Lecture #7: Overview of the Earth's Magnetosphere

I. Basics of the Earth's Environment

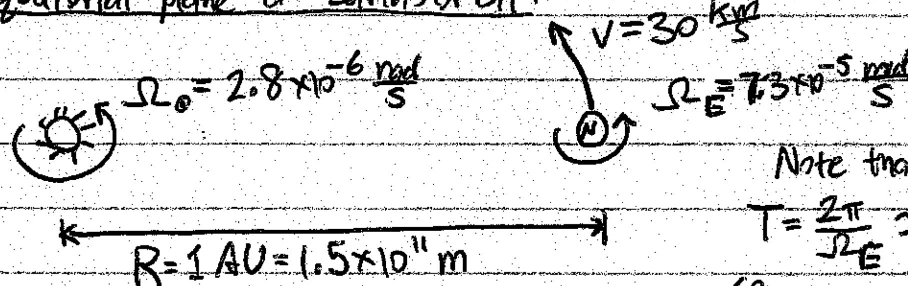
A. General Comments:

1. The sun and its effect on the Earth has traditionally been studied as the field of Solar–Terrestrial Physics, but today is encompassed in the more broad field of Space Physics.
2. This lecture aims to provide a qualitative view of the Earth's magnetosphere as a general introduction to the field.

B. The Sun and the Earth

1. Equatorial plane of Earth's orbit:

a.

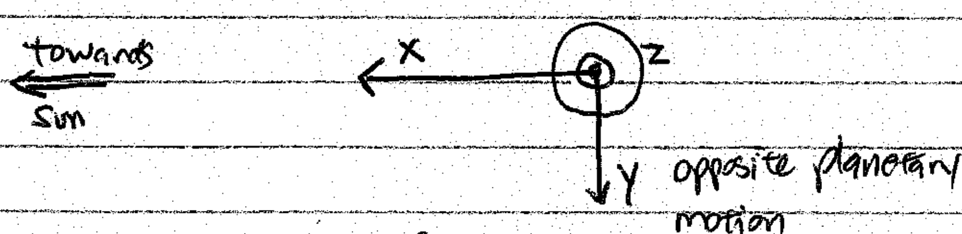


Note that

$T = \frac{2\pi}{\Omega_E} \simeq 23.9h$ ← Sidereal day

(Rotation rate in inertial space)

b. Geocentric Solar Ecliptic (GSE) Coordinates



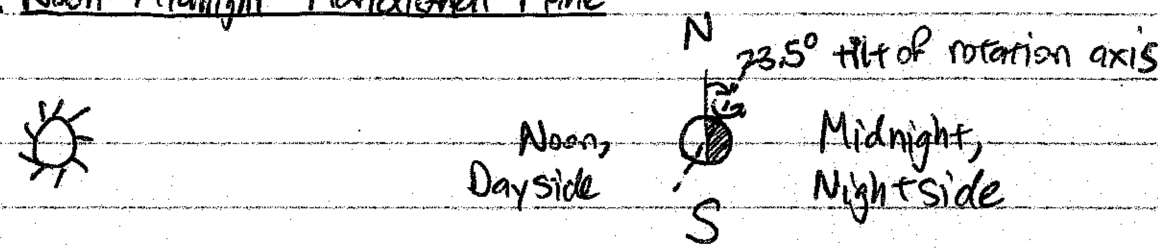
NOTE: Numerous other useful coordinate systems are defined in Appendix A of KR95.

Lecture #7 (Continued)

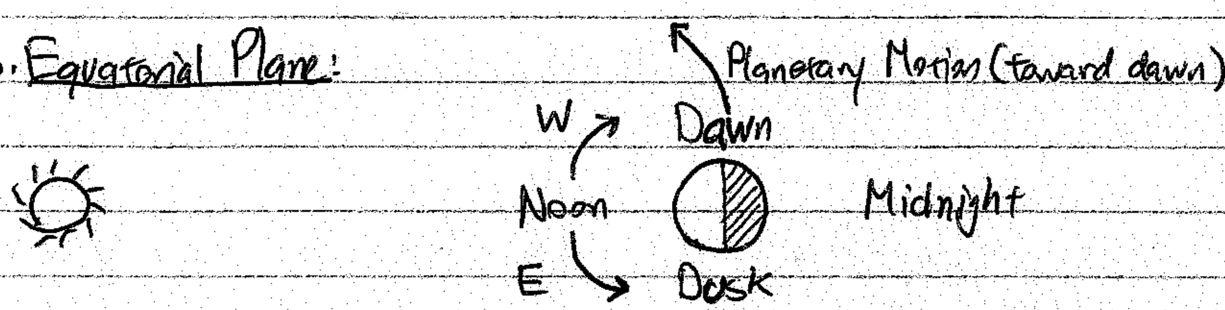
I. B. (Continued)

2. Typical Views and terminology

a. Noon-Midnight Meridional Plane



b. Equatorial Plane:



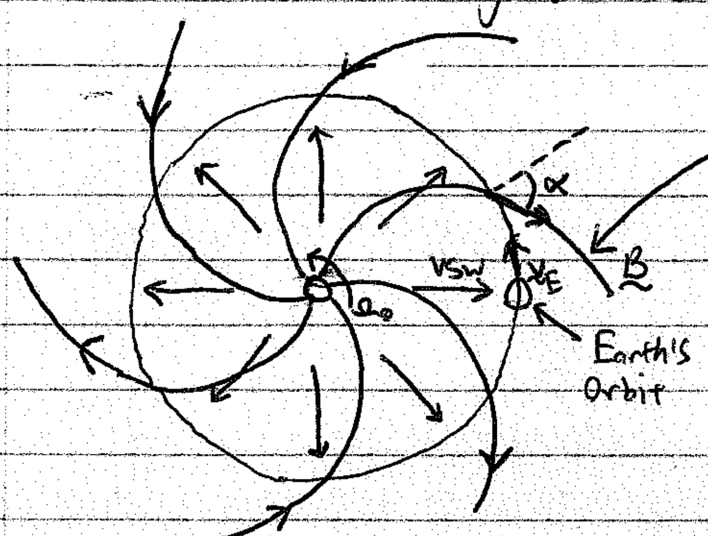
3. Solar Wind Flow and the Interplanetary Magnetic Field (IMF)

a. The solar wind flows radially outward from the sun

b. The low resistivity of the interplanetary medium means that, at large scales, ideal MHD is a reasonable representation of the magnetized solar wind plasma.

c. Therefore, the magnetic field lines are frozen into the radial flow.

d. But, the sun rotates with a period of about 26-27 days, and this twists the magnetic field into a spiral



"Parker Spiral"

Average IMF has angle of $\alpha \simeq 45°$ (w.r.t. radial) at the orbit of the Earth.

I. B. (Continued)

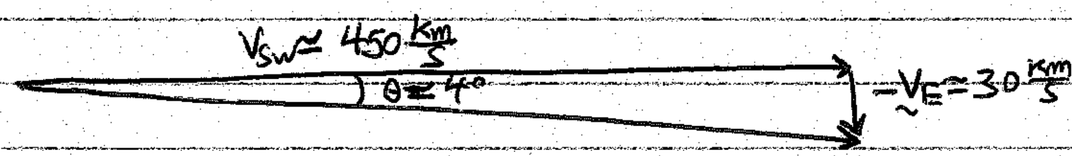
4. Solar Wind Properties (see KR Table 4.1)

a. At $R \simeq 1$ AU,

Proton density, n_p	$6.6\ cm^{-3}$
Electron density, n_e	$7.1\ cm^{-3}$
Alpha (He^{2+}) density, n_α	$0.25\ cm^{-3}$
Solar wind speed, V_{sw}	450 km/s
Proton temperature, T_p	1.2×10^5 K
Electron temperature, T_e	1.4×10^5 K
Magnetic Field, B	7 nT
Ion Plasma Beta, $\beta_i = \frac{2\mu_0 n_p T_p}{B_0^2}$	0.56
Sound speed	60 km/s
Alfven speed	40 km/s
Average collision time	4×10^6 s
Travel time to 1 AU	4×10^5 s $\simeq 4$ days

General Properties
- i) Super-Alfvenic flow
- ii) Plasma $\beta \sim 1$
- iii) $T_p \sim T_e$
- iv) Weakly collisional

b. Relative to the Earth, the solar wind hits the Earth's magnetosphere with an aberration of $\sim 5°$.



This is usually neglected in simple models.

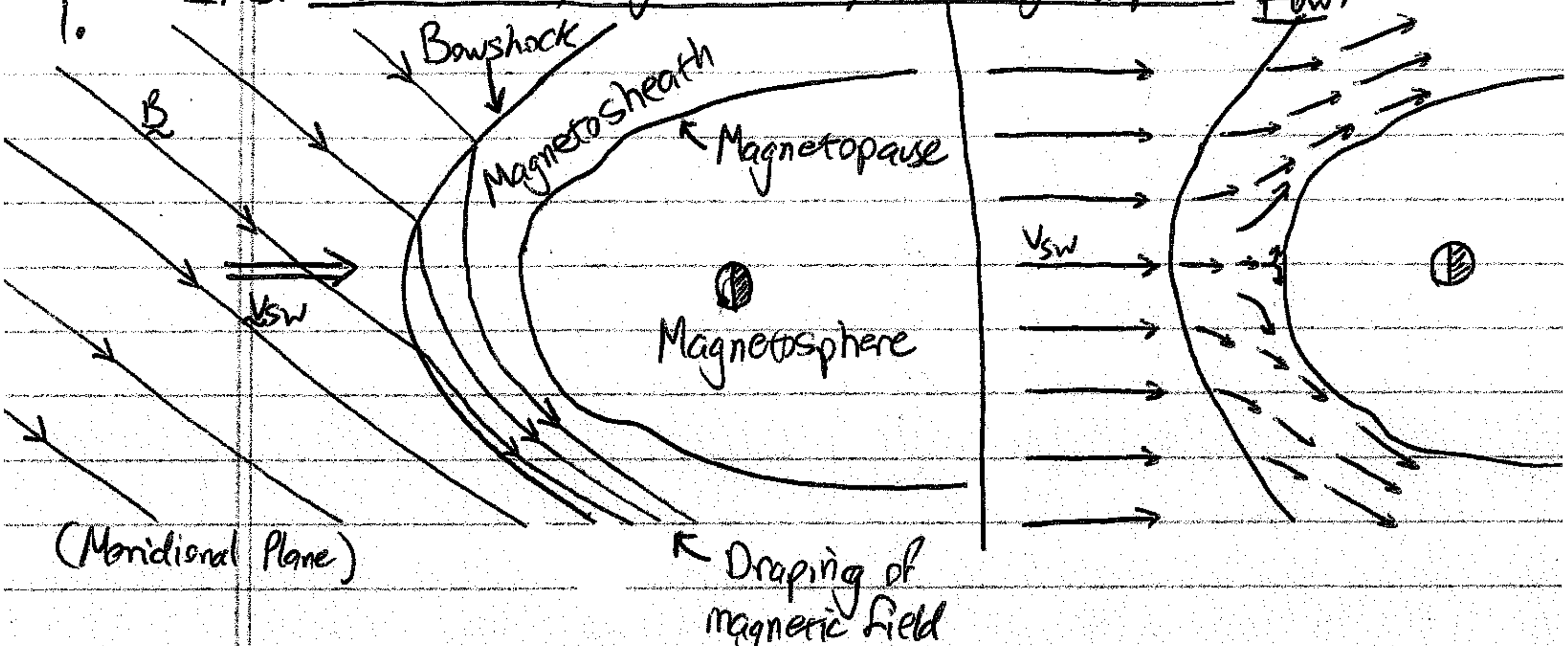
II. Interaction of the Solar Wind with the Earth's Magnetosphere

A. General Comments:

1. Because the solar wind flow is super-sonic and super-Alfvenic, $\frac{V_{sw}}{V_A} \simeq 10$, a bowshock is generated ahead of the magnetosphere.
2. At the bowshock, the solar wind flow abruptly drops to subsonic/subAlfvenic velocities in the magnetosheath, allows to drop to zero at magnetopause.

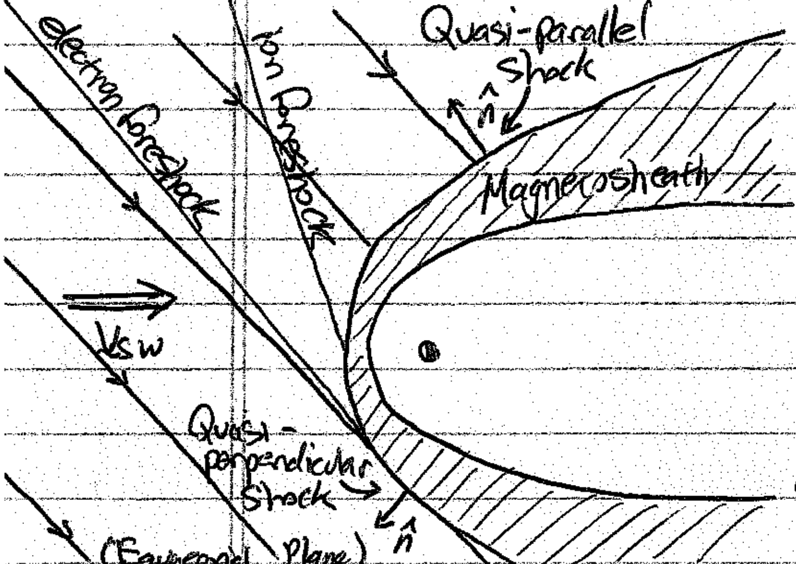
II. B. The Bowshock, Magnetosheath, and Magnetopause

1.



a. The Bowshock transitions from supersonic to subsonic flow
   1. Plasma is compressed and heated at the bowshock
b. The plasma slows down in the magnetosheath and changes direction to flow around the magnetopause
c. The magnetopause is the outer boundary of the Earth's magnetosphere
   1. There is no flow through the magnetopause, separating shocked solar wind plasma from magnetospheric plasma.

2. Ion and Electron Foreshocks, Quasi-parallel & Quasi-perpendicular Shocks

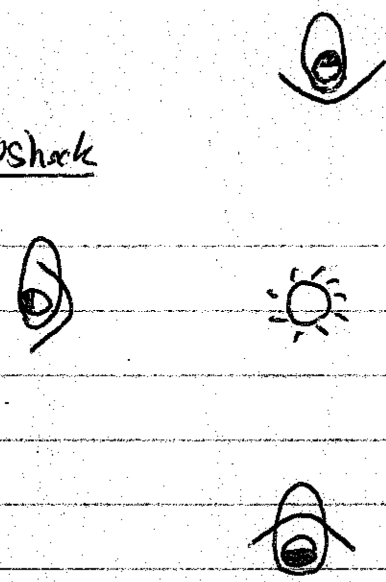


a. Interplanetary Magnetic Field (IMF) arrives at Parker angle $\alpha \simeq 45°$
b. Regions where $\underset{\sim}{B} \parallel \underset{\sim}{\hat{n}}$ (shock normal) are quasi-parallel shocks
c. Regions where $\underset{\sim}{B} \perp \underset{\sim}{\hat{n}}$ are quasi-perpendicular shocks
d. Accelerated electrons and ions can stream along $\underset{\sim}{B}$, leading to electron & ion foreshocks.

Lecture #7 (Continued)

II. B. 3. Spacecraft Sampling of Bowshock and Solar Wind

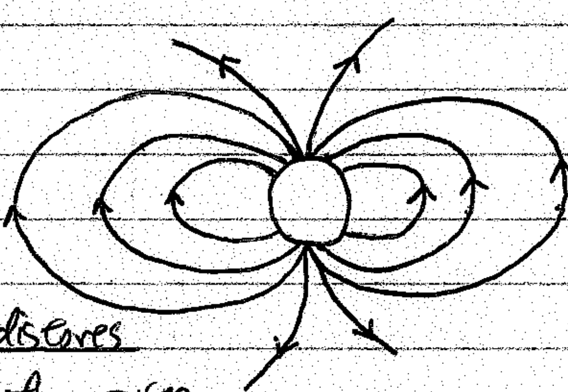
a. Orbit of spacecraft remains constant in inertial space as Earth orbits the Sun.



III. Earth's Magnetosphere:

A. Intrinsic Dipole Field

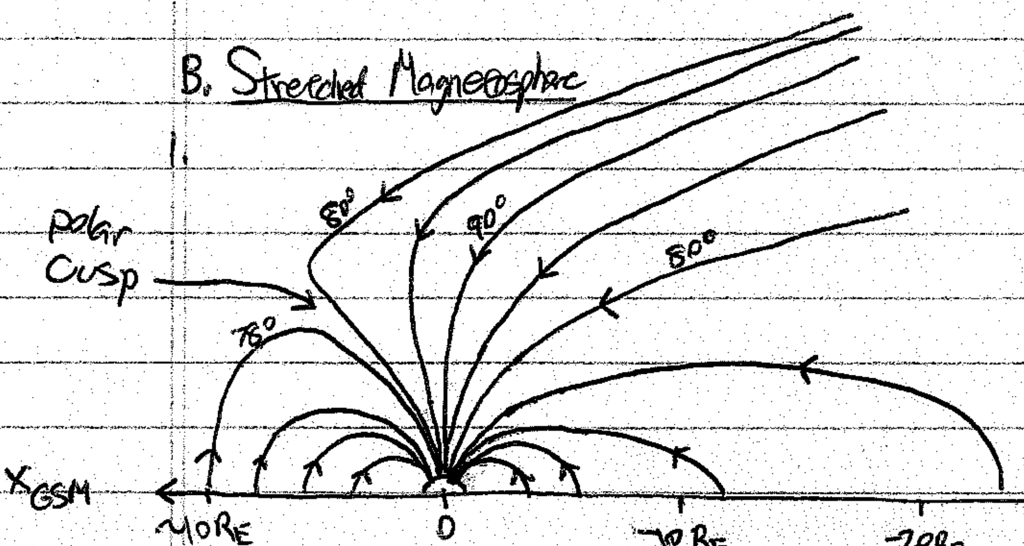
1. The dipole field is tilted from the rotational axis by 10.8°.



2. The solar wind strongly distorts the internal dipole field in the outer magnetosphere beyond a few $R_E = 6378$ km.

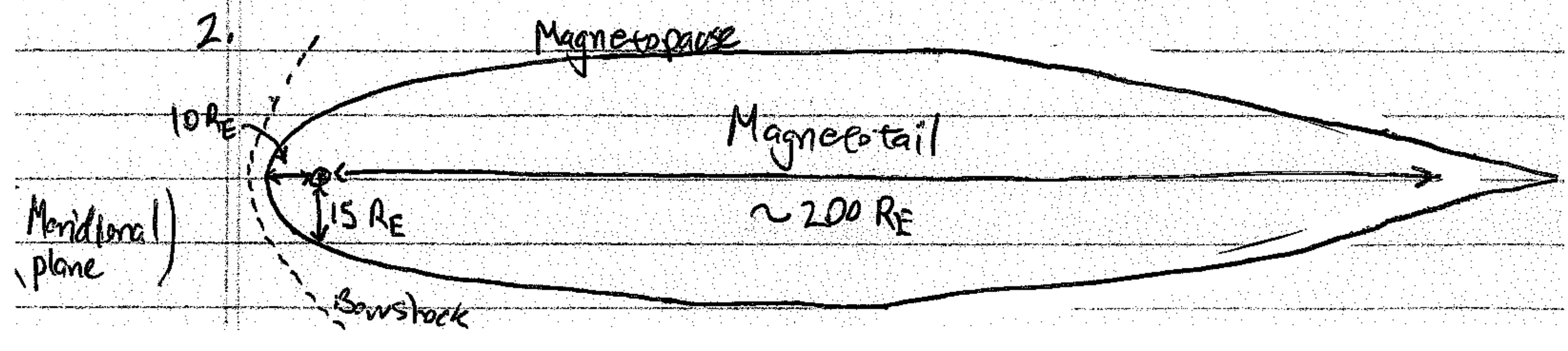
B. Stretched Magnetosphere

1.



GSM - Geocentric Solar Magnetospheric System (see KR, App. A)

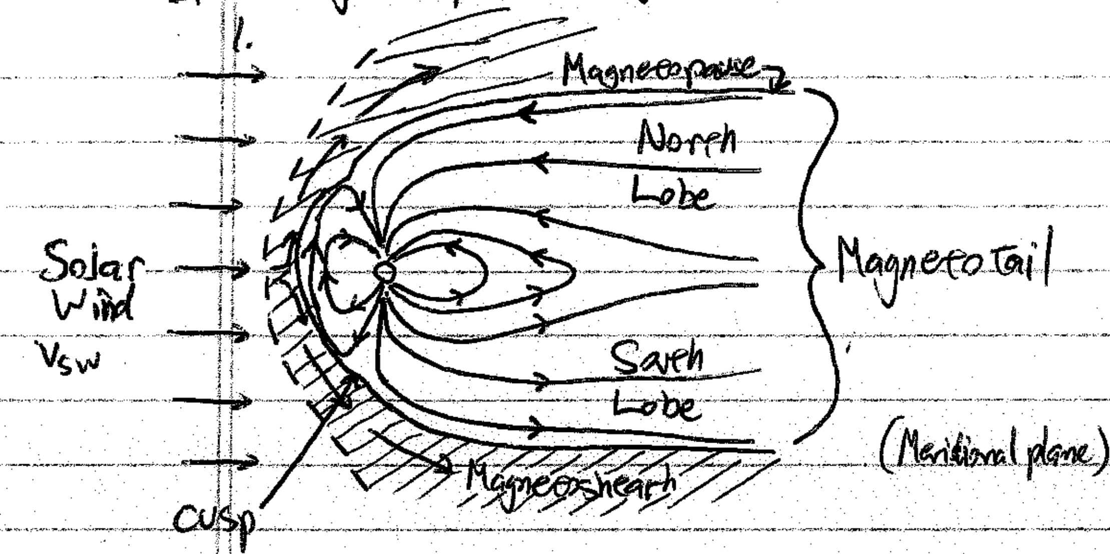
2.



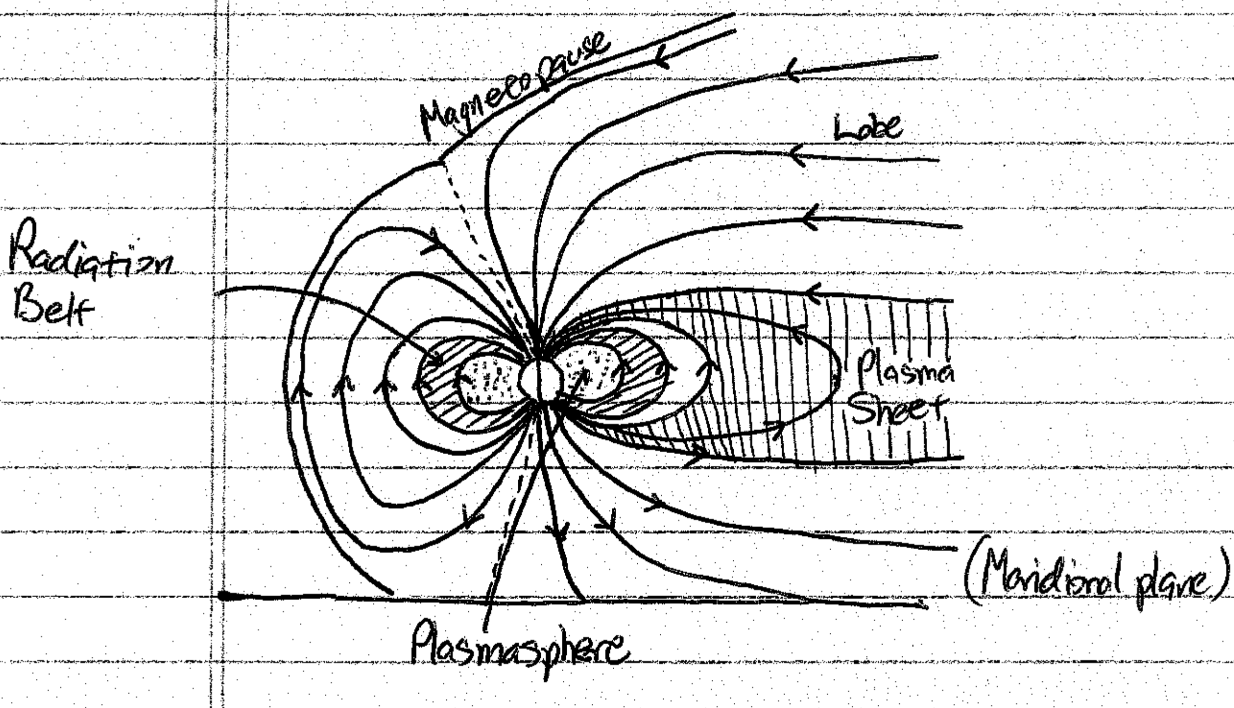
Lecture #7 (Continued)

III.C. Magnetospheric Magnetic Field

1.



D. Inner Magnetosphere



1. Solar UV radiation leads to ionization of the neutral atmosphere, leading to the generation of the ionosphere above 80 km
2. The ionosphere at low & mid-latitudes gradually merges into the plasmasphere, a torus-shaped cool, dense plasma in which the magnetosphere co-rotates with the Earth.
3. Outer boundary is the plasmapause, where n_e drops from $500\ cm^{-3}$ to $1\ cm^{-3}$.

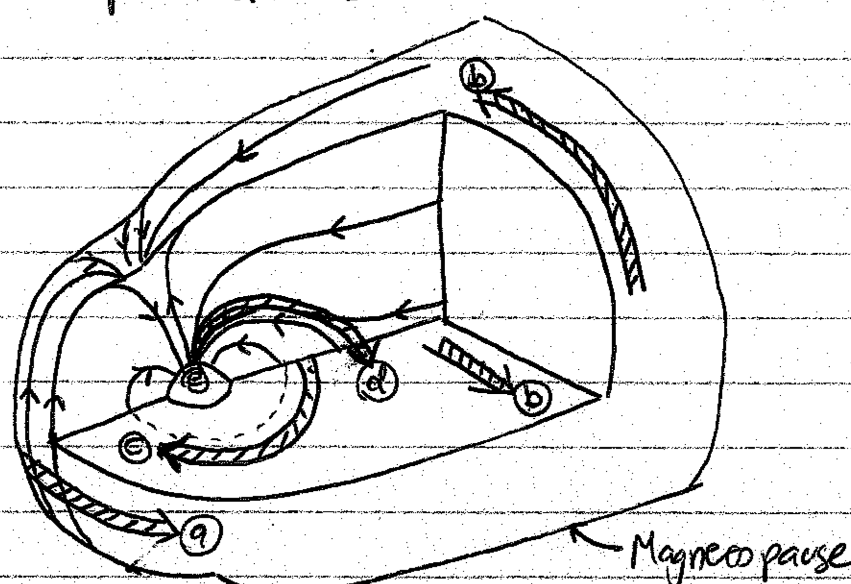
Lecture #7 (Continued)

III D. (Continued)

4. Beyond the plasma pause, at $2 R_E \lesssim r \lesssim 6 R_E$, are the radiation belts, consisting of trapped, high energy (keV) populations of ions and electrons (discovered by Van Allen).
5. In the magnetotail, most of the plasma is contained in the midplane in the plasma sheet, connected magnetically to the high-latitude auroral ionosphere.

E. Currents in the Magnetosphere:

1. Five principal current systems
   a. Magnetopause (Chapman-Ferraro) current
   b. Tail (Neutral Sheet) current
   c. Ring current
   d. Field-aligned (Birkeland) currents
   e. Ionospheric currents



2. These currents play a strong role in modifying the outer magnetospheric magnetic field configuration.

III. F. Dynamics of the Magnetosphere

1. The dayside magnetospheric field is oriented northward.
2. When the IMF has a northward component, the solar wind plasma primarily flows around the magnetopause boundary.
3. When the IMF has a southward component, however, magnetic reconnection can occur at the dayside, allowing some of the dayside magnetic flux to be swept towards the tail, dragged by the solar wind flow.
4. At the tail, reconnection of the sunward north lobe with the antisunward south lobe can occur, leading to an antisunward flow in the equatorial plane (plasma sheet).

5. Dungey Model