Thomas Collins

Physics 712/812
Instructors
W. D. Cramer/H. Kucharek

Final Exam

Spring 2020

This is a Take-Home Exam. You are allowed to use the lecture notes of this course, your own notes, and the course book(s). It is very important that you write down all your explanations and arguments. You will still earn partial credit if your arguments are correct, but your equations are not.

You sign here to indicate that you did not give, or receive any help from others:

Due date/time: May 7th at 5pm

Introduction to Space Plasma Physics, Phys 712/812

1) Types of Solar Wind: **(5 points)**

Fast solar wind:

a) What types of regions on the sun are the source of the fast wind?

Fast streams originate at coronal holes, located at the poles.

b) What is the magnetic field line configuration in these regions?

Fast solar wind yeilds open field line configurations.

c) Where are the regions mainly located during solar minimum?

During solar min, these regions are more prevalently located at the polar holes.

Slow solar wind:

a) What is the typical density of the slow solar wind?

The slow solar wind is typically twice as dense as the fast solar wind. Density: 7-8.7 protons cm^{-3} at Earth (1AU)

b) What is the topology of the magnetic field lines in regions where the slow solar wind is emitted?

Slow streams originate at streamers, located at the equator.

c) Where are these regions mainly located during solar minimum?

During solar min, these regions are mainly located at the streamer belt.

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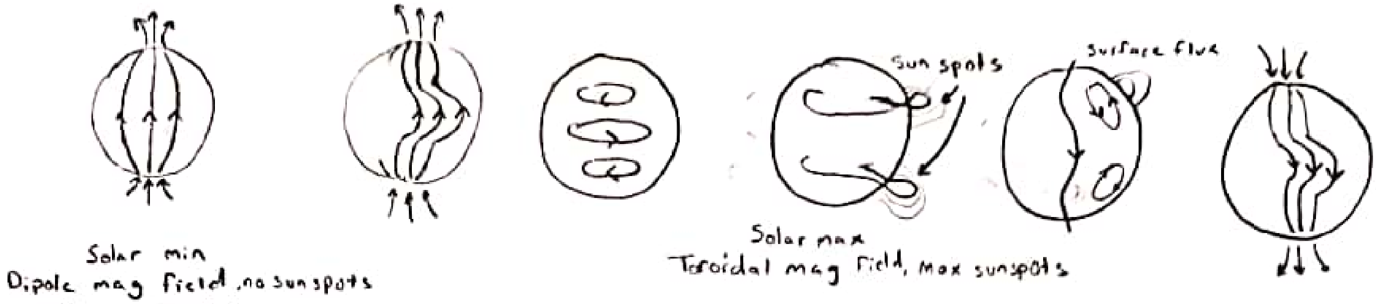
2) Solar Magnetic Field: **(5 points)**

a) Describe in sketches and words how the solar magnetic field changes during a solar cycle.



b) Explain why sunspots come in pairs with opposite polarity, and why the polarities are reversed in the two solar hemispheres.

Sunspots appear in pairs at the suns visible surface because they are connected by coronal loops, huge loops of magnetic field projected into the solar atmosphere (corona). The polarities are reversed in the two solar hemisphere due to the general polarity of the suns solar magnetic flux. ie. North and South polarity.

3) Interplanetary Disturbances: **(10 points)**

a) Explain why the magnetic field in interplanetary space has a "Parker spiral" configuration.

The heliospheric magnetic field is the component of the solar magnetic field that is dragged out from the solar corona. As the sun rotates, this field twists into an archimedean spiral. This is what creates the "Parker spiral" configuration.

b) If the solar wind velocity is faster, how does that change the spiral?

With an increase in the solar wind velocities, the parker spiral will exhibit higher peaks with greater amplitude in its ripples.

c) Explain how stream interaction regions are formed? (Please use a sketch, if necessary).

A stream interaction region is formed by the interaction of high velocity solar wind created within a coronal hole at the sun with slower solar wind. This leads to a region of compressed plasma along the leading edge of the stream.

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4) The solar corona in hydrostatic equilibrium: **(20 points)**

The hot corona ($T \sim 10^6$ K) far above the Sun's surface the temperature drops off slowly with increasing distance.

$$T(r) = To\left(\frac{r_0}{r}\right)^{2/7}$$

where r_0 is a base radius in the corona, often assumed to be about 2 $R_\odot$ (Solar radius), and T_0 is the temperature at the base radius.

Assuming a corona with no fluid flow (i.e., u = 0 everywhere) in spherical symmetry, write the equation of hydrostatic equilibrium and show that it can be simplified into the form:

$$\frac{d}{dr}\left(\frac{\rho}{r^{2/7}}\right) = -C_1 \frac{\rho}{r^2}$$

and give an expression for the constant C_1 in terms of the solar mass, the properties at r_0, and other physical constants.

(Hint: Start with a spherical symmetry and the equation of hydrostatic equilibrium i.e. the gradient of the thermal pressure balances the gravitational force. Assume an ideal gas)

Hydrostatic Equilibrium : $\frac{dP}{dr} = -\rho g$ (1) Gravitational Eqv. $g = \frac{GM_1 m_2}{r^2}$ (2)

w/ $G = 6.67 \times 10^{-11} \frac{Nm^2}{kg^2}$ $M_1 >> m_2$

$\frac{dP}{dr} \rightarrow$ Ideal gas law $PV = k_B N T$ $\rho V = m$ $V = \frac{m}{\rho}$

$P\left(\frac{m}{\rho}\right) = k_B N T \rightarrow P = \frac{k_B N \rho T}{m}$ (3)

$\frac{dP}{dr} = \frac{k_B \rho T}{\mu m_H}\frac{d}{dr}$ Combine equ (1) and (2) substituting μm_H in,

$\frac{k_B \rho T}{\mu m_H}\frac{d}{dr} = \frac{k_B T_0 r_0^{2/7} \rho}{\mu m_H r^{2/7}}\frac{d}{dr}$ isolate $\left(\frac{\rho}{r^{2/7}}\right)$ to one side

$$\frac{d}{dr}\left(\frac{\rho}{r^{2/7}}\right) = -\left(\frac{GM_1 \mu m_H}{k_B T_0 r_0^{2/7}}\right)\frac{\rho}{r^2}$$

thus, $C_1 = -\left(\frac{GM_1 \mu m_H}{k_B T_0 r_0^{2/7}}\right)$

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5) Magnetic reconnection: **(10 points)**

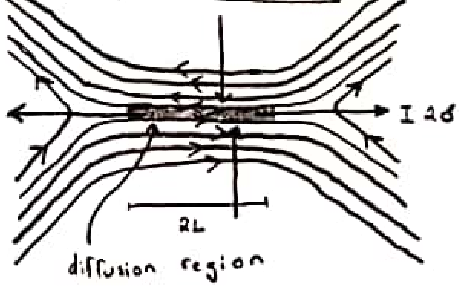
Reconnection Models

Make sketches of the following reconnections models and indicate the following important parameters: Inflow, outflow, and diffusion region for:

- Sweet Parker
- Petschek
- And the so-called "Hall reconnection" model

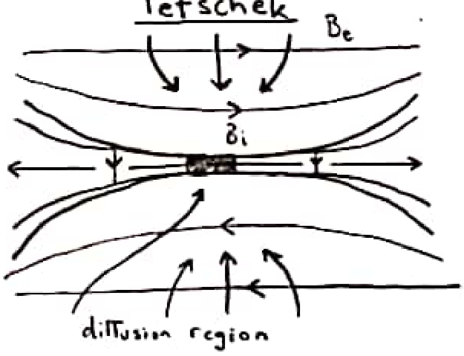
Describe the basic differences

Sweet Parker



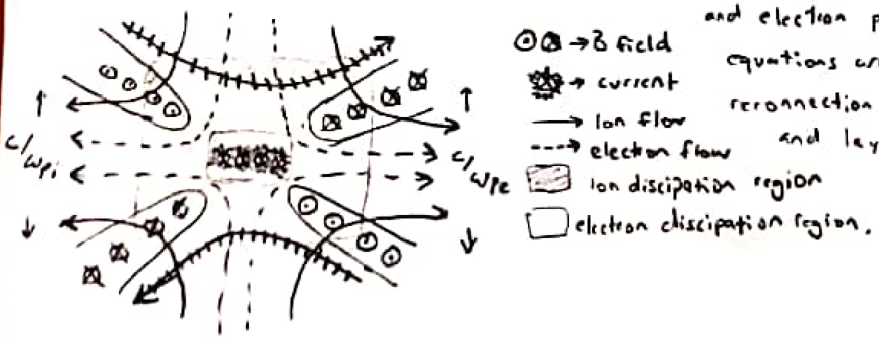
Centered around time independent magnetic reconnection in a resistive mHD frame when the reconnecting mag fields are in opposite direction. This model interprets reconnection rates faster that that of global diffusion but is unable to explain fast reconnection rates found in the earths atmosphere and solar wind.

Petschek



Petschek model proposed a mechanism where the outflow and inflow regions are seperated by static slow mode shocks, with these properties the aspect ratio of the diffusion region allows the maximum reconnective rates.

Hall Reconnection



Model based off of Hall-mHD equations that include Hall and electron pressure terms for electric current. These equations are then solved in a local region across the reconnection electron layer, including only the upstream and layer center.

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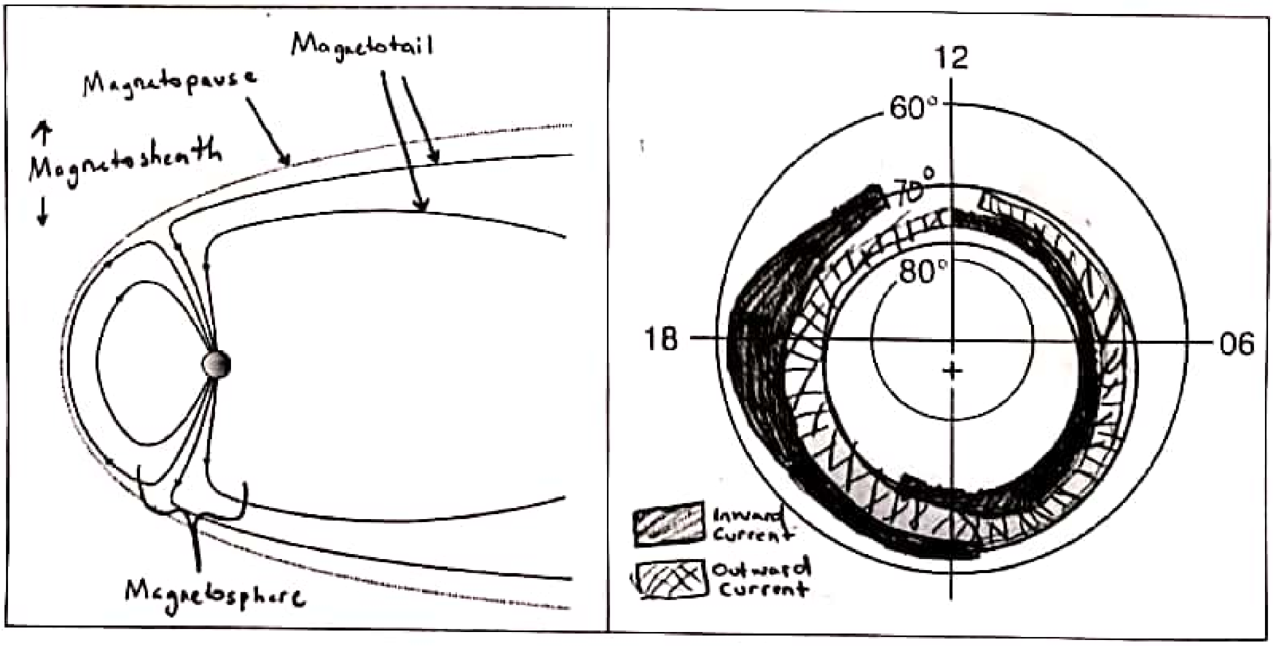
6) Geomagnetic activity **(10 points)**

Describe the differences between a geomagnetic storm and a substorm.

- Substorms are much more frequent, shorter in direction and are associated with auroral effects.
- Geomagnetic storms are defined by periods of disturbed equitoral surface magnetic field, where Geomagnetic sub storms are reconnection events in the magnetotail that direct plasma earthward.
- Storms are triggered by periods of southward Bz, which can be caused by CME's, CIR's or when IMF happens to be directed that way. Substorms are caused by magnetospheric disturbances.

7) Magnetosphere and ionosphere currents **(15 points)**

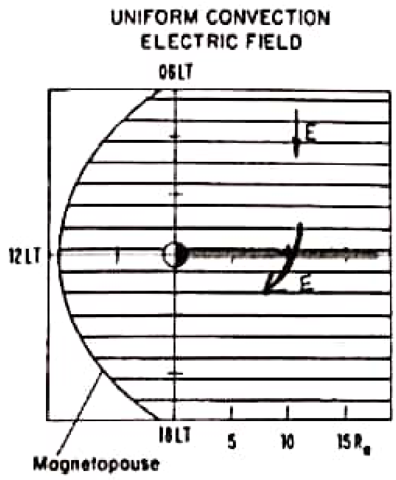
Draw and label the major magnetosphere and ionosphere current systems on the following figures. Use the standard symbols (⊗,⊙) for currents into and out of the page and arrows for those in the plane of the page.



8) Inner magnetosphere particle drifts **(25 points)**

The drift path of a charged particle in the inner magnetosphere is dictated by the vector sum of the drift velocities caused by (1) gradient/curvature drift and ExB drift due to both the (2) convection and (3) corotation electric fields.

Answer the following questions for a particle with $\alpha_{eq} = 90°$ in the magnetic equator and the midnight local time meridian (purple line in the figure). Assume that the convection electric field is as shown in the figure and that the Earth's magnetic field is a dipole.



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a) Draw the direction of the drift velocity vectors associated with (1)-(3) listed above at the "+" sign on the figure (at L=10).

b) Calculate the particle energy required as a function of L-shell, W(L), for the net velocity of the particle to be pointed directly earthward. (Hint: the contribution of one of (1)-(3) can be ignored)

$W_{kin} = \frac{1}{2} m v^2 + \vec{E}_{cor}$

$\frac{1}{2} m v^2 = \frac{1}{2} m (v_\parallel^2 + v_\perp^2)$

$\vec{E}_{cor} = -\frac{\omega_E B_0 R_E}{L^2} \hat{r}$

$v_\parallel^2 = v^2(1 - \sin^2\alpha)$

$v_\perp^2 = v^2(1 - \cos^2\alpha)$

$v_\parallel^2 = v^2\left(\cancel{1 - \frac{B}{B_{eq}}} \sin^2\alpha_{eq}\right) \rightarrow 0$

$W_{kin}(L) = \frac{1}{2} m \left[v^2\left(1 - \left(\frac{BL^3}{B_E}\right)\right)\right] - \frac{\omega_E B_0 R_E}{L^2} \hat{r}$

$v_\perp^2 = v^2\left(1 - \frac{B}{B_{eq}} \cos^2(\alpha_{eq})\right)$

$v_\perp^2 = v^2(1 - B/B_{eq})$

c) Would it be possible for this particle to drift directly earthward along the midnight meridian from L=15 to L=5 under purely adiabatic conditions? Explain.

Under purely adiabatic conditions a particle would not be able to drift from L=15 to L=5. Due to the first law of adiabatic invariants particles must move through convective field lines and not along free paths.