Interhemispheric Dynamos and Poynting Flux

Stephan C. Buchert, Swedish Institute of Space Physics

CEDAR 2020 Workshop: Poynting Flux

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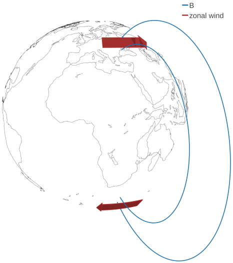
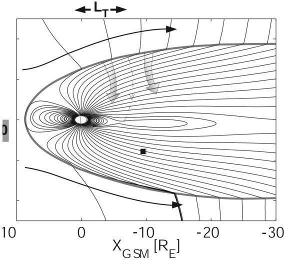


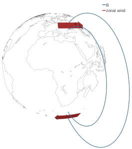


Rosenqvist et al., 2006

- I/the audience? perhaps understand Joule/frictional heating at high latitudes:

1. the plasma in space, above the ionosphere, needs to move/convect:
2. causes are magnetosheath flow, magnetic reconnection, pressure gradients, . . .
3. the plasma short-cuts $E_{\|} \neq 0$ (electric potential non-const along $\vec{B}$);
4. in the ionosphere this forces the plasma to move relative to the neutral gas, causing
5. $\rightarrow$ frictional heating,
6. $\rightarrow -\nabla \cdot \vec{S} = \vec{E}_{\perp} \times \delta\vec{B}/\mu_0 = \vec{J} \cdot \vec{E} > 0$,
7. i.e. EM power is dissipated.

But how does a neutral dynamo (e.g. at mid-latitudes) work?



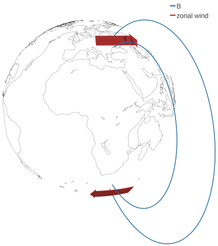
- according to Ohm's law:
- if in the reference frame of the neutral gas $\vec{E}^* \neq 0$, then $\vec{J} \cdot \vec{E}^* > 0$;
- for a dynamo $\vec{J} \cdot \vec{E} < 0$ is needed!
- Hmm, textbooks/articles state that in another reference frame there is a neutral wind $\vec{u} \neq 0$ and possibly $\vec{J} \cdot \vec{E} = \vec{J} \cdot \left(\vec{E}^* + \vec{u} \times \vec{B} \right) < 0$?
- but the choice of the describing reference frame should not effect processes in the thermosphere?
- and which reference frame (Earth, sun-aligned, star-aligned, ...) would be the correct one?

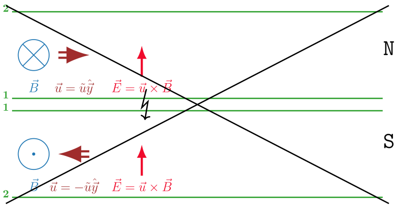
Answer:

- $\vec{E}^*$, $\vec{E}^* \times \vec{B}$ only in the frame of the neutral gas are relevant!
- But the neutral gas can define many different reference frames...

The most simple scenario considers zonal winds at conjugate points

(assuming a thin ionosphere, perfectly centered dipole $\vec{B}$, no meridional winds, ...)





- For $u_N \neq u_S$ $\vec{u} \times \vec{B}$ does not map between N and S!
- $\rightarrow$ the plasma has to move relative to the neutral gas,
- equivalently $\vec{E}^* \neq 0$ in the neutral gas frames!

- the condition $E_{\|} = 0$ translates to

$$\vec{E}^* (z) + \vec{u} (z) \times \vec{B} (z) = const \tag{1}$$

  z a field-aligned coordinate, or

$$E_N^* = E_S^* + \Delta u B, \text{with } \Delta u = u_N - u_S \tag{2}$$

  for the non-mapping zonal winds.
- $\nabla \cdot \vec{j} = 0$ and Ohm's law give the 2^{nd} condition:

$$\int \vec{j}_\perp (z)\, dz = \int \sigma_P (z)\, \vec{E}^* (z)\, dz = 0 \tag{3}$$

  or

$$\Sigma_N E_N^* + \Sigma_S E_S^* = 0 \tag{4}$$

  with $\Sigma_{N,S}$ the Pedersen conductances in N and S.

the solutions of (2) and (4) are:

$$E_S^* = -\frac{\Sigma_N}{\Sigma_N + \Sigma_S}\Delta u B = -\frac{\Sigma_N}{\Sigma_S}E_N^* \tag{5}$$

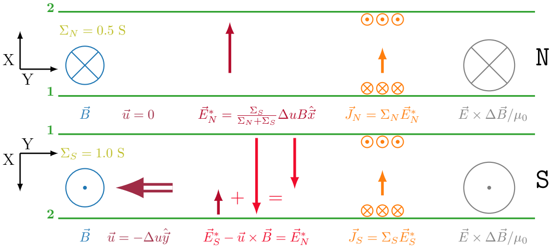
and

$$J = \frac{\Sigma_N \Sigma_S}{\Sigma_N + \Sigma_S}\Delta u B \tag{6}$$

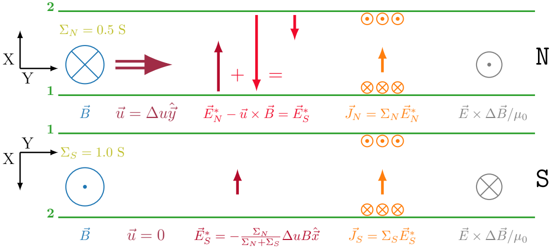
- pse see also the open discussion of `https://angeo.copernicus.org/preprints/angeo-2019-71/#discussion`.

Same scena, different reference frames

Reference frame neutral gas at N:



Reference frame neutral gas at S:



Same scene, different reference frames

Reference neutral gas at N:

- at N:
  - JH (of course)

    $$Q_N = \Sigma_N \left(\frac{\Sigma_S}{\Sigma_N + \Sigma_S} \Delta u B \right)^2$$

  - Poynting flux $E \times \delta B = E_N \times \delta B$ is into the ionosphere!
- at S:
  - $J \cdot E = J \cdot (E_S - \Delta u B) = -Q_N < 0$, dynamo!
  - $E \times B = (E_S - \Delta u B) \times B$ is out of the ionosphere!

Reference neutral gas at S:

- at N:
  - $J \cdot E = J \cdot (E_N - \Delta u B) = -Q_S < 0$, dynamo!
  - $E \times B = (E_N - \Delta u B) \times B$ is out of the ionosphere!
- at S:
  - JH (of course)

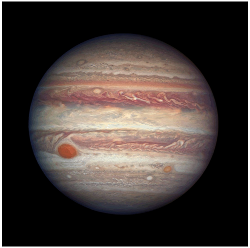
    $$Q_S = \Sigma_N \left(\frac{\Sigma_S}{\Sigma_N + \Sigma_S} \Delta u B \right)^2$$

  - Poynting flux $E \times \delta B = E_S \times \delta B$ is into the ionosphere!

- by switching between different reference frames we can see that
  - JH takes place at N;
  - the corresponding dynamo is at S,
  - with Poynting flux out of S and into N.

  and
  - JH takes place at S;
  - the corresponding dynamo is at N,
  - with Poynting flux out of N and into S.
- for reference frames other than the neutral gas in either N or S $J \cdot E$ and $E \times B/\mu_0$ have arbitrary values/directions,
- I cannot see the physical meaning of $J \cdot E$ and $E \times B/\mu_0$ for such frames.

Generalization and Conclusions



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- the notion that a neutral wind $\vec{u} \neq 0$ per se constitutes a dynamo, eg. Chapman (1924), is not correct;
- only a non-constant $\vec{u}(z) \times \vec{B}(z)$, z field-aligned has a dynamo effect;
- a wind field can have a complicated structure, vortices, etc.
- if, for a dipolar centered $\vec{B}$, the wind field is mirror-symmetric with respect to the magnetic equator, there is no EM dynamo;
- the interhemispheric "entangled" dynamos and $j \times B$ forces act to establish such mirror symmetry;
- the Earth's Sq variations are basically explained by this process;
- the mirror symmetry is practically never achieved, mainly because of the angular misalignment between magnetic dipole and rotation axes.

Conclusions regarding Poynting flux

- Poynting flux is commonly defined in plasma, geo- and space physics including the "motional field" $\vec{v} \times \vec{B}$;
- it is therefore a frame dependent vector;
- on closed field-lines the neutral gases at both conjugate points are meaningful reference frames;
- use of other reference frames (incl. Earth-fixed) have an unclear physical meaning;