Lecture notes

"sun-planet connections"

given at MPS

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Magnetic field in electrically conductive medium (fluid, gas)

Electric field

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

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

(Ampère's law)

Induction eq.

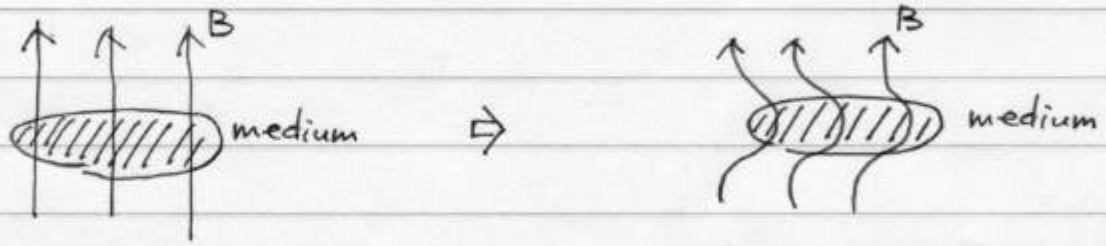
$$\partial_t \vec{B} = -\nabla\times\vec{E} \qquad \dots (3)$$

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

↘

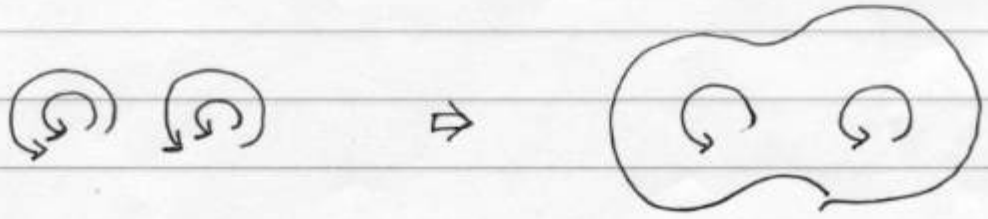
$$\underbrace{\partial_t \vec{B}}_{\text{Evolution of mag. field}} = \underbrace{\nabla\times(\vec{V}\times\vec{B})}_{\text{(A) frozen-in}} + \underbrace{\frac{1}{\mu_0\sigma}\nabla^2\vec{B}}_{\text{(B) diffusion}} \qquad \dots (4)$$

(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

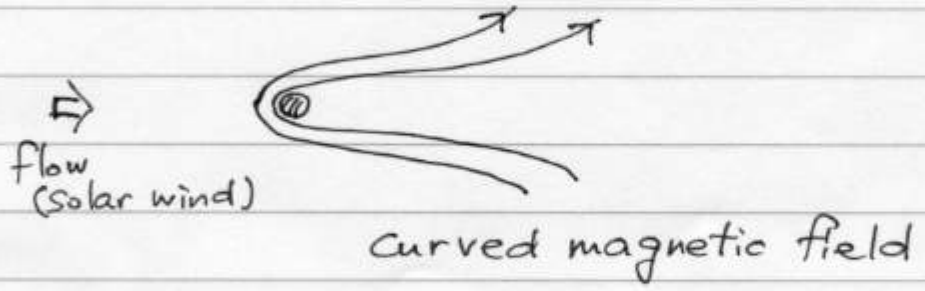
(1) Magnetic field moves with flow
(e.g. solar wind)

(2) Different media cannot be mixed.

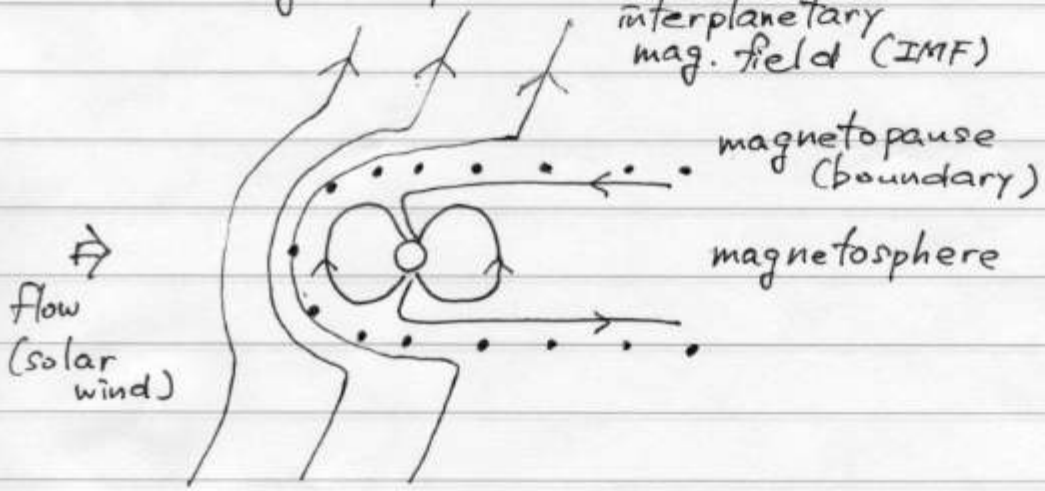
↘ Formation of boundaries
(e.g. magnetopause)

Applications

(1) Comet tail (Alfvén's idea, 1957)



(2) Magnetosphere



How large is magnetosphere ?

Pressure balance

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

dynamic pressure	magnetic pressure
(kinetic energy density)	(mag. energy density)
solar wind	planet

Dipole magnetic field (for planet)

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

$$\therefore \frac{B}{B_{surf}} = \left(\frac{R_{surf}}{R_{mp}}\right)^3 \quad \cdots (6)$$

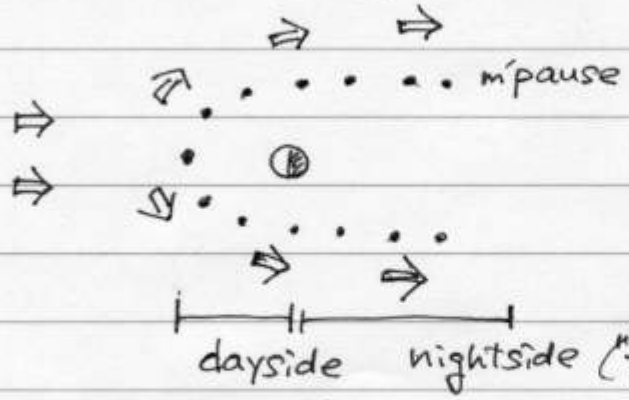
Combine (5) and (6)

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

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

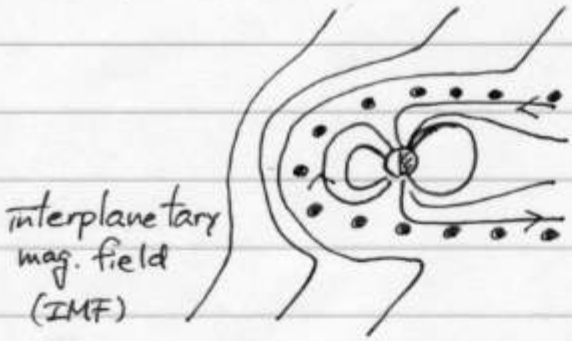
- Flow around magnetosphere



Surface mag. field 30 000 nT

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

- Magnetic field



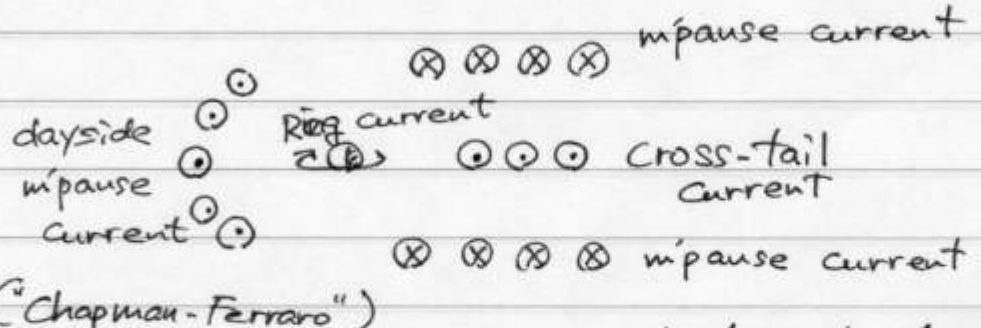
solar wind ... curved mag. field

dayside magnetosphere
... dipolar field

nightside ... elongated / stretched field

- Plasma populations

• Electric current

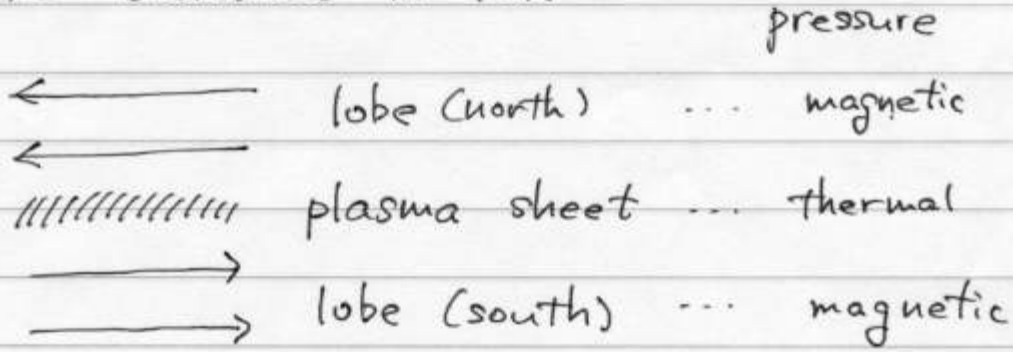


("Chapman-Ferraro")

consistent with Ampère's law

~~[illegible]~~ $\vec{j} = \frac{1}{\mu_0} \nabla \times \vec{B}$

• Pressure balance in tail

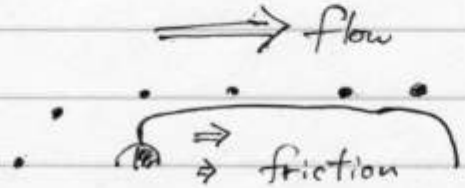


P_{th} (plasma sheet) = P_{mag} (lobe)

• Why is tail-field stretched?

possibility 1 ... viscosity / friction

(Axford and Hines, 1961)



"closed" field line