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H- stripping in the Booster proton injector line

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H⁻ STRIPPING IN THE BOOSTER PROTON INJECTION LINE

AD Booster Technical Note No. 79

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A purely electric or magnetic field in one frame of reference will appear as a mixture of electric and magnetic fields in another frame of reference if the second coordinate system is in motion relative to the first. Therefore a particle moving at velocity vthrough a magnetic field of magnitude B will experience an electric field of magnitude Egiven by the Lorentz transformation¹

$$E = \gamma v B = c \ \beta \gamma B$$
 (MKS units)

For the H⁻ injection line this electric field might cause stripping of the H⁻ ion to neutral hydrogen. The decay of H⁻ ions in an electric field can be represented by the differential equation²

$$\frac{df(t)}{dt} = -\frac{f(t)}{\tau(t)}$$

where f(t) is the fraction of the beam remaining at time t, f(t=0) = 1, and $\tau(t)$ is the average lifetime of an ion in the field E in which the ion is moving at the time t. If the magnetic field is constant along the path of the particle then τ is constant and f(t) is simply an exponential decay function.

The average lifetime of H^- ions as a function of the electric field strength has been found experimentally³ to be

$$\tau(E) = \frac{7.96 \times 10^{-6} \text{ Vs/m}}{E} \exp\left[\frac{4.256 \times 10^9 \text{ V/m}}{E}\right]$$

The H⁻ transfer line to the Booster requires that the ions bend through an angle of 126.165° (excluding the 7.5° bend at the kicker in the HEBT line and the 6.968° bend in Booster dipole magnet MDC5 through which the beam is injected). For 200 MeV H⁻ ions, $\beta = v/c$, = 0.5662 and $B\rho = 2.1496$ T-m. Therefore, since

$$BL = (B \rho) \theta$$

where θ is in radians, and *BL* is the product of the constant dipole field of the bending magnets in the H⁻ line and their total magnetic length,

$$BL = 1.1834 \text{ T} \cdot \text{m}$$

¹John David Jackson, Classical Electrodynamics, p. 380.

²K. Prelec, "Stripping of H⁻ in a Magnetic Field," AGS Division Technical Note No. 110, June 4, 1974.

³G. M. Stinson, et. al., Nucl. Instrum. Methods, 74, 333 (1964).

Physical restrictions and construction requirements suggest the use of four bending magnets of equal length, l, so L = 4l. We wish to choose a length that gives insignificant stripping.

$$\%$$
 stripped = 100 $\%$ $\left[1 - e^{-t/\tau}\right]$

where t = 4l/v and τ is calculated from the equations given above. The results are shown in the table below. Ramesh Gupta, who is specifying the design of the H⁻ injection line, has chosen the values of 1.3 m and 0.91 T for the lengths and strengths of the four dipole magnets since these values give negligible ion stripping.

l	B	au	t	% Lost
(m)	(T)	(μs)	(ns)	(%)
0.5	2.367	1.01×10^{-4}	11.78	100.00
0.6	1.972	6.97×10^{-4}	14.14	100.00
0.7	1.691	4.66×10^{-3}	16.50	97.09
0.8	1.479	3.06×10^{-2}	18.85	46.04
0.9	1.315	1.97×10^{-1}	21.21	10.20
1.0	1.183	1.26	23.57	1.86
1.1	1.076	7.92	25.92	0.33
1.2	0.986	$4.96 imes 10^1$	28.28	0.06
1.3	0.910	$3.08 imes10^2$	30.63	0.01
1.4	0.845	1.90×10^3	32.99	0.00
1.5	0.789	1.17×10^{4}	35.35	0.00
1.6	0.740	7.15×10^{4}	37.70	0.00
1.7	0.696	$4.35 imes 10^5$	40.06	0.00
1.8	0.657	$2.64 imes10^{6}$	42.42	0.00
1.9	0.623	1.60×10^{7}	44.77	0.00
2.0	0.592	$9.66 imes 10^7$	47.13	0.00