The different systems of units in magnetism, encapsulating to some extent the history of physics, is an interesting but somewhat confusing subject. The modern standard is the SI system which incorporates the “rationalized MKS” system in electromagnetism. Unfortunately, much of the geophysical literature uses the emu or electromagnetic system of units, which is based on the CGS system of units. Thus we need to deal with both.

emu units:

B = "magnetic induction", the fundamental magnetic field vector which produces the force field experienced by a moving charge. The force, F, is directed perpendicular to both the velocity of the moving charge, V, and the magnetic field vector, B:

$$ F = q V \times B $$

where q is the electrical charge of the particle and the expression $V \times B$ is the vector cross product. The vector F is perpendicular to both V and B in the direction given by the right hand rule. In emu units, a field of 1 gauss, a velocity of 1 cm/sec, and a charge of 1 abcoulomb (10 coulombs) produces a force of 1 dyne. Small field values encountered in the study of Earth’s crustal magnetic anomalies are often expressed in gammas, where

1 gamma or $1 \gamma = 10^{-5}$ gauss

H = "magnetic intensity", is the force field proposed to exist between magnetic "poles". In emu (electromagnetic) units, two poles each with pole strength, p, equal to one and located 1 cm apart will exert a force of repulsion of 1 dyne. The force per unit pole in this system is the magnetic field, H, in oersteds in the emu system.

In the presence of magnetized material, the H field is considered to be the field due to sources external to the magnetized body, while the net field within the body produced by this external field plus the effects of the magnetization of the body is measured by the B field. The relationship between B and H is

$$ B = \mu H $$
where \( \mu \) is the permeability of the medium. In free space, the emu system has the convenient property that \( \mu = 1, B = H \), and oersteds and gauss are the same numbers. The permeability of air is very close to 1, so this relationship effectively holds for observations in Earth’s atmosphere.

\[ J = \text{magnetization of medium, a vector quantity.} \]

Magnetization is dipole moment per unit volume, often quoted simply as "emu units of magnetization". A simple dipole field is formed by two magnetic poles of opposite sign, of strength \( +p \) and \( -p \), located at a distance, \( h \), apart, where the axis of the dipole field is aligned along the line connecting the two poles. The strength of this dipole field is measured by the \( m \), the magnetic moment of the dipole, where

\[ m = ph \]

Magnetization can be considered as a volumetric distribution of dipoles in a medium. The net magnetic moment of the dipoles in a unit volume would be the dipole moment per unit volume given by \( J \). Thus a small piece of the material will have a magnetic moment of \( J \) times the volume of the piece.

The net field, \( B \), within magnetized material is the summation of the external field \( H \) and the internal field due to the effect of the dipoles in the magnetized medium measured as dipole moment per unit volume \( J \):

\[ B = H + 4\pi J \]

where the \( 4\pi \) term comes the fact that the magnetization effect is equivalent to two infinite sheets of poles on either side of the point of observation.

\[ \chi = \text{susceptibility of medium where} \]

\[ J = \chi H, \]

\( \chi = 0 \) in free space and is practically 0 for air. The susceptibility \( \chi \) measures the amount of magnetization induced by the field \( H \). Also, \( \mu = 1 + 4\pi \chi \)

\( \sigma = \text{pole strength per unit surface area, with the same units as } J \) (pole strength x distance/volume = pole strength/ area)

**SI units**

For the magnetic induction vector \( B \) the basic unit is the *tesla* which is one "weber per square meter" in MKS. In more basic terms, a charge of one coulomb moving with a velocity of 1
m/sec perpendicular to a field of 1 tesla produces a force of 1 newton mutually perpendicular to the velocity and magnetic vectors. The conversion to gauss is

\[ 1 \text{ tesla} = 10^4 \text{ gauss} \]

The unit most often used is the nanotesla or \( \text{nt} \), where, by an extremely fortunate coincidence,

\[ 1 \text{ nt} = 10^{-9} \text{ tesla} = 10^{-5} \text{ gauss} = 1 \text{ gamma} \]

In the SI system the unit of magnetic dipole moment, \( \text{m} \), is \( \text{ampere\textbullet turn\textbullet meter}^2 \). This comes from the fact that a circular current loop also produces a dipole. It is formed by a wire with current \( i \) wound with \( n \) turns around a loop that encloses an area \( A = \pi r^2 \) where \( r \) is the radius of the circular loop. This loop produces a simple dipole magnetic field just like the one formed by two "magnetic poles" of opposite sign separated by a small distance. In the case of the wire loop the axis of the dipole is perpendicular to the plane of the loop and the magnetic moment is given by \( i \) (amperes) times \( n \) (turns) times \( A \) (square meters). Current loops on an atomic scale formed by the motions of electrons is a more physically realistic view of magnetization, but the math involving dipole moment per unit volume is the same.

magnetization, \( \mathbf{J} \) = magnetic moment per unit volume:

\[ \text{ampere turn meter}^2/\text{meter}^3 = \text{ampere turn per meter} \]

**Magnetic field vector components**

The earth's magnetic field, \( \mathbf{H} \), is a vector field requiring three quantities for its specification. The three quantities that we will use most include the following:

\( \mathbf{I} \) = inclination of magnetic field vector with respect to the horizontal, in degrees
\( \mathbf{D} \) = declination of magnetic field vector which is the azimuth of the projection of the magnetic field vector onto a horizontal plane. The declination is measured in degrees with respect to geographic north (positive clockwise from north as 0).

In terms of structural geology, the inclination and declination correspond to the "plunge" and "azimuth" of the magnetic field vector.

\( \mathbf{F} \) = total intensity of the magnetic field vector, which is the magnitude of the vector. (don't confuse this with the \( F \) above used for force; again, the context will usually save us).
The earth's magnetic field \( \mathbf{H} \) also has the three standard components in a spherical coordinate system: \( H_R \), \( H_S \), and \( H_E \) for the radial or upwards vertical, southwards horizontal (same as \( H_\theta \) where \( \theta \) is co-latitude), and eastwards horizontal (same as \( H_\phi \), where \( \phi \) is eastwards longitude), respectively.

Magnetic observatories measure the amplitude of the horizontal component of \( \mathbf{H} \), equal to \( (H_S^2 + H_E^2)^{1/2} \). This quantity is unfortunately often referred to as \( H \) in many textbooks, just to make things confusing, so one has to be careful. Other quantities often used include

\[
Z = \text{the vertical component of } \mathbf{H}, \text{ or } H_R
\]

and

\[
D = \text{declination as defined above.}
\]