Table 3 shows the components for 2004 at sea level for different geographic coordinates. The vector components whose magnitudes are the numbers Bx, By and Bz are defined in units of nano-teslas (nT), B is the total field strength also in units of nT. You can use this information to calculate D, the declination angle between geographic and magnetic north, and I, the inclination or Dip Angle, in degrees below the local horizontal plane from Equations 7 and 8 in Section 1.7. The Declination angle, D, is the angle you will find on a geographic map that gives the compass correction to True North.

For example, in Chicago the components of the field are 26,454 nT, 1271 nT and 55,605 nT. The total magnitude of the field at the surface is then 55,605 nT or since there are 10,000 Gauss units per tesla, this equals 0.556 Gauss. The angle between geographic north and magnetic north at this location is 2.8 degrees, so that your compass will point 2.8 degrees west of true north. The needle of the compass will dip 61.6 degrees from the horizontal plane. You can actually see this if you have a compass with a needle suspended at its middle point.

IV. Magnetism Measurement Techniques

4.1 The Soda Bottle Magnetometer

Compasses are great for measuring the direction of a magnetic field locally, but don't provide enough detailed information to make these measurements precise enough for scientific study. They also don't tell us the actual strength of the magnetic field. To gather this data, we have to develop sensitive instruments. One simple instrument that is the next step up from a compass is the Soda Bottle or 'Jam Jar' magnetometer. It provides a greatly amplified measurement of the compass needle motion, and the direction changes of the ground-level magnetic field.

This instrument is nothing more than a magnet suspended by a thread in a compass-like manner, which merely indicates the local direction of the horizontal component of the magnetic field. Details for constructing and using this instrument may be found at the IMAGE education web site:

http://image.gsfc.nasa.gov/poetry

Here is a photo of a typical set up created by a middle-school student:

Figure 29 - A soda bottle magnetometer and its setup. The lamp illuminates a mirror on the suspended magnet, and creates a spot on the wall, whose displacement is measured by the ruler. For more accurate measurements, a laser pointer can be used, attached securely to a stand (test tube holder) so that the pointer-soda bottle system does not move during the course of the measurement program. This can be built with simple woodworking skills.

4.2 The Dip Circle

A bit more mechanically complex than the soda bottle magnetometer is the Dip Circle. Magnetic dip in the vertical direction went unrecognized until 1576, when Robert Norman stumbled upon the effect while carefully watching a compass needle mounted in such a way that it was free to move in the vertical plane. He constructed a simple instrument to measure this movement in 1576. It must have been an exhilarating moment when Norman first saw this effect, because it was a new aspect of magnetism that no one had thought to look for before. The compass, soda bottle, and Dip Circle all measure the direction of the local magnetic field, but not its strength. Instruments with this ability require much more care, and a deeper understanding of electromagnetism.

4.3 The Bache Magnetometer, circa 1844

A simple pendulum acted upon by gravity alone, and made from a non-magnetic material, will have a well-defined period of oscillation given by:

Equation 9 $2 \pi T = (L / g)^{1/2}$

where L is the length of the pendulum in centimeters and G is the acceleration of gravity, 980 cm per second per second. The addition of another force, such as magnetism, will change the oscillation period in a way that the period change can be used to measure the strength of the applied force. A pendulum with a non-magnetic weight of the same mass as a ferro-magnetic weight will oscillate at the gravity-induced frequency, but a ferro-magnetic weight will be influenced by the local magnetic field and have a different period of oscillation. The change on the period of the pendulum can be used to measure the strength of the magnetic field in which it is swinging, a principle first applied by Bache in 1844.

4.4 Electromagnetic Magnetometer

Beginning with the 1831 researches by Michael Faraday and Wilhelm Weber, several instruments were designed, based on a radically different principle. Instead of measuring the period of a magnetized pendulum, the new instruments measured the current generated by a rotating copper plate. As the plate is spun perpendicular to the plane of the magnetic field, a weak current is produced. Weber replaced the copper plate with a coil of wire that could be rotated, and a deflection caused by the current appeared on a galvanometer dial. This type of magnetometer allowed scientists to measure a changing strength and direction of a magnetic field, and is still used.

4.5 Proton Precession magnetometer

This magnetometer design can only measure the total magnetic field strength, but is often used for underwater location of metallic objects such as submarines. The operating principle here is that protons in a liquid (like ordinary water!) have a precession frequency of about 2000 Hertz in a 50 microTesla field. The precession frequency depends on the applied field strength. To sense the precession frequency, a non-ferromagnetic container with hydrogen-rich liquid such as alcohol is surrounded by a coil of wire. A current is passed through the wire to magnetize the liquid, then the field is turned off, and the current produced by the low-frequency radio signal from the gyrating protons is measured.

Although this device sounds complicated, in fact it is well within the skill of an amateur scientist/hobbyist to produce. There are several designs for this kind of instrument on the Web.

V. The fluxgate magnetometer

Although it was mainly built to detect submarines during World War II, the fluxgate magnetometer provides information about both the intensity and orientation of a magnetic field. It has become, by far, the most widely used instrument both for prospecting on Earth and for space-based research applications. This is the type of magnetometer used in the THEMIS ground-based and satellite observatories, including the education stations.

5.1 Operating principles

Consider an electromagnet with wires wrapped around a nail and attached to a battery. When the circuit is completed and the electricity flows, the coils produce a magnetic field. The iron nail is not necessary for an electromagnet, but it is used to enhance the magnetic field. A fluxgate magnetometer uses some of these same concepts, plus more.

A fluxgate magnetometer measures an external magnetic field in any direction by determining the amount of electric current needed to reduce the magnetic field strength in the core to zero along that direction. The core is in the center of the fluxgate sensor (like the iron nail in the electromagnet) and usually consists of a nickel ring wrapped with magnetic material, as shown in Figure 30. If there is an external magnetic field, a magnetic field in the core will exist before the fluxgate magnetometer is turned on. If there is no external magnetic field, there will be no magnetic field in the core before the fluxgate magnetometer is turned on. Around the core is a primary coil of wire (like the wire around the nail in the electromagnet) that magnetizes the core, in addition to any external magnetic field magnetization. A secondary coil is wrapped around the core to detect signals coming from it.

To magnetize the core, a fluxgate magnetometer applies an oscillating magnetic field (one that changes quickly and periodically in time) around the core that alternately produces a magnetic field parallel and anti-