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An estimate of the critical current for the case of breakup by an arc has been previously obtained. It is the purpose of this memo to show that the same technique allows a quick estimate of the critical current in the case of no arc but using neutral and plasma breakup instead.

I. Arc Breakup

The relevant equations are:

$$n_+ = \frac{I_+}{V} - \frac{n_+^2}{2} \sigma_c v_P - n_+ n_o \sigma_{cx} v \quad (1)$$

$$n_o = \frac{N_o v_o}{4} \frac{S}{V} - \frac{n_o v_o}{4} \frac{S}{V} - n_+ n_o (\sigma_{cx} + \sigma_i) v \quad (2)$$

where the notation is the same as in ORNL-2354. Before burnout occurs, the ion density is determined only by the mean free path for charge exchange. Another way of saying this is that n_+ and the coulomb loss term in Eq. 1 are negligible until burnout sets in. Thus, by Eq. 1

$$n_+ n_o \sigma_{cx} v \approx \frac{I_+}{V} \quad (3)$$

From Eq. 2 it is also clear that n_o will be small and $n_o \approx N_o$ until the last term becomes comparable in size to either of the neutral streaming terms. This is the qualitative criterion for the onset of burnout. Thus burnout can occur when, by Eq. 2,

$$n_+ n_o (\sigma_{cx} + \sigma_i) v \approx \frac{N_o v_o}{4} \frac{S}{V} \quad (4)$$

Substituting from Eq. 3, one obtains

$$\frac{(\sigma_{cx} + \sigma_i)}{\sigma_{cx}} \frac{I_+}{V} \approx \frac{N_o v_o}{4} \frac{S}{V} \quad (5)$$

Since $I_0 = \frac{Nv_0}{4} S$, we find

$$\boxed{I_+^{\text{crit}} \approx \frac{\sigma_{cx}}{\sigma_i + \sigma_{cx}} I_0} \quad (6)$$

which is the usual result.

II. Neutral and Plasma Breakup

The relevant equations are now:

$$\dot{n}_+ = \frac{I_+}{V} \ell \sigma_{b+}^{o+} + \frac{I_+}{V} \ell \sigma_{b+}^{++} - \frac{n_+^2}{2} \sigma_c v_P - n_+ n_o \sigma_{cx} v \quad (7)$$

$$\dot{n}_o = \frac{N_0 v_0}{4} \frac{S}{V} - \frac{n_o v_0}{4} \frac{S}{V} - n_+ n_o (\sigma_{cx} + \sigma_i) v \quad (8)$$

where σ_b^{o+} is the breakup cross section for either neutrals or ions and ℓ is the total path length of the injected ion in the device. Again, until burnout occurs, coulomb scattering and ion breakup are negligible, as is $\dot{n}_+$. Hence, by Eq. 7

$$n_+ n_o \sigma_{cx} v \approx \frac{I_+}{V} \ell \sigma_{b+}^{o+} \quad (9)$$

Again, burnout occurs when, by Eq. 8,

$$n_+ n_o (\sigma_{cx} + \sigma_i) v \approx \frac{Nv_0}{4} \frac{S}{V} \quad (10)$$

Substituting from Eq. 9 into Eq. 10,

$$\frac{\sigma_{cx} + \sigma_i}{\sigma_{cx}} \frac{I_+^{\text{crit}}}{V} \ell \sigma_{b+}^{o+} \approx \frac{Nv_0}{4} \frac{S}{V}$$

or

$$I_+^{\text{crit}} = \frac{\sigma_{\text{cx}}}{\sigma_{\text{cx}} + \sigma_1} I_0 \frac{1}{n_0 \sigma_b^0 l} \quad (11)$$

Comparing Eqs. 11 and 6, one sees that the critical current is raised by the factor $(n_0 \sigma_b^0 l)^{-1}$ which is just the ratio of probability for breakup, as is expected. Even more important, the critical current for neutral breakup is pressure independent and cannot be reduced by pumping down the system.

The value of I_+^{crit} for neutral breakup at 300 kev is readily obtained. We know that $I_+^{\text{crit}} = 80 \text{ ma}$ for arc breakup at 10^{-6} mm pressure. Hence, the new value is

$$I_+^{\text{crit}} = \frac{80 \text{ ma}}{n_0 \sigma_b^0 l}$$

Now

$$n_0 = 3 \times 10^{10}$$

$$\sigma_b^0 = 10^{-17}$$

$$l = 10^3 \text{ (at best).}$$

Hence

$$I_+^{\text{crit}} = \frac{80 \text{ ma}}{3 \cdot 10^{-4}} \approx 250 \text{ amperes}$$

and this is true for all values of the pressure at 300 kev.

A final point is the influence of increased energy. The critical current is reduced because of the decrease of the ratio σ_{cx}/σ_1 and this is equally true for arc breakup and neutral breakup. It is easy to estimate the energy at which the critical current for neutral breakup can be reduced to reasonable values. Since it is 250 amps at 300 kev, we must reduce this by a factor of about 10^3 or more. Now the energy dependent terms in I^{crit} are $\sigma_{cx}/\sigma_1 \sigma_b^0$. The breakup cross section may be expected to vary in energy as σ_1 which is as $1/E$. In addition $\sigma_{cx} \sim E^{-4}$. Hence the net dependence is as E^{-2} . Thus, an increase in energy by about a factor of 30 would be required, or to about 10 Mev.