Modelling the Neutraliser Plasma of ITER Negative Ion Beams

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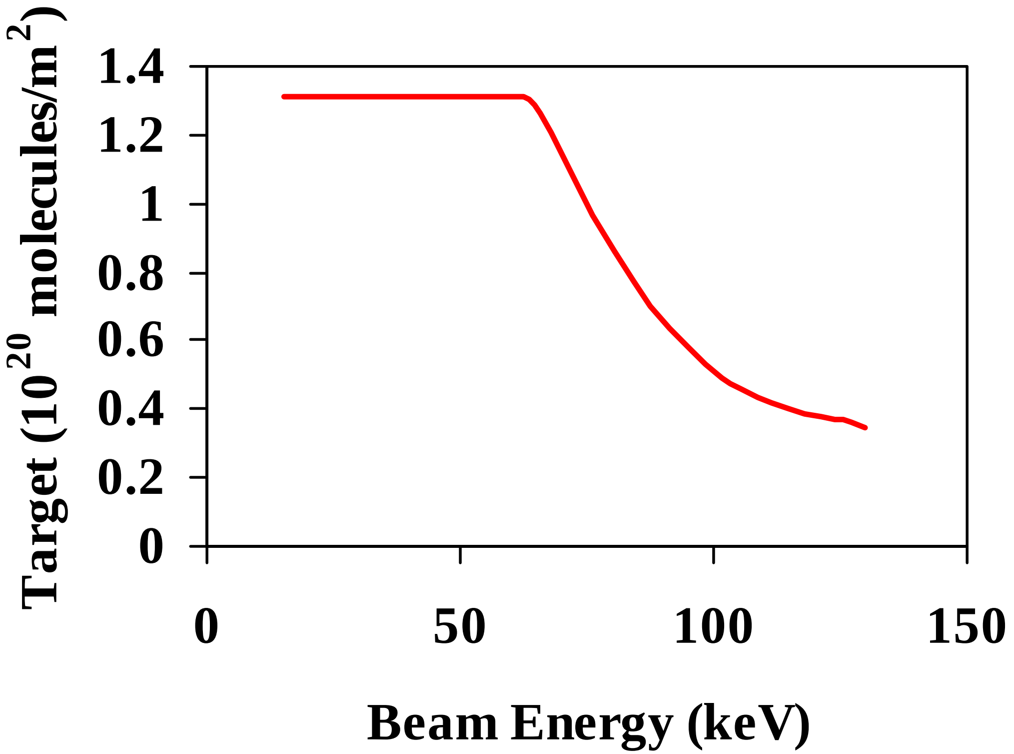
Plasma, Gas Heating and Neutralisation Efficiency I

- Gas heating is major contribution to the reduction in neutralisation efficiency

  - Effect can be severe

70% loss of effective gas target in JET NBI

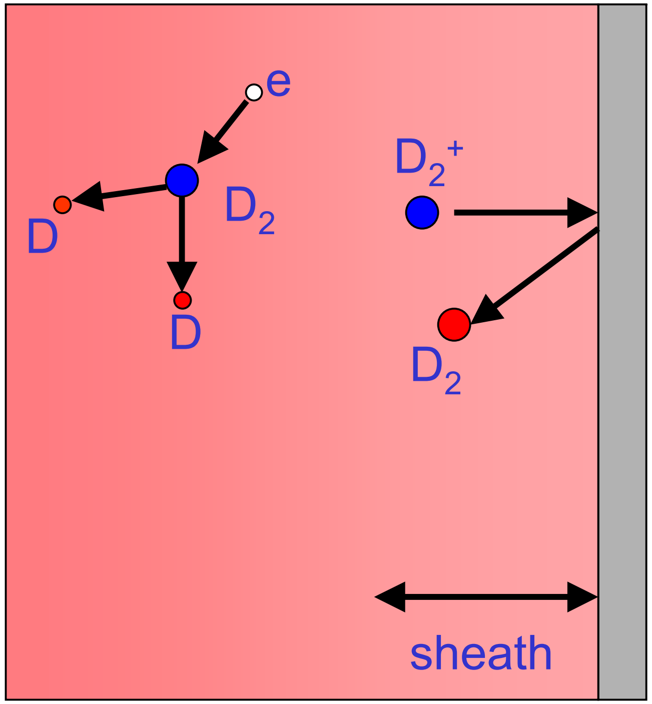


Plasma, Gas Heating and Neutralisation Efficiency II

Gas heating is mainly due to collisions of gas with plasma electrons and hot neutrals

Hot neutrals formed from plasma ions accelerated across the sheath and reflected as energetic neutrals at wall

To predict gas heating we need to predict plasma conditions



The Neutraliser Model I - Source Terms

Beam evolution through the neutraliser

$$\frac{dn^p}{dz} = N\left[n^q\sigma_{qp} + n^r\sigma_{rp} - n^p\left(\sigma_{pq} + \sigma_{pr}\right)\right]$$

p,q,r represent charge states -1, 0, +1

Ionisation term

$$S_x = \frac{NI_b}{A_b e}\left[f^-(z)\sigma_{x\bar{1}} + f^0(z)\sigma_{x0} + f^+(z)\sigma_{x1}\right]$$

Power to plasma from beam

$$P = \frac{NI_b\Delta z}{e}\left[f^-(z)\varepsilon^- + f^0(z)\varepsilon^0 + f^+(z)\varepsilon^+\right]$$

The Neutraliser Model II - Boundary Conditions

$$j_i - \frac{j_e}{4} exp\left(-\frac{\varphi}{T_e} \right) - j_s\, exp\left(-\frac{\varphi}{T_e} \right) - \frac{\varphi}{E_{sB}} = j_{cx} - j_s$$

Exact form depends upon degree of thermalisation of stripped electrons with plasma

Un-thermalised, $E_{sB} >> \varphi$

$$j_i - \frac{j_e}{4} exp\left(-\frac{\varphi}{T_e} \right) = j_{cx}$$

Thermalised, $E_{sB} \sim T_e$

$$j_i - \frac{(j_e + j_s)}{4} exp\left(-\frac{\varphi}{T_e} \right) = j_{cx} - j_s$$

The Neutraliser Model - Gas Heating

J. Paméla, Rev. Sci. Instrum., **57**, 1066 (1986)

$$A_w \alpha \frac{Nv}{4} k(T - T_w) = (\gamma - 1)[S_b(I_b, E_b) + S_e(n_e, T_e) + S_i(n_i, \varphi, R)]$$

α accommodation coefficient for gas molecules on wall

R ion reflection coefficient

γ specific heat capacity of neutraliser gas

Benchmark - Application to JET Neutraliser

Assume beam is full energy component only, uniform gas density

JET Neutraliser

Length 1.8m

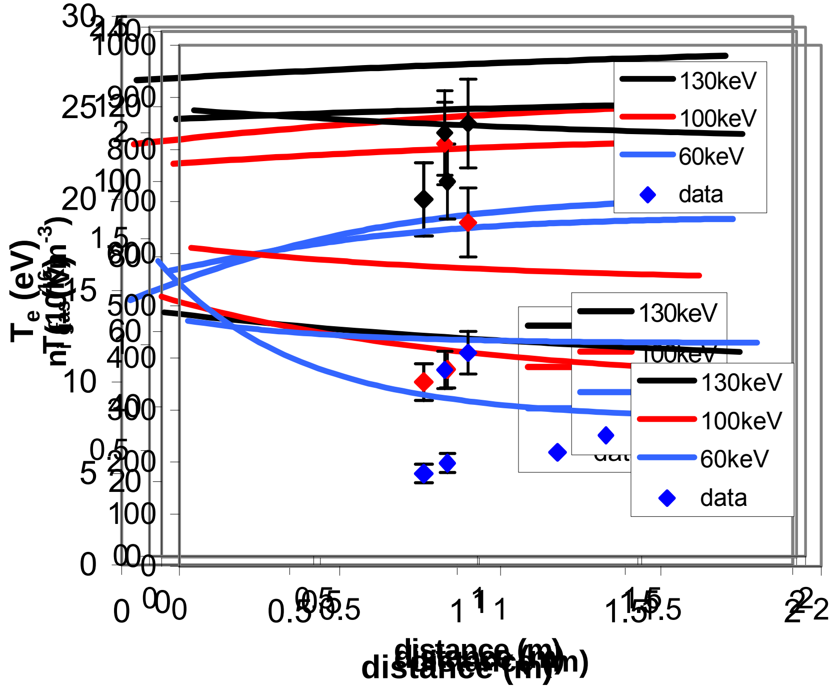
Height 0.4m

Width 0.2m

60kV 17A

100kV 36A

130kV 55A



Application to ITER Negative Ion Beams

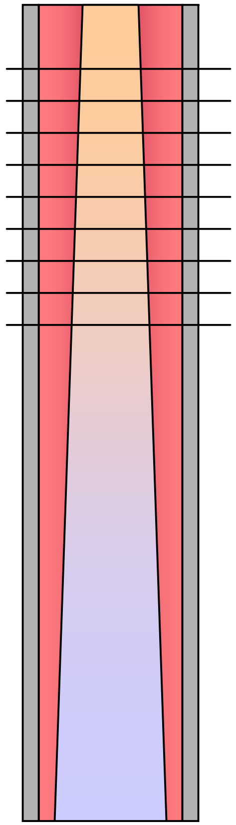
HNB	DNB
D^-	H^-
1MeV 30A	100keV 16.4A
4 Channels	4 Channels
7.5A per channel	4.1A per channel
Target 1.4×10^{20} molecules/m^2	Target 0.5×10^{20} molecules/m^2

Length 3m

Height 1.6m

Width 0.2m

D^-



D^-, D^0, D^+

Data issues

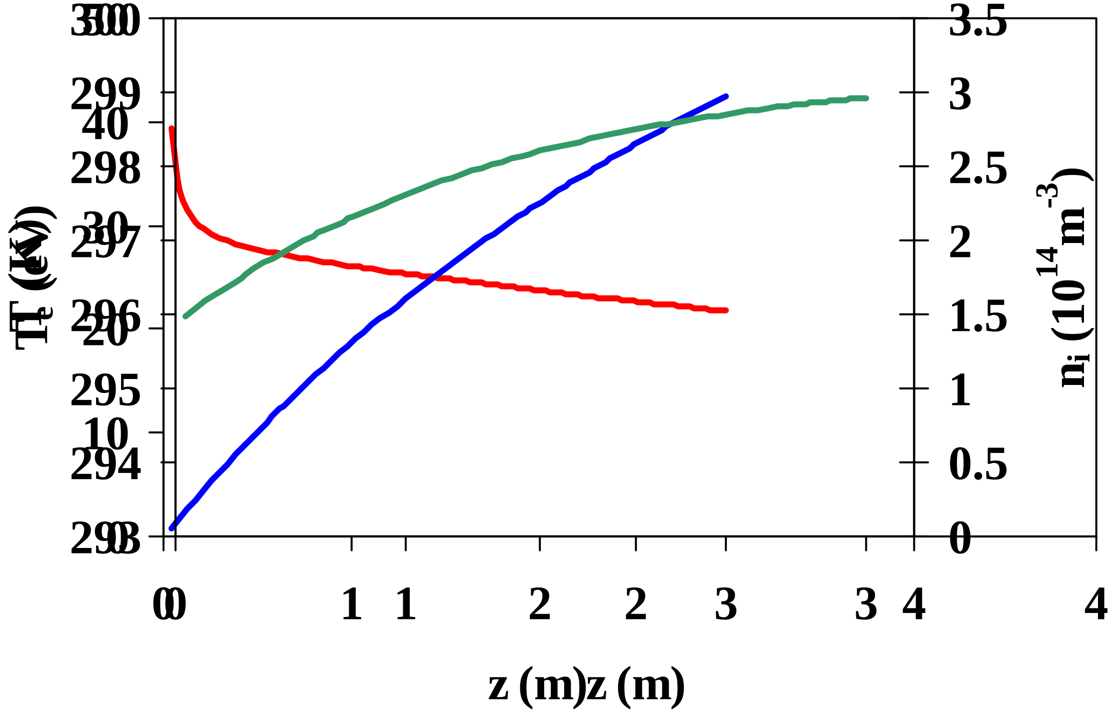
Ionisation cross sections

$\sigma_{i\bar{1}}$ $\sigma_{e\bar{1}}$

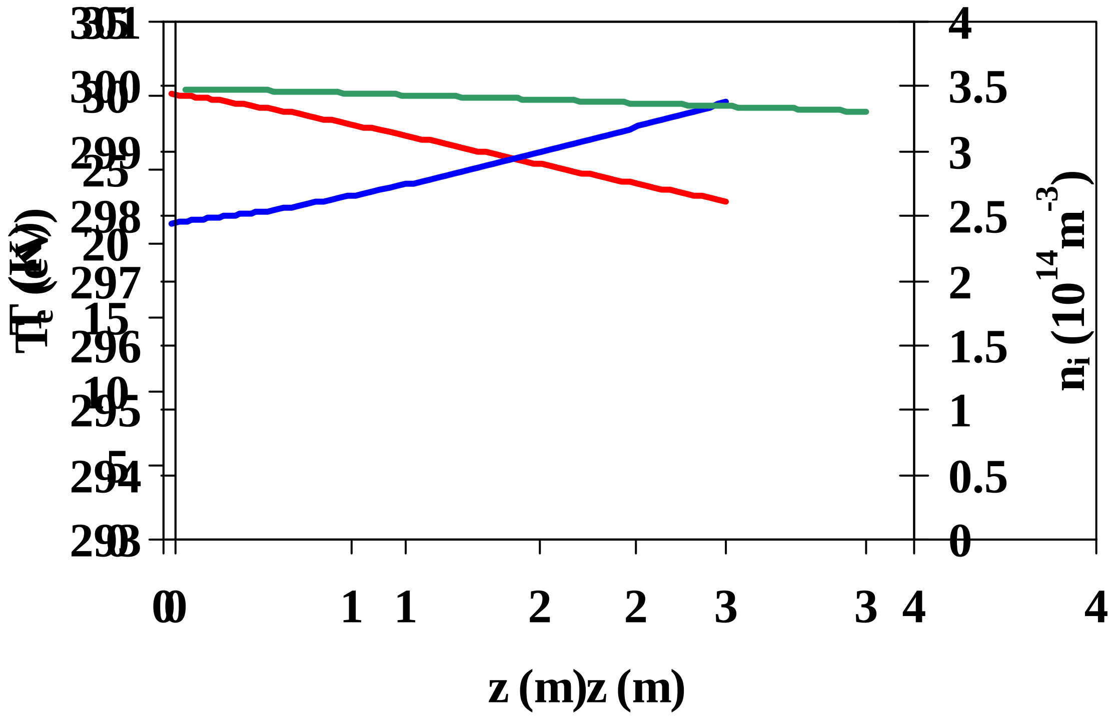
Stopping power

ε^{-}

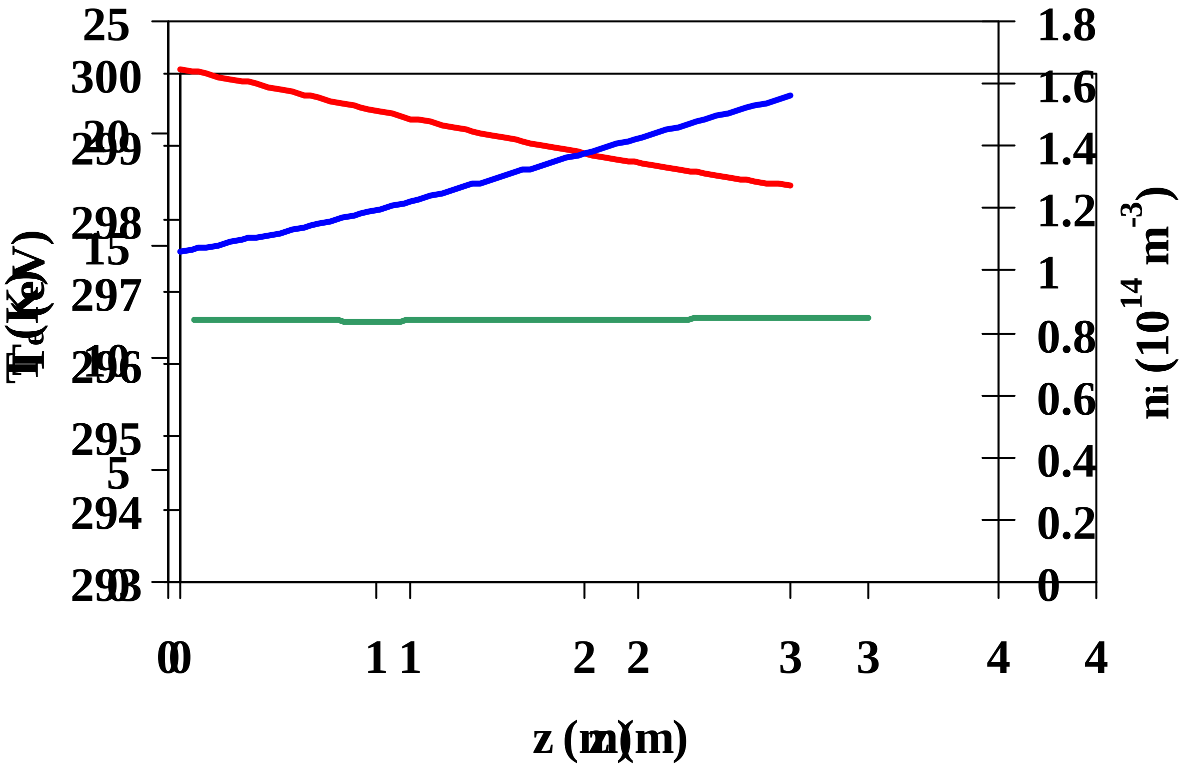
HNB 1MeV D$^-$ $\sigma_{i1}^{-}, \sigma_{e1}^{-} = 0 \quad \varepsilon^{-} = 0$



HNB 1MeV D$^-$ $\sigma_{i\bar{1}}, \sigma_{e\bar{1}} = \sigma_{i0}, \sigma_{e0}$ $\varepsilon^- = \varepsilon^0$



DNB 100keV H^- $\sigma_{i\bar{1}}, \sigma_{e\bar{1}} = \sigma_{i0}, \sigma_{e0}$ $\varepsilon^- = \varepsilon^0$



Thermalisation of Stripped Electrons I

Initial energy of stripped electrons $E_s = \frac{m_e}{m_i} E_b$

HNB E_s=272eV

DNB E_s=54.5eV

For $E_s >> T_e$ energy loss is dominated by inelastic collisions

HNB energy loss per stripped electron 31eV, T_e ~25eV

DNB energy loss per stripped electron 16.4eV, T_e~20eV

For DNB coulomb collisions will be significant and stripped electrons will be thermalised

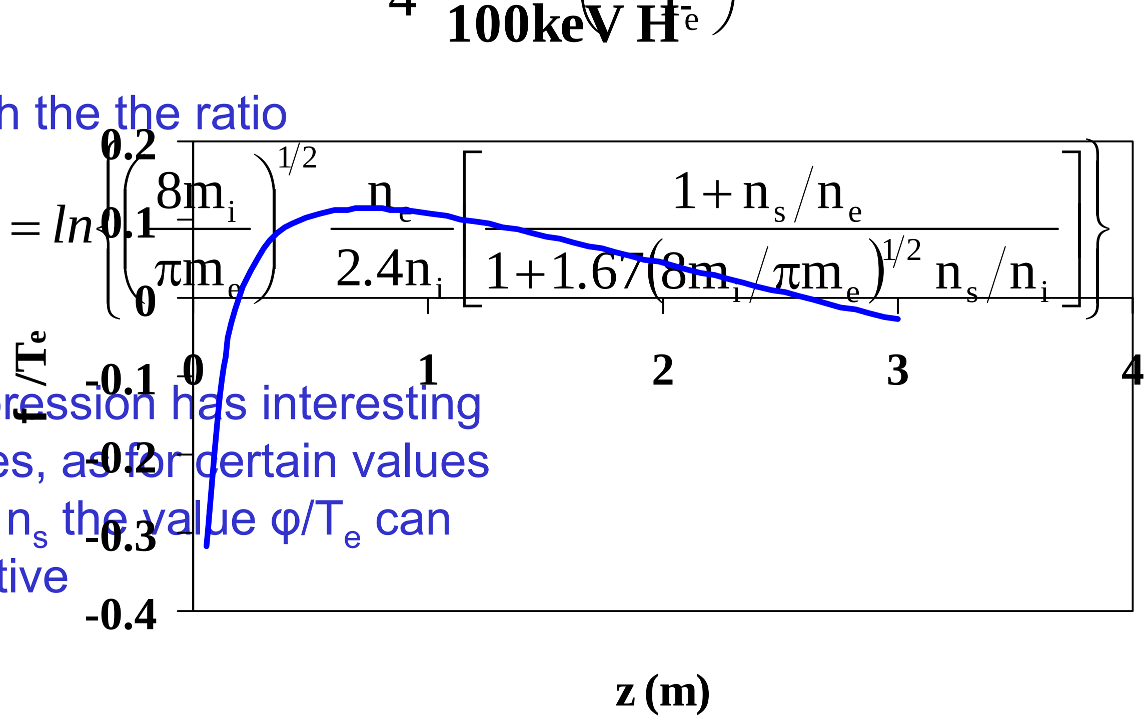
Thermalisation of Stripped Electrons II

Boundary condition

$$j_i - \frac{(j_e + j_s)}{4} exp\left(-\frac{\varphi}{T_e}\right) = j_{cx} - j_s$$

From which the the ratio

$$\frac{\varphi}{T_e} = ln\left\{\left(\frac{8m_i}{\pi m_e}\right)^{1/2} \frac{n_e}{2.4n_i}\left[\frac{1+n_s/n_e}{1+1.67(8m_i/\pi m_e)^{1/2} n_s/n_i}\right]\right\}$$



This expression has interesting properties, as for certain values of n_i, n_e, n_s the value φ/T_e can be negative

Conclusions

- Plasma density in the neutraliser is low

  Division into four channels reduces beam current per channel

- In HNB stripped electrons do not influence plasma

- In DNB conditions may give rise to negative plasma potential

- Gas heating is not expected to be severe in the ITER beams