The Three Regimes of Neoclassical Diffusion

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There are three basic regimes which constitute the more general diffusion regime called neoclassical. That is, the Pfirsch-Schlüter, plateau and banana regimes. Operation of a steady state tokamak at temperatures on the order of 10-15keV and densities on the order of $10^{20}/m^3$ results in diffusion characterized by the banana regime. In this case,

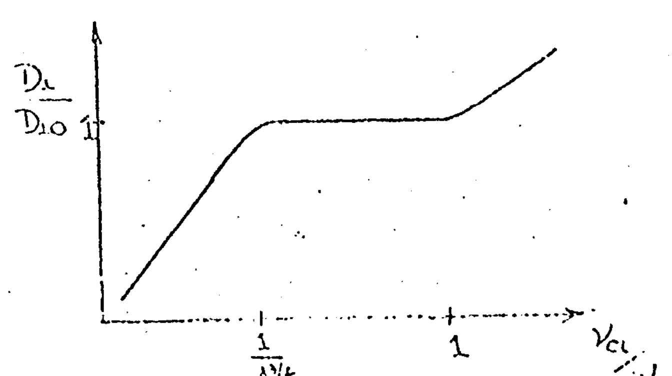
$$\tau_b \sim \frac{r_p^{\,2} B_T^{\,2}}{q^2 A^{3/2}} \frac{\sqrt{T}}{n} .$$

In other work, such as heating and ignition studies, where the temperatures and densities are, at least initially, typically lower, particle diffusion may be governed by either the plateau or Pfirsch-Schlüter regime. In these cases,

$$\tau_p \sim \frac{B_T^{\,2} r_p^{\,3} A}{q} T^{3/2}$$

$$\tau_{ps} \sim \frac{r_p^{\,2} B_T^{\,2}}{q^2} \frac{\sqrt{T}}{n} .$$

The transition between the various regimes is not clear cut. However, by using the results of Kadomtsev and Pogutse[1] temperature and density profiles which bound the three regimes can be estimated. From the schematic below,



(Ref 1)

where $D_{\perp o}$ ≡ diffusion coefficient in cylindrical system

$D_{\perp}$ ≡ diffusion coefficient in axisymmetric toroidal system

Λ ≡ aspect ratio

ν_{ei} ≡ electron-ion collision frequency

ν_2 ≡ V_{th}/qR

V_{th} ≡ electron thermal velocity

q ≡ stability margin

R ≡ major radius

it is seen that each of the three regimes exists under certain conditions, i.e.,

$$\frac{\nu_{ei}}{\nu_2} > 1 \implies \text{Pfirsch-Schlüter}$$

$$\frac{1}{\Lambda^{3/2}} < \frac{\nu_{ei}}{\nu_2} < 1 \implies \text{Plateau}$$

$$\frac{\nu_{ei}}{\nu_2} < \frac{1}{\Lambda^{3/2}} \implies \text{Banana.}$$

For the system presently being considered by the University of Wisconsin-Madison,

$\Lambda = 5$

$q = 1.5$

$R = 12.5$ meters

Assuming $ne = ni$ and $Te = Ti$, the following equations have been solved to obtain the boundary lines between the three diffusion regimes.[2]

$$v_{th} = 3.90 \times 10^{3} T^{1/2} \text{ m/sec} \qquad (T \text{ in } °k)$$

$$\Lambda = \frac{1.23 \times 10^{7} T^{3/2}}{n^{1/2}} \qquad (T \text{ in } °k) \; (n \text{ in } m^{-3})$$

$$\nu_{ei} = 3.62 \times 10^{-6} \frac{n}{T^{3/2}} \ln\Lambda \sec^{-1} \qquad (T \text{ in } °k) \; (n \text{ in } m^{-3})$$

Figure I shows the results for $q = 1.5$ and 2.5. For example, with $n = 10^{20}/m^3$ and $q = 1.5$, diffusion is governed by the Pfirsch-Schlüter regime for temperatures less than 0.46keV, the plateau regime for temperatures between 0.46-1.63keV, and the banana regime for temperatures greater than 1.63keV.

References

1. Kadomtsev B. B., Pogutse O. P., Nuclear Fusion 11 (1971) 67.

2. Tanenbaum B. S., Plasma Physics, McGraw-Hill, Inc., New York, 1967.

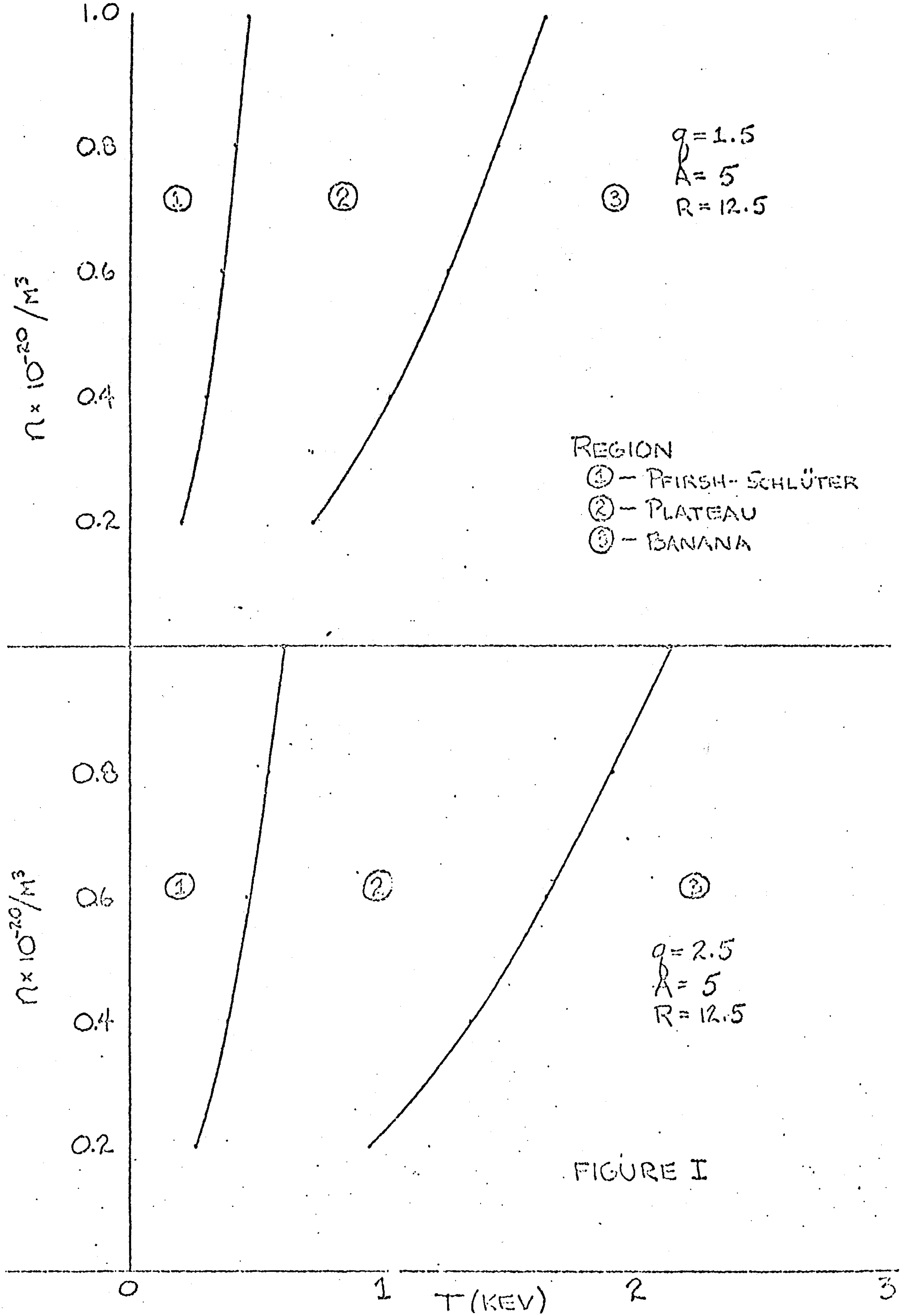

1.0
0.8
0.6
0.4
0.2
$n \times 10^{-20}/M^3$
①
②
③
q = 1.5
A = 5
R = 12.5
REGION
① – PFIRSH-SCHLÜTER
② – PLATEAU
③ – BANANA
0.8
0.6
0.4
0.2
$n \times 10^{-20}/M^3$
①
②
③
q = 2.5
A = 5
R = 12.5
0
1
2
3
T (KEV)

FIGURE I