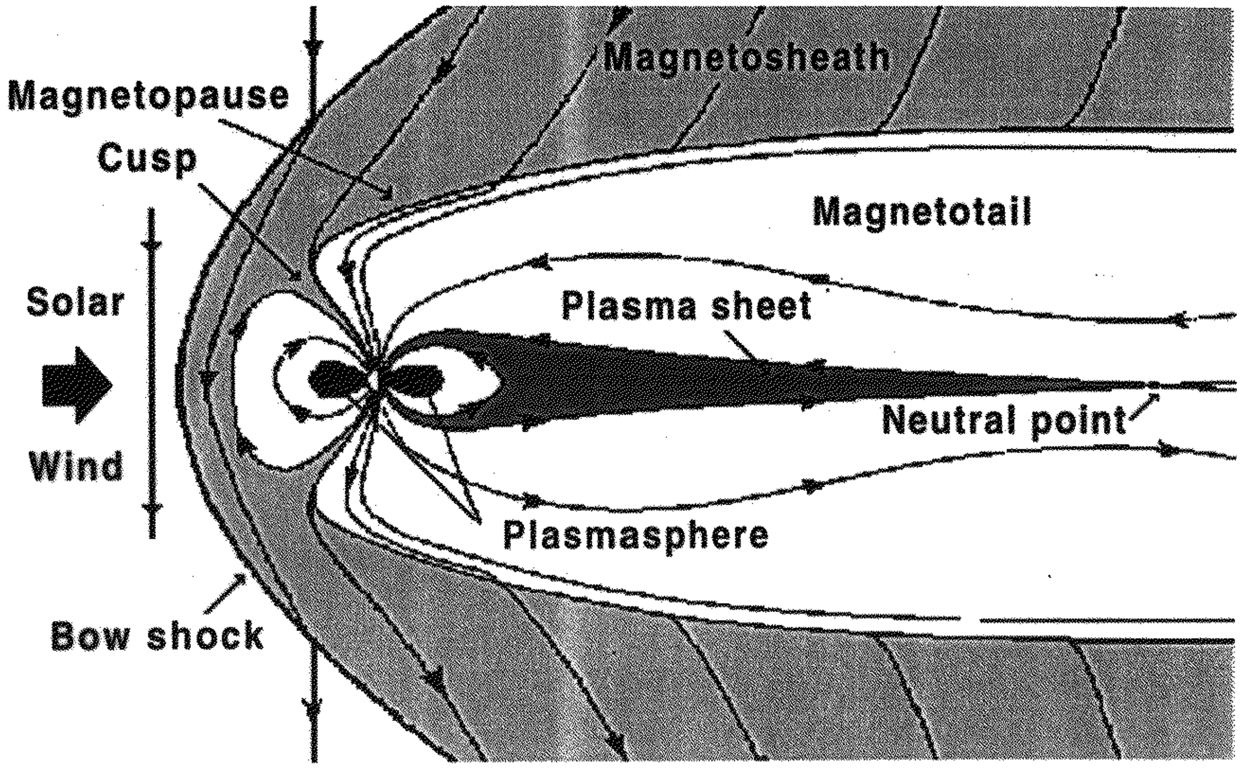
<u>Space Physics Handout 2 : The Earth's magnetosphere and ionosphere</u>

The previous handout discussed the highly conducting plasma which the Sun emits, known as the solar wind. This highly conducting plasma travels at supersonic speeds of about 500 km/s as a result of the supersonic expansion of the solar corona. As a result of this plasma being highly conductive, the solar wind magnetic field is frozen into the plasma (something we will discuss and derive in the lectures). The implication of this is that when the solar wind encounters the dipolar magnetic field of the Earth, that it simply cannot penetrate through it and what happens is that it is slowed down and to a large extent deflected around it. Since the solar wind hits the obstacle (the Earth's magnetic field) at supersonic speeds, a shock wave is formed, which is known as the bow shock.

At this bow shock the solar wind plasma is slowed down and a substantial fraction of the kinetic energy of the particles is converted into thermal energy. The region of thermalised subsonic plasma behind the bow shock is called the magnetosheath. The magnetosheath plasma is denser and hotter than the solar wind plasma and the magnetic field values are higher in this region compared to out in the solar wind. The shocked solar wind plasma in the magnetosheath cannot easily penetrate the Earth's magnetic field and is deflected around it. The boundary separating the two different regions is called the magnetopause and the cavity generated by the solar wind interaction with the Earth's magnetic field is known as the magnetosphere. All of these regions can be seen in Figure 1 which also shows how the magnetic field of the Earth is compressed on the sunward side and stretched out on the anti-sunward or nightside of the planet.



<u>Figure 1</u> : Schematic cross-section of the magnetosphere in the noon-midnight meridian, showing some of the most important regions.

On the dayside of the planet, the magnetopause is usually found at a distance of about 10 Earth radii (R_E), although when the solar wind pressure is particularly strong the magnetopause can be compressed to < 6 –7 R_E. The bow shock is usually found at a distance of 12 – 14 R_E on the dayside. On the nightside of the planet, the magnetosphere is stretched into a long magnetotail, to a distance of about 1000 R_E. The magnetotail has the form of a cylinder of about 40 R_E in diameter.

The plasma in the magnetosphere consists mainly of electrons and protons (i.e. ionised hydrogen atoms). The sources of these particles are the solar wind itself and the Earth's ionosphere (see below). The plasma inside the magnetosphere is not uniformly distributed but is grouped into different regions with quite different densities and temperatures. In the magnetotail there is a central region, known as the plasma sheet, which consists of hot (5 x 10^6K), low density plasma (0.5cm^{-3}) with magnetic field values of B ~ 10 nT. Near the Earth it reaches down to the high-latitude auroral ionosphere. The plasma sheet separates the northern and southern lobes of the plasma sheet and these lobes contain very low density (~ 10^{-2} cm^{-3}) and low temperature (5 x 10^5K) plasma with magnetic field values of B ~ 30 nT. In the northern tail lobe the magnetic field points towards the Earth and in the southern tail lobe it points away from the Earth.

Closer in to the Earth the radiation (Van Allen) belts lie between about 2 – 6 R_E, following the magnetic field lines. These belts consist of energetic electrons and ions which move along the field lines and oscillate back and forth between the two hemispheres. Typical electron densities in this region are ~ 1 cm^{-3}, electron temperatures are ~ 5 x 10^7K and magnetic field strengths range from 100 – 1000nT. Near the Earth there is also a torus-shaped region, the plasmasphere which contains plasma of ionospheric origin. This plasma is dense (~ 10^2 cm^{-3}) but cold (~ 5 x 10^3K) and corotates with the Earth. In the equatorial plane, the density of the plasmasphere drops sharply down to about 1 cm^{-3} - this boundary is known as the plasmapause and occurs at about 4 R_E. Two other important regions are the southern and northern cusps. These are funnel-shaped regions, which on the dayside consist of closed, compressed magnetic dipole field lines, whereas on the nightside they are almost all open stretched out magnetic field lines reaching deep into the magnetospheric tail. In this funnel, solar wind plasma from the magnetosheath can penetrate deep inside the magnetosphere – allowing mixing of plasma from two different origins.

The shape and different regions of the magnetosphere undergo significant changes in response to different solar wind conditions.

Ionosphere

The solar ultraviolet light which impinges on the atmosphere of the Earth ionises a fraction of the neutral atmosphere. At altitudes above 80km collisions in the atmosphere are too infrequent to result in rapid recombination and a permanent ionised population results, known as the ionosphere. Typical values of electron density in the mid-latitude ionosphere are ~ 10^5 cm^{-3} and typical temperatures ~ 10^3K, with magnetic field strengths of the order of 10^4 nT.

The major fraction of ionisation within the ionosphere is produced by solar X-ray and ultraviolet radiation and by corpuscular radiation from the Sun. The most noticeable effect is seen when the Earth rotates with respect to the Sun; ionisation increases in the sunlit atmosphere and decreases on the shadowed side.

The ionosphere extends to rather high altitudes and at low and mid-latitudes gradually merges into the plasmasphere which was mentioned above. At high latitudes plasma sheet electrons can precipitate along magnetic field lines down to ionospheric altitudes, where they collide with and ionise neutral atmosphere particles. As a by-product, photons emitted by this process create lights, known as the aurora.

The ionosphere is a dynamic system controlled by many parameters including acoustic motions of the atmosphere, electromagnetic emissions and variations in the Earth's magnetic field. Since it is very sensitive to changes in the atmosphere – it can be used as a very sensitive monitor of atmospheric events.

For convenience, the ionosphere is divided into four broad regions called the D, E, F and topside regions. The D-region between 75 –95 km above the Earth is mainly responsible for absorption of high-frequency radio waves. The E-region lies between about 95 – 150km above the surface. Above this height the F-region contains both an important reflecting layer and is also the region of primary interest to radio communications. Above the F-region the topside ionosphere is a region of decreasing density above which the weak ionisation has little influence on radio signals. All of these will be described in more detail later in the course.