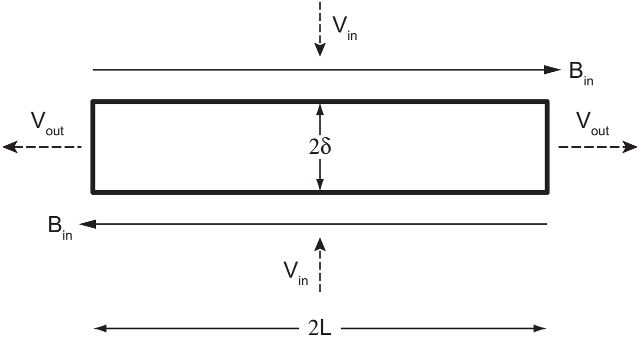
The Sweet-Parker model provides the simplest description of resistive magnetic reconnection



- Elongated current sheet of half-length L and half-width δ
- Characteristic inflow velocity V_{in} and magnetic field B_{in}
- Characteristic outflow velocity V_{out}
- Uniform density ρ and resistivity η

Assumptions of Sweet-Parker model

- Steady-state
  - Uniform out-of-plane electric field
  - Balance stuff going into sheet with stuff leaving it
- Elongated current sheet
  - Neglect kinetic energy of inflow
  - Neglect magnetic energy of outflow
- Resistive electric field important only inside current sheet
- For scaling, ignore pressure effects/thermal energy
- Ignore 3D effects
- Don't worry about factors of order unity (e.g., $2 \approx 1$)

Deriving the Sweet-Parker model

- Conservation of mass: mass flux in equals mass flux out

$$LV_{in} \sim \delta V_{out} \tag{1}$$

- Conservation of energy (magnetic energy flux in equals kinetic energy flux out)

$$LV_{in} \left(\frac{B_{in}^2}{8\pi} \right) \sim \delta V_{out} \left(\frac{\rho V_{out}^2}{2} \right) \tag{2}$$

- Combining these two equations shows that the outflow scales with the upstream Alfvén speed

$$V_{out} \sim V_A \equiv \frac{B_{in}}{\sqrt{4\pi\rho}} \tag{3}$$

Finding the current density and inflow velocity

- The ideal electric field outside the layer balances the resistive electric field inside the layer

$$\frac{V_{in} B_{in}}{c} \sim \eta J \tag{4}$$

- We find the current from Ampere's law: $\mathbf{J} = \frac{c}{4\pi} \nabla \times \mathbf{B}$

$$J \sim \frac{c}{4\pi} \frac{B_{in}}{\delta} \tag{5}$$

- Inflow occurs at a rate which is balanced by resistive diffusion

$$V_{in} \sim \frac{D_\eta}{\delta} \tag{6}$$

where $D_\eta \equiv \frac{\eta c^2}{4\pi}$ is in units of length^2 time^{-1}

How does the Sweet-Parker reconnection rate scale with Lundquist number?

- The dimensionless reconnection rate scales as

$$\frac{V_{in}}{V_A} \sim \frac{1}{S^{1/2}} \tag{7}$$

  where the Lundquist number is the ratio of a resistive diffusion time scale to an Alfvén wave crossing time scale

$$S \equiv \frac{L V_A}{D_\eta} = \frac{\tau_{res}}{\tau_{Alf}} \tag{8}$$

- In astrophysics, the Lundquist number is huge
  - S is typically somewhere between 10^9 and 10^{20}

The Sweet-Parker model predicts reconnection rates much slow than observed in solar flares and space/lab plasmas

- Solar flares occur on timescales of tens of seconds to tens of minutes whereas the Sweet-Parker model predicts times of months
- Many of the Sweet-Parker approximations are not well justified
- Sweet-Parker-like current sheets are unstable to the *plasmoid instability* above a critical Lundquist number of $S_c \sim 10^4$
  - The Sweet-Parker model does not describe astrophysical reconnection!
- How do we explain reconnection that is fast in the limit of low resistivity?

Fast reconnection through anomalous resistivity?

- Thus far, we've calculated the Lundquist number based on Spitzer resistivity
- What if there are other mechanisms that generate a higher effective resistivity?
  - Kinetic instabilities, wave-particle interactions, microturbulence
- Often an *ad hoc* function of current density or position in theory and simulations
  - But what would cause an anomalous resistivity enhancement?
- Laboratory experiments provide support against several mechanisms