1   The Earth's Magnetic Field

The form of the Earth's magnetic field is called a *dipole magnetic field*. This is the same type of magnetic field that a bar magnet has. $\longrightarrow$ See online plots and diagrams The equation for a dipole field can be given in terms of unit vectors $\hat{r}$ and $\hat{\theta}$. This form of the field is

$$\vec{B} = \left(\frac{\mu_0}{4\pi}\right) m \left[\frac{\cos\theta}{r^3}\hat{r} + \frac{\sin\theta}{r^3}\hat{\theta}\right] \tag{1}$$

At the poles, the magnetic field is pointing straight out or straight in. At the equator, the field is pointing straight north or straight south, depending on the sign of m. Notice that the strength of the field falls off as the inverse cube of the distance.

   The strength of the magnetic field depends on the *dipole moment m*. The Earth has a large dipole moment, and thus a strong magnetic field. At the surface of the Earth, the typical value of the field is $B_{\oplus} = 3.1 \times 10^{-5}$ Tesla. On Jupiter, the value is $B = 4.2 \times 10^{-4}$. On Venus, it is $B = 3.1 \times 10^{-5}$

2   Charged Particles in Magnetic Fields

We have just seen that in the upper atmosphere, plasmas are important. They are also important throughout the rest of astronomy. In a plasma, at least some of the particles that make up the gas are charged. Electrons are charged negatively, ions are positively charged.

   One of the most basic laws of physics is that a charged particle moving with respect to a magnetic field feels a force. We call this the *Lorentz Force*. It is given by

$$\vec{F} = q\vec{v} \times \vec{B} \tag{2}$$

The SI unit for magnetic field is the Tesla. A Tesla is a whopping large magnetic field. The units of electric charge in the SI system is the *Coulomb*. A Coulomb is an awful lot of charge. The *fundamental electric charge*, which is that possessed by an electron and proton is 1.602×10^{-19}

This is a vector cross product. Remember our rules of vector algebra that govern the cross product. Let's see what this force does to a charged particle moving perpendicular to a magnetic field $\longrightarrow$ drawing on blackboard.

The Lorentz force makes the charged particle move on a circular path. Let's see what the characteristics of this path are. Since the force produces a *centripetal acceleration*, we have

$$\frac{mv^2}{r} = qvB \tag{3}$$

$$r = \frac{mv^2}{qvB} \tag{4}$$

$$r = \frac{mv}{qB} \tag{5}$$

This radius is called the *Larmor radius*. Let's work out a numerical example. The thermal speed of a proton in the solar wind is about 50 km/sec. The magnetic field in the solar wind at 1 AU from the Sun is about 5 nT $= 5 \times 10^{-9}$ T. Let's see what the Larmor radius is.

$$r = \frac{mv}{qB} \tag{6}$$

$$r = \frac{1.67 \times 10^{-27}(50 \times 10^3)}{1.602 \times 10^{-19}(5 \times 10^{-9})} \tag{7}$$

$$r = \frac{8.35 \times 10^{-23}}{8.01 \times 10^{-28}} \tag{8}$$

$$r = 1.04 \times 10^5 \tag{9}$$

Units? How big is this?

What the Lorentz force tells us is that charged particles cannot move across a magnetic field. They will be bent on to circular paths. Charged particles can move *along* magnetic fields, since then $\vec{v} \times \vec{B} = 0$. This then means that magnetic fields act like force fields to deflect beams of charged particles.

Charged particles can travel *force-free* along a magnetic field. This gives us some insight into Auroras.

3   The Van Allen Radiation Belts

In 1912, the *Cosmic Rays* were discovered. There are charged particles coming into the Earth's atmosphere. For decades there were questions about where they come

from. One of the leading investigators in the 1950s was James Van Allen of the University of Iowa.

The first United States satellite, Explorer I, launched in January 1958, carried an instrument to detect radiation. This instrument was built in the Physics Department here, then located in MacLean Hall.

Explorer I and subsequent satellites over the next few months showed evidence for two donut-shaped regions of intense radiation. $\longrightarrow$ see online diagrams. These are the inner belt and outer belt. The inner has the greater intensity of radiation, that extends to higher energies, perhaps 100 MeV (million electron volts).

In August, NASA launched a dual spacecraft called the Radiation Belt Storm Probes, that carried instruments built at the University of Iowa by Professor Kletzing and his group.

Last week, these spacecraft were officially renamed the *Van Allen Probes.* $\longrightarrow$ see picture of spacecraft in online figures.

4   Van Allen Belts of Other Planets

The general term for the region of space dominated by the Earth's magnetic field is called the *magnetosphere*. The magnetosphere included the Van Allen Belts. As part of the exploration of space that has occurred since the 1970s, we have found large magnetospheres around the planets Jupiter and Saturn as well.