Lecture notes

"sun-planet connections"

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Chap. 1 Introduction

Magnetic field in electrically conductive medium (fluid, gas)

Electric field

$$\vec{E} = \underbrace{-\vec{V}\times\vec{B}}_{\text{convective}} + \underbrace{\frac{1}{\sigma}\vec{j}}_{\text{Ohmic}} \qquad \cdots (1)$$

$$= -\vec{V}\times\vec{B} + \frac{1}{\mu_0\sigma}\nabla\times\vec{B} \qquad \cdots (2)$$

(Ampère's law)

Induction eq.

$$\partial_t \vec{B} = -\nabla\times\vec{E} \qquad \cdots (3)$$

Combine (2) and (3) and $\nabla\cdot\vec{B} = 0$

↳

$$\underbrace{\partial_t \vec{B}}_{\substack{\text{Evolution of} \\ \text{mag. field}}} = \underbrace{\nabla\times(\vec{V}\times\vec{B})}_{\text{(A) frozen-in}} + \underbrace{\frac{1}{\mu_0\sigma}\nabla^2\vec{B}}_{\text{(B) diffusion}} \qquad \cdots (4)$$

(A) Frozen-in magnetic field

Magnetic field moves with flow/medium.

(B) Diffusion

Magnetic field becomes weaker.

Space plasma … collisionless, conductive medium.
Conductivity σ very large.

↘ Frozen-in magnetic field

Consequences

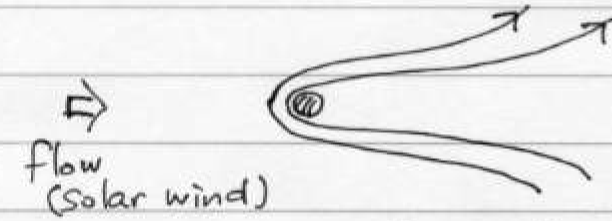
(1) Magnetic field moves with flow
(e.g. solar wind)

(2) Different media cannot be mixed.

↘ Formation of boundaries
(e.g. magnetopause)

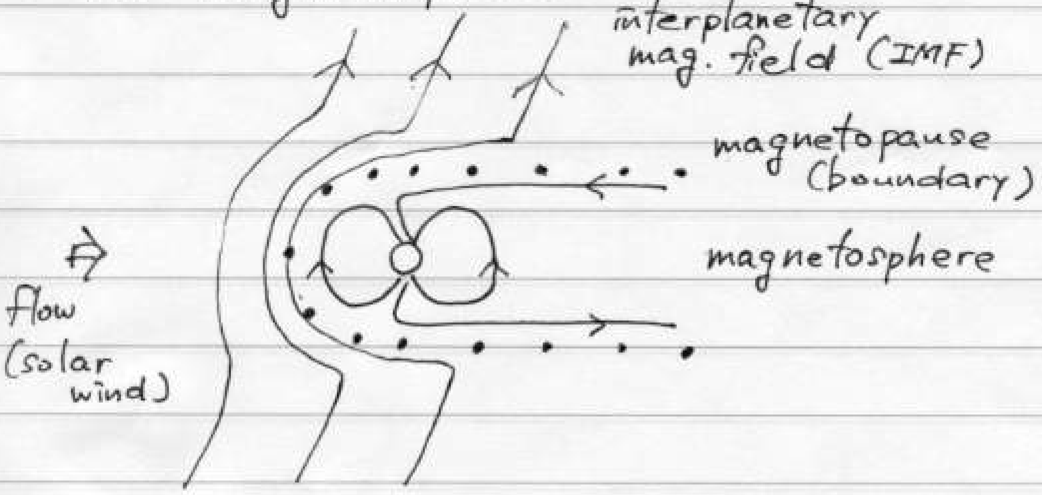
Applications

(1) Comet tail (Alfvén's idea, 1957)



curved magnetic field

(2) Magnetosphere



How large is magnetosphere?

Pressure balance

$$\frac{1}{2}\rho V^2 = \frac{B^2}{2\mu_0} \qquad \ldots (5)$$

dynamic pressure (kinetic energy density) — magnetic pressure (mag. energy density)

solar wind — planet

Dipole magnetic field (for planet)

$$B \propto \frac{1}{r^3}$$

$$\rightsquigarrow \quad \frac{B}{B_{surf}} = \left(\frac{R_{surf}}{R_{mp}} \right)^3 \qquad \ldots (6)$$

Combine (5) and (6)

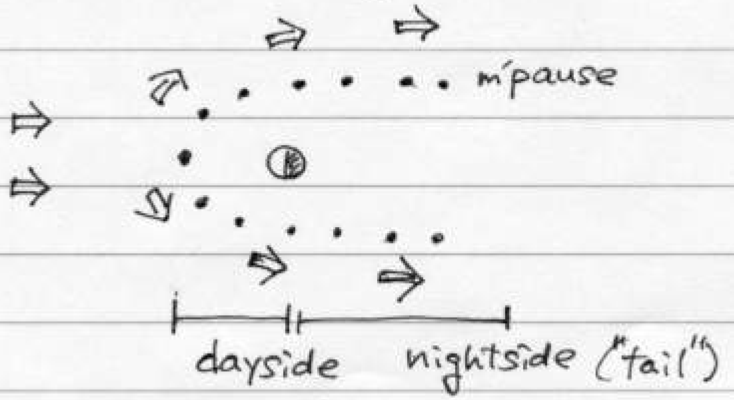
$$\rightsquigarrow \quad \frac{R_{mp}}{R_{surf}} = \left(\frac{B_{surf}^2}{\mu_0 \rho V^2} \right)^{1/6} \qquad \ldots (7)$$

Classification of planets

	$R_{mp} > R_{surf}$	$R_{mp} < R_{surf}$
Solid Surface	Mercury	Earth Moon
gas surface (atmosphere)	Earth Jupiter, Saturn Uranus, Neptune	Venus, Mars

Chap. 2 Earth (static picture)

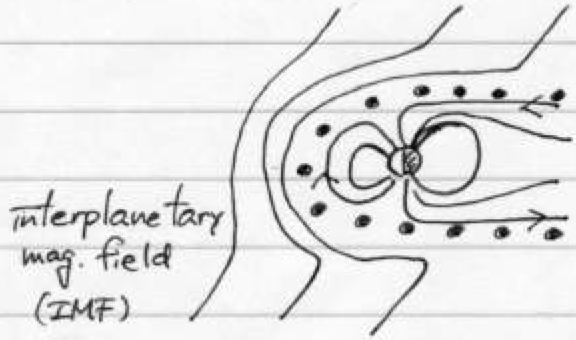
- Flow around magnetosphere



Surface mag. field 30 000 nT

Magnetopause distance ··· 10 ~ 11 R_E (dayside)

- Magnetic field

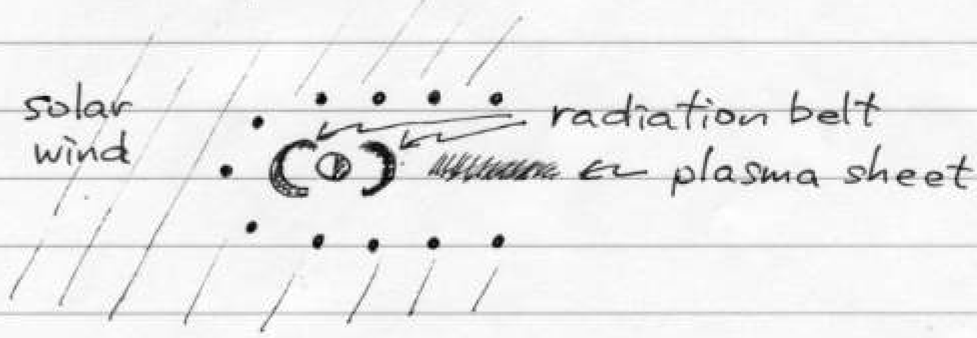


solar wind ··· curved mag. field

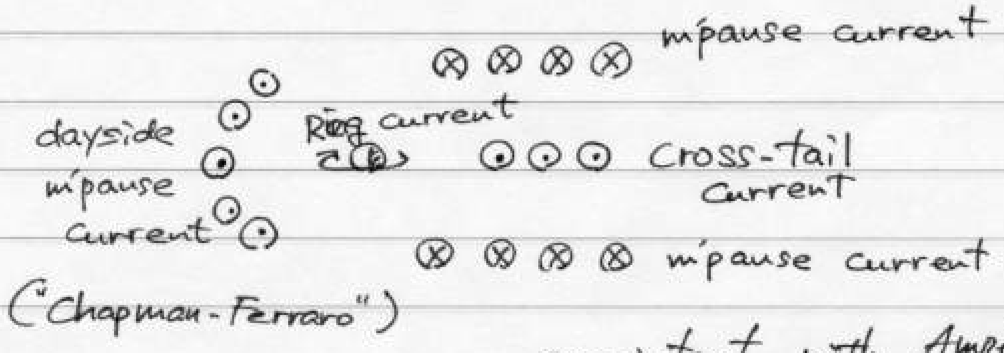
dayside magnetosphere ··· dipolar field

nightside ··· elongated / stretched field

- Plasma populations



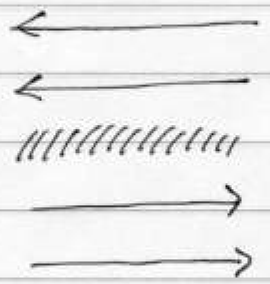
- Electric current



consistent with Ampère's law

$\vec{j} = \frac{1}{\mu_0} \nabla \times \vec{B}$

- Pressure balance in tail



pressure

lobe (north) ... magnetic

plasma sheet ... thermal

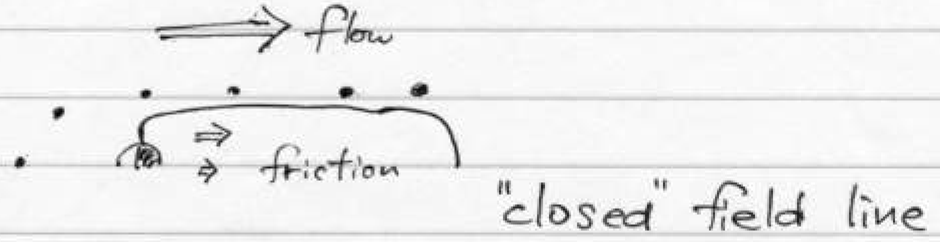
lobe (south) ... magnetic

$$\underset{\text{plasma sheet}}{P_{th}} = \underset{\text{lobe}}{P_{mag}}$$

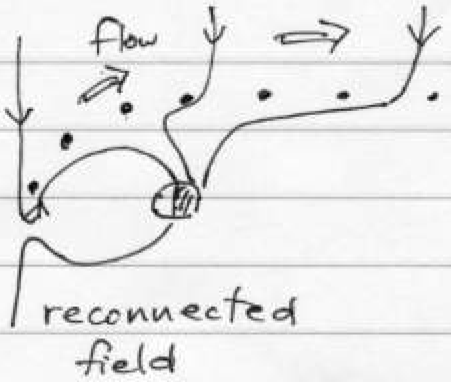
- Why is tail-field stretched?

possibility 1 ... viscosity/friction

(Axford and Hines, 1961)

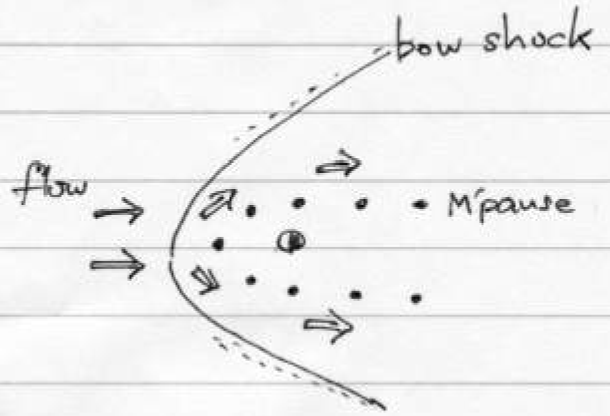


possibility 2 … reconnection (Dungey 1961)



"open" field line

- bow shock



- standing shock wave
- m'sphere as obstacle
- flow speed changes from super-magnetosonic to sub-magnetosonic

cf. magnetosonic speed
$V \sim \sqrt{V_A^2 + C_s^2}$

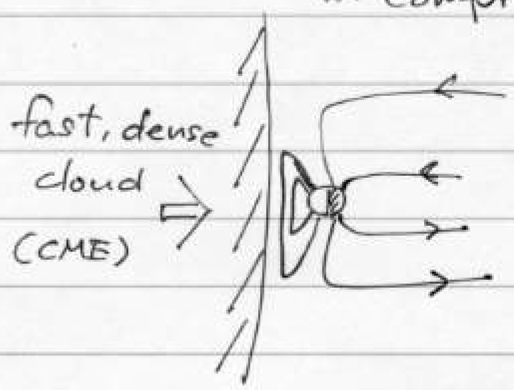
- plasma is
(1) compressed, (2) heated

- magnetic field also compressed

Chap. 3 Earth (dynamic picture)

Geomagnetic storm

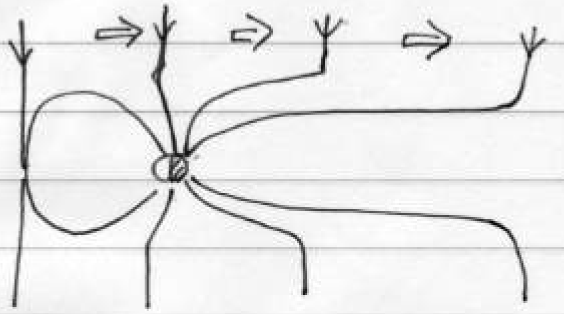
... compression of magnetosphere (Chapman, 1930)



1. dayside compression ~ minutes
2. nightside compression ~ hours
3. recovery phase (expansion) ~ days

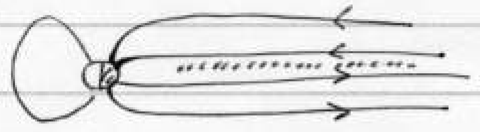
Substorm (reconnection model)

1. growth phase (T ~ 40 min.)



- magnetic field transport from dayside to tail (energy charge in tail)
- reconnection on dayside (southward IMF)

2. expansion phase (T ~ 10 min.)



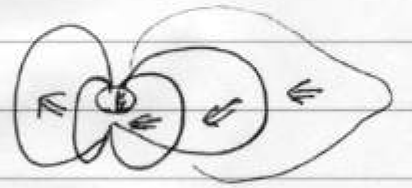
thin current sheet
anti-parallel mag. field

⇩ tail reconnection (energy discharge)

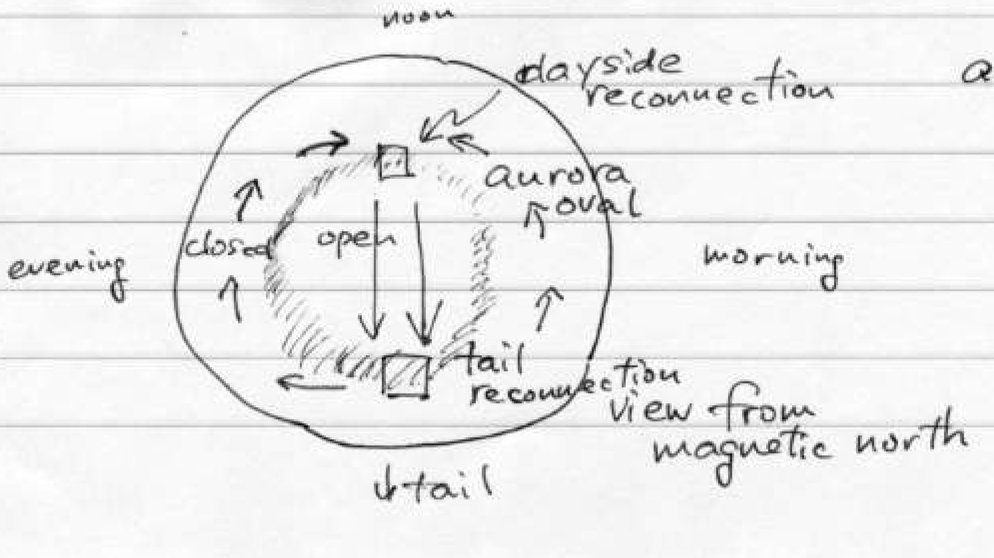
- "dipolarization"
- plasma jet ("plasmoid")
- field-aligned current
  into/out of ionosphere
  → bright aurora

3. recovery phase (T ~ hours)

- magnetic field transport
  back to dayside



<u>ionospheric convection pattern</u> (southward IMF)



auroral oval
... open/close
boundary