Neutralization and Stripping in 750 keV Transport Line

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1. Neutralization

750 keV H^- beam in H_2 gas with number density n_g

σ_i = ionization cross section $\sim 5\times10^{-17}\ cm^2$

V_b = H^- velocity $\sim .04c = 1.2\times10^9$ cm/sec

n_b = H^- beam density $\sim 10^8/cm^3$

Number of e^--ion pairs formed per unit volume in time τ = $n = n_b V_b \sigma_i n_g \tau$.

Assuming all e^- ejected from beam and no recombination:

$$\tau(n=n_b) = \tau_N = \frac{1}{n_g \sigma_i V_b}$$

T=300K	P (torr)	n_g (H_2/cm^3)	τ_N (μsec)
	2×10^{-6}	2×10^{11}	100
(norm)	1×10^{-5}	10^{12}	20
	2×10^{-5}	2×10^{12}	10

2. Stripping of H^- in H_2 gas at 750 keV

σ_{-0} = cross section for $H^- \to H^0$ $\sim 7\times10^{-17}\ cm^2$

σ_{-+} = " " " $H^- \to H^+$ $\sim 4\times10^{-19}\ cm^2$ (neglect)

σ_{0+} = " " " $H^0 \to H^+$ $\sim 2\times10^{-17}\ cm^2$

$\sigma_{+0}, \sigma_{0-}, \sigma_{+-}$ negligible at 750 keV, so adequate to keep only σ_{-0} and σ_{0+}.

Decay equations for H^- beam:

Define "thickness" $\eta \equiv n_g \ell$ (H_2/cm^2)

$F^-(\eta=0) = 1$ (initial H^- beam fraction)

$$dF^-/d\eta = -\sigma_{-0} F^-$$

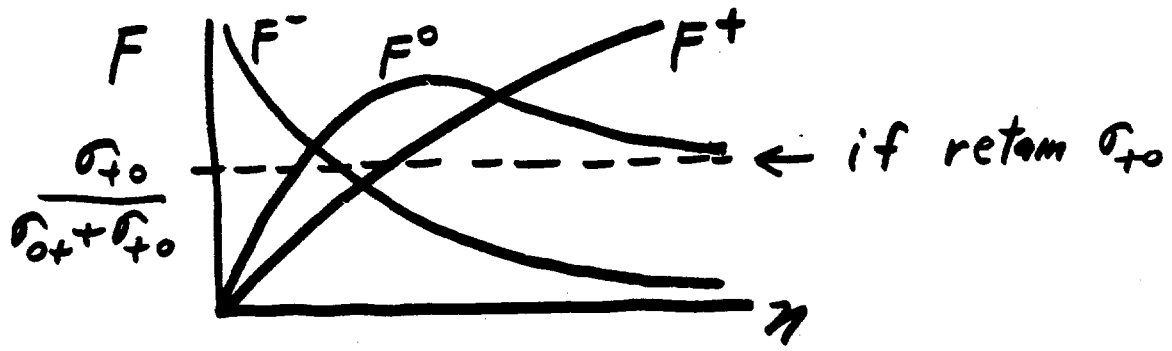
$$dF^0/d\eta = \sigma_{-0} F^- - \sigma_{0+} F^0$$

$$F^+ = 1 - F^- - F^0$$

Solution:

$$F^-(\eta) = e^{-\sigma_{-0}\eta}$$

$$F^0(\eta) = \frac{\sigma_{-0}}{\sigma_{-0} - \sigma_{0+}}\left(e^{-\sigma_{0+}\eta} - e^{-\sigma_{-0}\eta}\right)$$



For 750 keV H^- line, $\ell = 300$ cm:

P(torr)	n_g (H_2/cm^3)	τ_N (μsec)	$n_g \ell$ (H_2/cm^2)	F^-	F^0	F^+
2×10^{-6}	2×10^{11}	100	6×10^{13}	~1	~0	~0
10^{-5}	10^{12}	20	3×10^{14}	.98	.02	~0
2×10^{-5}	2×10^{12}	10	6×10^{14}	.96	.04	~0

Measure: $F^-(10^{-5}\text{torr}) \sim .97$, $F^-(2\times10^{-5}\text{torr}) \sim .93$

3. Plasma Neutralization + Stripping

A preformed plasma of density $\sim 10^8/cm^3$ in 750 keV line would provide neutralization with $\tau_N \ll 30\ \mu sec$.

Plasmas have higher H^- stripping cross sections than neutral gases:

$$\sigma_{-0}^{e} \sim 7 \times 10^{-16}\ cm^2 \quad \text{at } 750\ keV$$

$$\sigma_{-0}^{H_2} \sim 7 \times 10^{-17}\ cm^2$$

Since $n_p \sim 10^8/cm^3 \ll 10^{11}/cm^3 = n_g\ (10^{-6}\ torr)$ stripping would be due to H_2 alone:

$$F^- = e^{-(\sigma_{-0}^{e} n_p \ell + \sigma_{-0}^{H_2} n_g \ell)}$$

$$= e^{-(2\times10^{-5} + 4\times10^{-3})} \sim \underline{1}$$

With low density plasma, we get rapid beam neutralization with negligible stripping if $P(H_2) \sim 10^{-6}$ torr.