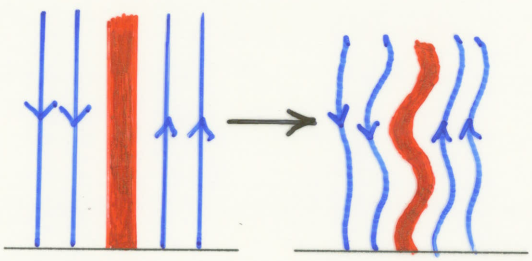
The Theory of Magnetic Reconnection

Energy Conversion: magnetic → kinetic

Two Possibilities:

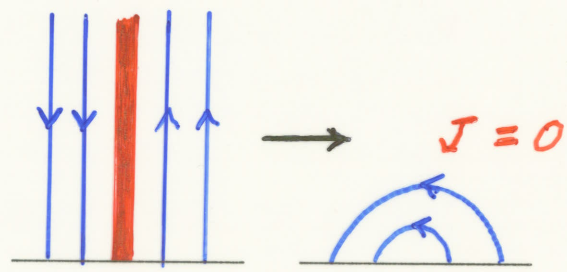
Ideal MHD

e.g. kink instability



Resistive MHD

e.g. reconnection



poor efficiency < 10 %

frozen flux constraint

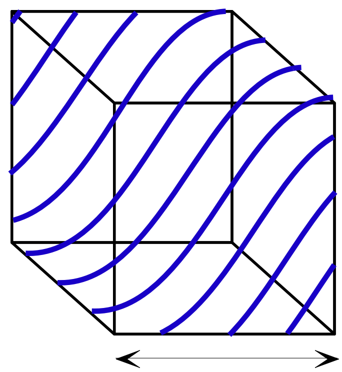
good efficiency 100 %

no topological constraints

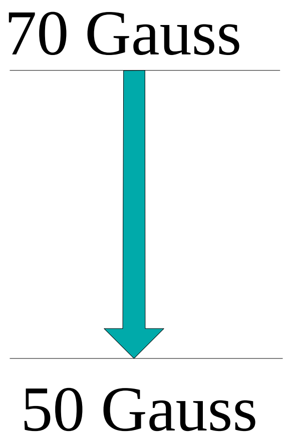
fast

slow

Reconnection Rate



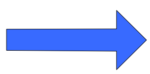
$L = 6 \times 10^4$ km



$W_B = 10^{32}$ ergs

$$\tau_d = L^2 / \eta$$

$\eta = 0.35$ m^2/s
(collisional)



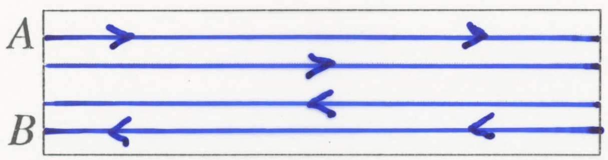
$\tau_d = 3 \times 10^8$ yrs !

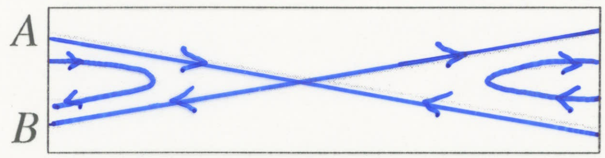
Two routes to fast reconnection:

1. Reduce scale-length L
2. Anomalous resistivity for η

Definitions

Most general definition: Change in connectivity

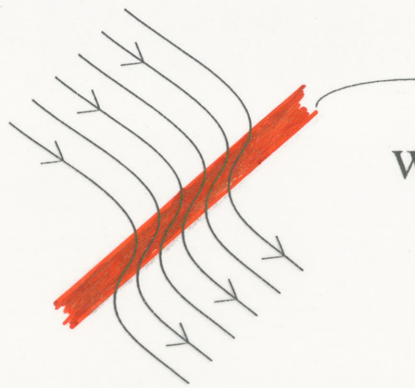




violation of frozen-flux

magnetic diffusion

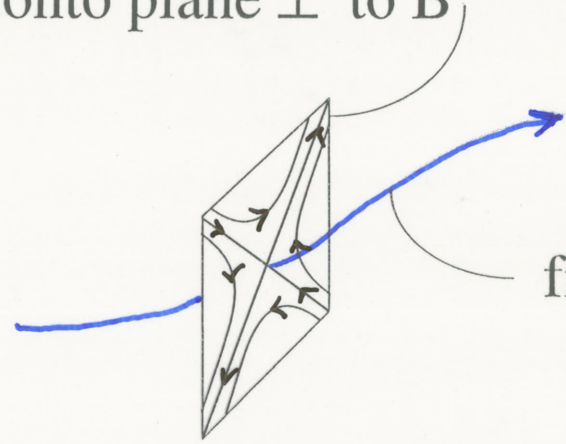
$\eta\,\mathbf{j} \neq 0$ $\mathbf{E}\cdot\mathbf{B} \neq 0$



3D shock transition with field line slippage

Restricted definition: *x*-type topology required

projection of adjacent lines onto plane ⊥ to B



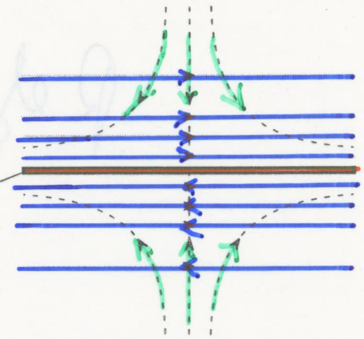
field line with $\mathbf{E}\cdot\mathbf{B} \neq 0$

Changes in Terms with Dimension

1D

merging (annihilation)

E $\neq$ 0 at neutral sheet



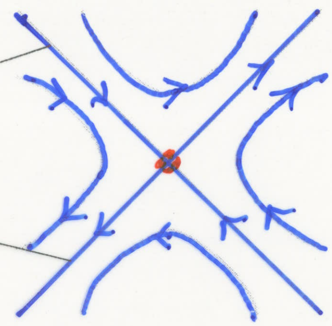
stagnation-point flow

2D

reconnection

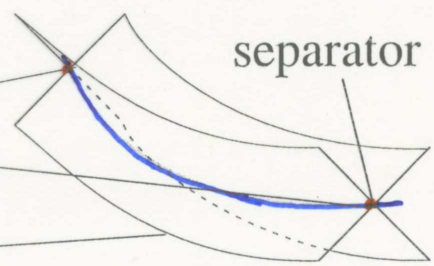
E $\neq$ 0 at *x*-line (*x*-point)

separatrix lines



3D with nulls

separator



x-point pairs

separatrix surfaces

$\mathbf{E}_{||} \neq 0$ along separator line

3D without nulls

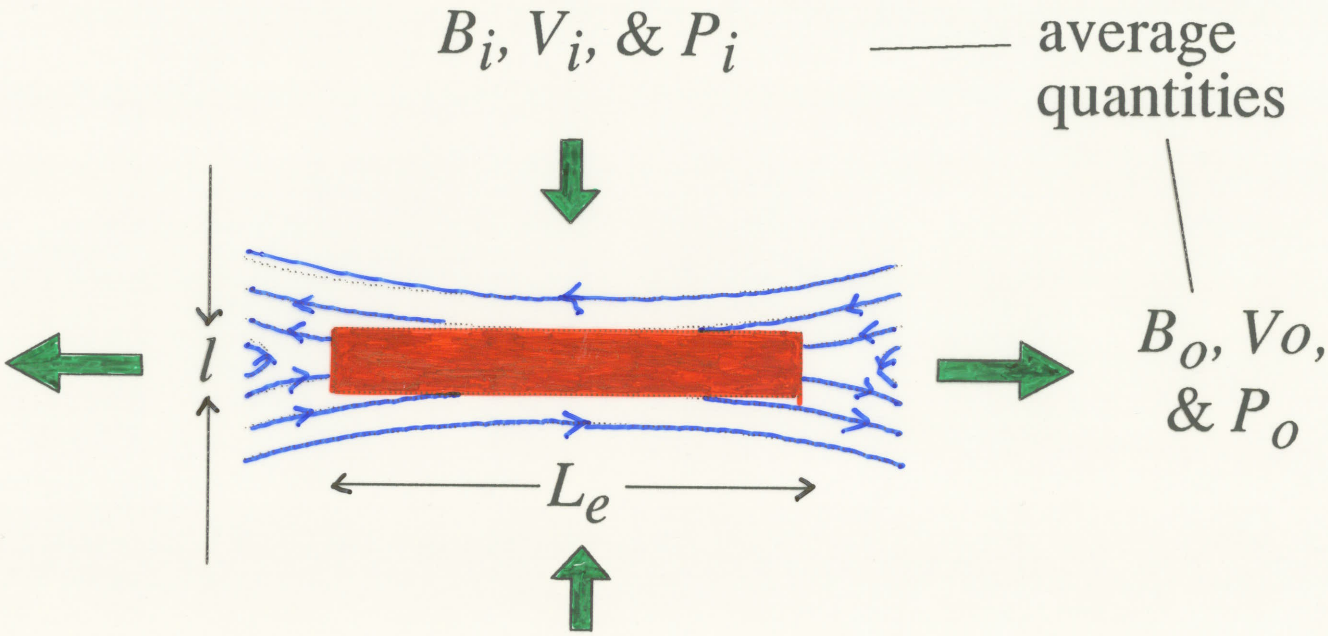
x-type topology

$E_{||} \neq 0$ in volume

separator volume

quasi-separatrix layers

Sweet - Parker Reconnection



Knowns: L_e, B_i, & P_i

Unknowns: l, B_o, P_o, V_o, & V_i

$$M_e = M_i = R_m^{-1/2}$$

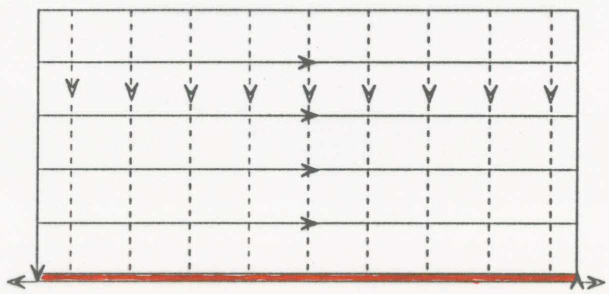
Solar corona: $M_e \approx 10^{-6}$: $t \approx 1$ year !

Slow

Steady-State Reconnection in Two-Dimensions

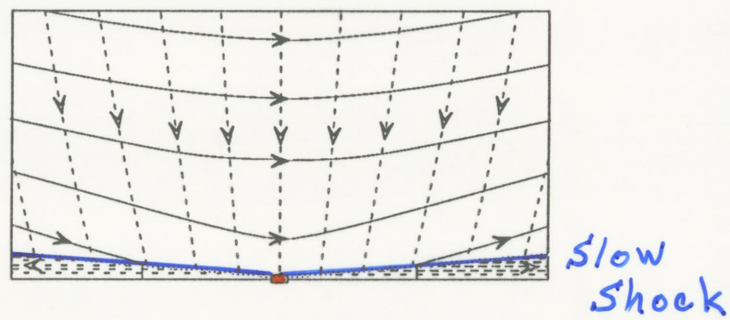
Simplest possible system
in which one can calculate a rate

Sweet-Parker



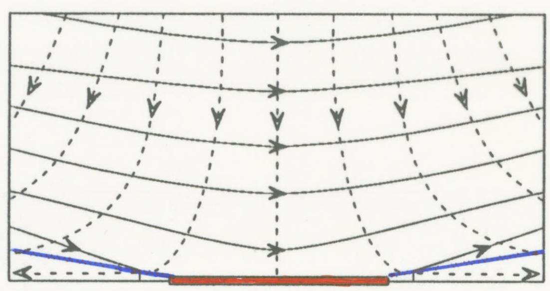
$$V_R = R_m^{-1/2} V_A$$

Petschek



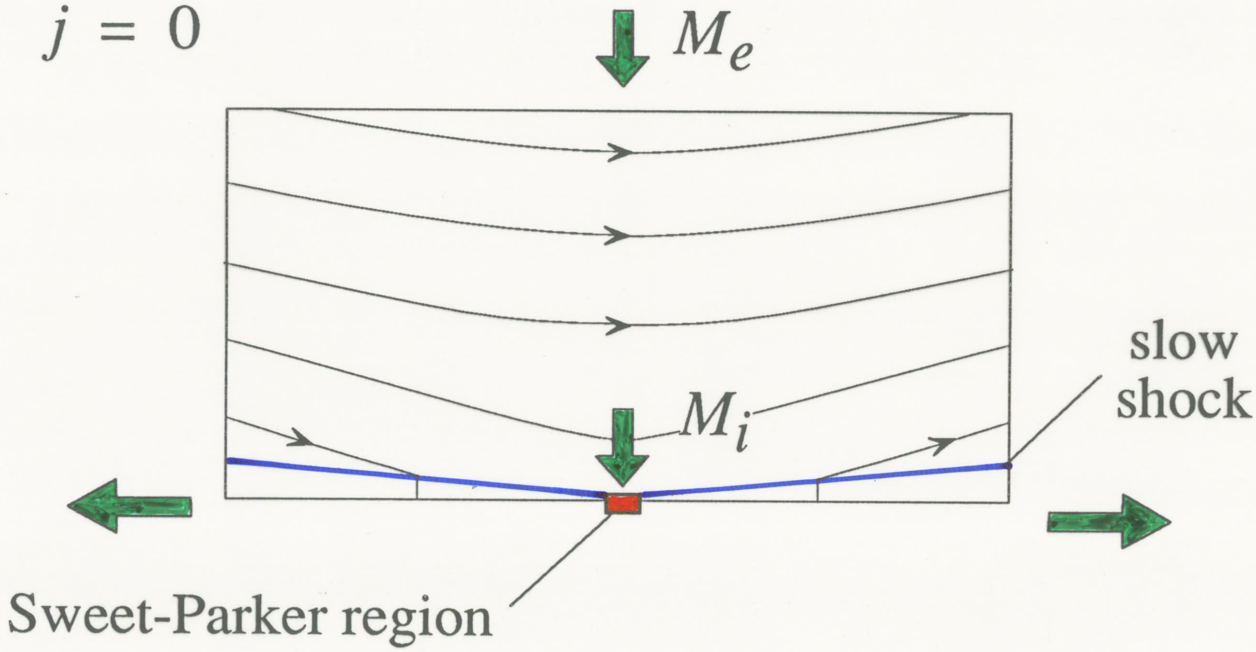
$$V_R \leq \pi / (8 \ln R_m) V_A$$

Flux-Pile-Up

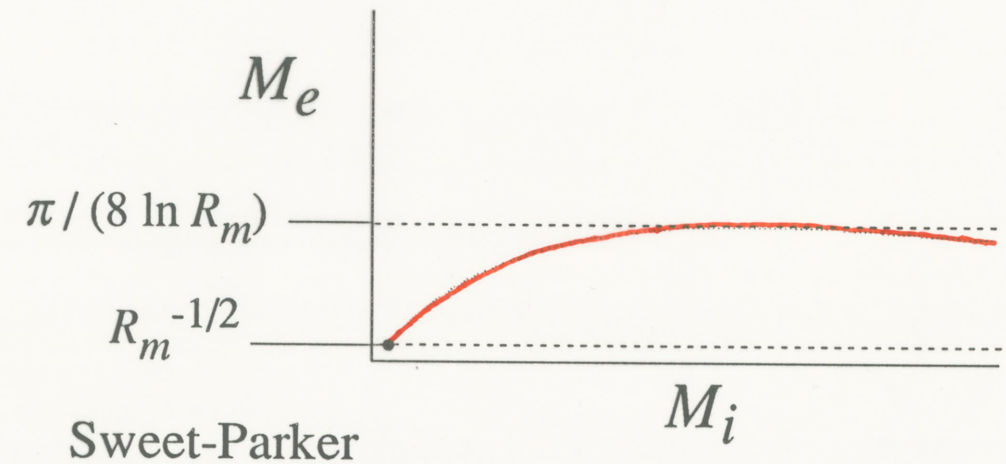


$$V_R \leq (\beta / R_m) V_A$$

Petschek's Reconnection Solution



M_e is now a known



$$R_m^{-1/2} \leq M_e \leq \pi / (8 \ln R_m)$$

Fast

10 minutes