10} \frac{\mu^2 z I^2}{r^2} \tag{3}$$

$$Y \sim \mu^{2.75} I^4 f(T_i) \tag{4}$$

where B is peak field at cathod (G), B_c is the field in the core of the plasmoid, r is cathode radius (cm), r_c is the plasmoid core radius, n_c is plasmoid ion density, I is peak current (A), μ is average ionic mass, z is ionic charge, Y is fusion reaction number and $f(T_i)$ is the reaction rate as a function of ion temperature T_i.

Conclusions:

- I^4 scaling is correctly predicted by the model.
- Yield increases with increasing atomic mass of the fill gas.

Quantum Magnetic Field(QMF) Effect

- Problem of high X-ray emission with p-B^{11} can be mitigated through the use of quantum magnetic field (QMF) effect.
- In strong magnetic field, electrons can have only discrete energy levels, termed Landau levels.

$$E_b = \left(n + \frac{1}{2}\right) \frac{e\hbar B}{mc}$$

- Very little energy can be transferred from ions to electrons by collisions.

Control of Angular Momentum and Efficiency of Energy Transfer to the Plasmoid

- For high efficiency, control of angular momentum is required.
- The plasmoid formation requires certain amount of angular momentum, so that kink instability can occur.
- Angular momentum can be imparted to the plasma sheath during the rundown by the interaction of the inward flowing electron flows and any small initial axial magnetic field. $\mathbf{J} \times \mathbf{B}$ accelerates the electron in the azimuthal direction.

Viscous Heating Mechanism

- Ions in the plasmoid might be heated by viscous heating.
- As plasmoid contracts, ions moving inward at different velocities start to mix. The ordered velocity of motion is converted into random velocity of heat.

$$T_i = 6.2 \times 10^{-4} z_{eff}^{1.6} n_i^{0.2} (\ln \Lambda L_{max} B)^{0.4}$$

  where $z_{eff} = (\sum fz^2)^{1/2}$, f is the number fraction of a given ion, z is the ionic charge and the summation is over all ions. z_{eff} is thus a dimensionless number, the effective number of charges per ion. L_{max} is the distance around the plasmoid, which in our model is $9.7(\mu z)^{1/3} L_p$, where L_p is the observed length of the plasmoid core along its axis. T_i is the ion temperature in eV.
- Higher T_i can be expected with higher z fill gas.

Induced Current Heating Mechanism

- Electron beam induces currents in the plasmoid electrons.
- Plasmoid has a great density, this current is distributed over these electrons.
- The slow electrons undergo collisions and converted their kinetic energy to heat.

$$T_e = 0.19(z_{eff}/r_b)^{0.8}(\ln \Lambda LI/z(\gamma - 1))^{0.4}$$

where r_b is the beam radius and γ is the relativistic factor for the beam electrons.

Lower Hybrid Heating Mechanism

- For the densest plasmoids, lower hybrid instability will lead to wave heating of ions by the electron beam.
- For current more than $I > 5.0/\mu^{1/6} z^{5/6}$MA, the majority of electron beam energy will go to ion heating, rather than electron heating.

Role of Impurities of Disrupting Filaments and Source of Impurities

- High z impurities increase radiation, limiting fusion yield.
- High z impurities decrease the conductivity of the plasma in the current-carrying sheath, leading to disruption of the filaments through over heating.
- High z impurities reduces density (and hence yield) due to asymmetric compression.
- The increasing presence of impurities is hypothesized to be the main reason for the plateauing of fusion yield.

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