PHYS 142
Introduction to Environmental Science

The Earth in Space

A global view of environmental science must include a survey of that most remote environment, that of “outer space” and the Earth’s place within it. Tides, climate, the yearly formation of typhoons and hurricanes, the el Niño/la Niña phenomena, and other daily and seasonal phenomena, are either driven or influenced by the space environment. Solar weather has been demonstrated to influence the corrosion of pipelines, while the Earth’s geomagnetic field, when disturbed, also disturbs, or degrades the navigational faculty of many animals. In this section, we’ll examine in overview some of the salient topics associated with the Earth in space.

Diurnal and Seasonal Changes

Diurnal changes refer to those observable changes that occur on a daily basis, such as the rising and setting of the sun and moon. *Seasonal changes* refer to those whose typical effects are on the order of months rather than days or hours. For example, the well-known change in the length of days over the course of the year, the attendant change in how “high” the sun rises in the sky and the length and direction of shadows cast by your dwelling at 4:00 P.M., climactic changes, *etc*., all represent seasonal changes.

To understand these changes, it’s important to understand the arrangement of the sun, the Earth-moon system, and the remainder of the solar system—the regular movement of which impressed philosophers and scientists of the Renaissance to sufficient degree to lead them to coin the phrase “dance of the planets” to represent this movement.

The Earth, other planets, and their moons travel in their paths under the influence of the gravitational force of their *central body*. The moon has the Earth as its central body, although the moon is sufficiently massive with respect to the Earth that both bodies actually rotate about an imaginary point inside the Earth, referred to as the *barycenter*. The Earth-moon system, and the remaining planets and minor bodies (such as comets and asteroids), have the sun as their central body. In all cases, the force F_g acting between the bodies is given by:

$$F_g = G \cdot M \cdot m / r^2,$$

where G is the universal gravitational constant, M and m are the masses of the greater and lesser body, respectively, and r is the distance between their centers (or centers of mass). The force acts between the bodies in a straight line. In the case of a planet in the solar system (for example, Venus), M would represent the mass of the sun and m the mass of Venus. In the case of the Earth-moon system, M represents the mass of the Earth and m is the mass of the moon. Other members of the solar system, referred to as *third bodies*, also tug on the others *via* gravitational force. Thus, all the other planets, even tiny Pluto, are constantly “pulling” on the Earth to a greater or lesser degree. However, both the mass and distance of most planets render these pulls almost negligible as compared to the gravitational forces exhibited on the Earth by the moon (because it’s near) and the sun (because it’s massive).

Usually, M is not only greater than m but much greater than m (remember, not really true for the Earth and moon). In this case, it's common to discuss these systems in terms of a (near) stationary central body of mass M and an orbiting second body of mass m. The speed of the orbiting body around its orbit is related to gravitational force by the general equation for the centripetal force F_c:

$$F_c = m\cdot v^2/r = m\cdot r\cdot \omega^2,$$

where v is the speed of the orbiting body of mass m, ω (Greek lower case "omega") is the angular speed, and all other variables are as defined previously. Here, v is measured in units of miles per hour or km per second, while the angular speed is the number of degrees traversed in a certain amount of time. Both representations are equally valid and use is generally dictated by the user's preference. To illustrate the concept of angular speed, consider the Earth: one orbit, or 360°, is traversed in approximately 365.25 days; thus, the Earth's angular speed is 360° per year or approximately 0.98° per day.

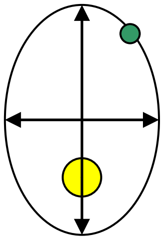
Working together, these simple equations determine the orbital speed (or angular speed) given the masses of the two attracting bodies and the distance between them. Mathematically,

$$F_g = F_c\text{; hence,}$$

$$G\cdot M/r = v^2$$

where like terms have been canceled algebraically. Taking the square root of both sides yields the velocity.

This is exactly the same case as a rock or other object on a string. If one twirls the string, the object will "orbit" your hand—in this case, the tension force in the string appears in the role of gravity. Increasing the length of the string results in a bigger orbit, though the object revolves more slowly. Decreasing the length of string speeds up the object. Finally, cutting the string would send the object flying off tangentially to its orbital path. In the absence of gravity, the same thing would happen to the planets and their moon. Perhaps the biggest difference between orbiting bodies and our object on a string is that the latter either travels in a circle or spirals inward at the string wraps around our finger. Planets and other bodies generally travel in elliptical orbits, or orbits whose shape is an ellipse, as depicted in Figure 1. Only in the case of zero (0) eccentricity does the ellipse turn into a perfect circle.



A: long (major) axis
B: short (minor) axis

Eccentricity:

$$\frac{\sqrt{A^2 - B^2}}{A}$$

Figure 1. An elliptical orbit.

In addition to forces and speeds acting on, or displayed by, a body or system of bodies, it's important to understand the geometry, or positions and orientations, of bodies. We'll limit ourselves to the Earth-sun system in this discussion, as its most pertinent to our study. Two coordinate systems are used to express the geometry found in this system. The first, the *heliocentric* coordinate system, is sun-centered as its name implies. The second is centered on the Earth and is named the *geocentric* coordinate system.

In the heliocentric system, the orbit of the Earth defines a plane in which the sun is at the origin and the Earth rotates in the plane. The orbits of the moon about the Earth and the other planets and minor bodies about the sun are inclined to various degrees about this plane. The planet with the greatest inclination, Pluto at 17.1° inclination, is also the planet with the most eccentric orbit; at times, Pluto's orbit dips below that of Neptune, nominally the eighth planet. The body's spin axis may also be inclined, or tilted, with respect to its orbit. This angle is called the obliquity of the ecliptic and, in the case of the Earth, is approximately 23.5°. In the case of Uranus, the spin axis is tilted 97.9°, leading at times to the appearance that Uranus is "rolling" about its orbit like a barrel. Such a condition, responsible for climactic changes on Earth, must lead to very interesting seasons on Uranus. These situations are shown in Figure 2 for the Earth-sun system and Figure 3 for the sun-Pluto system.

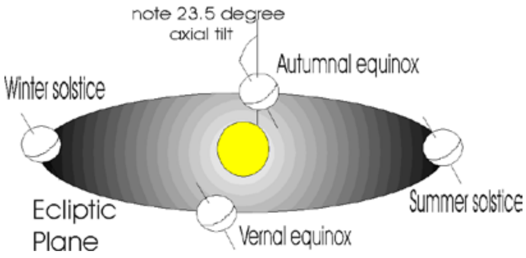


Figure 2: the Earth-sun system

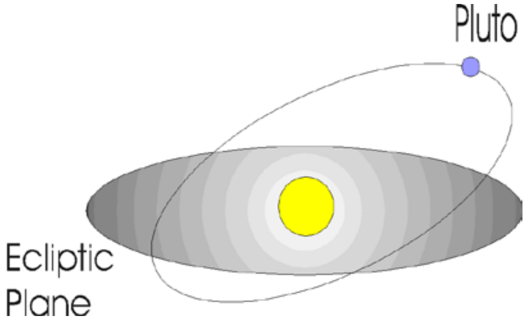


Figure 3. Orbital Inclination Illustrated

In the case of the geocentric coordinate system, the primary plane is defined by the Earth's equator. Hence, the moon, the sun, and all other celestial objects move with respect to this coordinate system. Their positions are usually defined in terms of their *declination* (similar to north and south latitudes) and *right ascensions* (similar to east and west longitudes). In this system, the obliquity of the ecliptic leads directly to the Tropics of Cancer and Capricorn on maps of the Earth's surface. Scrutiny of any world map will reveal that these imaginary lines lie at 23.5° north and south latitudes, respectively—in the geocentric coordinate system, they represent the limits of latitudes at which the sun may ever be directly overhead. For latitudes greater than these Tropics, the sun never rises to 90° above the horizon, but some lesser angle. In fact, the angle between the sun at local noon and the horizon was one of the first navigational techniques in common use, and let a sailor determine his latitude easily.

Tides

Tides, and their observation by humans in their commerce and everyday lives, represent a primary manifestation of the effects of non-earthly influence. Their clockwork-like precision is a direct product of the "dance of the planets". Less obvious until recent times, this dance also influences the solid Earth as well as the hydrosphere. These body tides (of much lesser magnitude, of course, than oceanic tides) are of sufficient magnitude to influence the navigation of Earth satellites due to the gravitational perturbation of their orbits. However, in this section, we'll discuss only oceanic tides, as they directly influence many segments of environmental science.

As in our previous discussion, the moon is of course much closer to the Earth than the sun. Because of this proximity, the gravitational pull of the moon is about twice that of the sun. Therefore, Lunar gravity is the primary driver of the tides in the Earth's oceans, and tends to pull the ocean's waters into two bulges. One is on the side of the Earth facing the moon, while the other is on the opposite side of the Earth. The sun produces similar, though smaller, bulges in the waters. Tides are the resultant of these two pulls. Tidal extremes occur twice a month. At the new moon, the moon is between the Earth and the sun; at full moon the moon lies on the opposite side of the Earth as the sun. At these times, the gravitational forces act in a line to produce tides higher than at other times. Such tides are called *spring tides*. When the moon is in its first or last quarters at "half moon", the forces pull at right angles to each other, producing the minimal tides called *neap tides*. Because the Earth is spinning about its own axis, point on the coasts experience a cycle of high and low tides each day. Actual tides also depend upon the shape of the coastline and the local depth of the water, as certain local features can lessen the tides or lead to exaggerated tidal variation between high and low tide. Also, because the moon's orbit is inclined with respect to the ecliptic plane, there exists a regular and predictable variation between the northern and southern hemisphere's tides.

Equinoxes and Solstices

An *equinox* ("equal night") is defined as that time when the sun passes across the celestial equator in the geocentric coordinate system. This is also the time when the day and night are equal in length and the sun is directly over the equator on the Earth's surface. This occurs twice a year. The *Vernal equinox* occurs on or about 21 March and marks the beginning of Spring in the northern hemisphere. The *Autumnal equinox* occurs on or about 23 September and marks the beginning of Fall in the northern hemisphere. Remember that the seasons are reversed in the southern hemisphere.

A solstice ("sun" + "stationary") is defined as an extreme in the length of daylight. The *Summer solstice* occurs on or about 21 June in the northern hemisphere and marks the beginning of Summer. This is also the longest day of the year, in terms of daylight hours. The *Winter solstice* occurs on or about 21 December in the northern hemisphere, and marks the beginning of Winter as well as the shortest day of the year in the northern hemisphere. Again, the seasons are reversed in the southern hemisphere. Thus, the Winter solstice marks the beginning of Summer in the southern hemisphere. In terms of the geocentric coordinate system, these points mark those times when the Earth's axis is inclined at its maximum with respect to the sun.

The Sun

The star nearest the Earth, our sun, provides the Earth light and warmth through its radiation. The sun is a typical, comparatively young, star in terms of size and radiation output. To understand its import, we'll review its structure, behavior, and radiation transport to the Earth. In addition to radiation, the sun is the central body of the solar system, containing approximately 99.9 % of its total mass. As such, the sun controls the motion of the planets and minor bodies within the system.

As a star, the sun is a ball of glowing gas. Energy (on the order of 3.9×10^{26} W or 5.2×10^{23} h.p.) is produced by nuclear fusion in the inner reaches of the sun and the energy thereby released heats the outer layers of the sun which are observable from Earth. Like a planet, the sun rotates on an axis. Unlike planets, however, different latitudes of the sun rotate at different rates. This is due to the fluid behavior of the sun's gaseous constituents. The period of rotation is about 24.7 days at the sun's equator and 34 days near the poles. Because of its structure and rotation rate, the sun also tends to flatten at the poles and bulge at the equator.

Those portions of the sun visible from the Earth are the *photosphere*, the *chromosphere*, and the *corona*. Each represents not a solid surface but a layer of gas. What differentiates each is the density and temperature of the gas. For any fluid, including gasses, temperature is directly related to molecular speed. Therefore, a "hot" gas is one which has a large *mean (average) free path,* or a long time between collisions with other molecules in the gas. For this to be true, the gas usually is of a low number density (number of molecules per unit volume). If the gas is very dense, then the molecules are crowded together, such that any molecule traveling through this gas will not travel far before undergoing a collision. Forces acting on the particle would not have a long time to accelerate the particle again before it undergoes another collision. Therefore, a "cold" gas corresponds to a relatively dense gas. Applied to the sun, we categorize the photosphere as a layer of relatively dense gas overlying the interior of the sun. Thickness of this layer is on the order of hundreds of km, and its "surface" is characterized by a granulated appearance due to the upwelling of hot gasses and subsequent sinking of cooled gasses in a convection process. Whereas the sun's interior temperature is estimated to be on the order of 15-20 million K (degrees Kelvin), the photosphere's temperature is only about 6000 K. This is the portion of the sun we see as the "yellow ball" in the sky, hence the name derived from "light sphere". This layer also marks a transition region to the chromosphere.

This layer, with a thickness on the order of thousands of kilometers, is composed of tenuous gas of relatively lower density subjected to the sun's strong and highly variable magnetic field. For that reason, temperatures rise up to approximately 1000000 K. The chromosphere ("color sphere") is visible as a pinking-orange glow during total solar eclipses or using special occulting telescopes to block out the much brighter photosphere. The chromosphere features considerable structure, as gasses are entrained (picked up) by the solar magnetic field and transported over the sun's surface in the form of *spicules*, *fibrils*, and *plages*. Spicules resemble spikes or blades of grass in shape. Fibrils are long strands of gas which flow over the surface. Plages are bright, hot patches. Several of these features are perhaps better known as *flares*, *prominences*, and *filaments*. These features are partially responsible for streams of particles which are ejected into space as the solar wind (*q.v.*).

Above the chromosphere lies the corona ("crown"). This layer extends out into space and is also a source for the solar wind. Because of a very low gas density in the corona, temperatures rise to approximately 4000000 K. Because of this extremely high temperature, the corona is a strong emitter of X-ray and ultraviolet radiation.

The Solar Cycle

Earlier, reference was made to the rotation of the sun. As the sun is a gaseous body, and most phenomena resident in the photosphere or chromosphere either have lifetimes much shorter than a day or are too miniscule (relatively speaking) to observe without sophisticated instruments, how did scientists and observers prior to the Enlightenment establish this rotation rate? The answer is provided by *sunspots*. These spots, literally appearing as blemishes or blotches on the surface of the sun (photosphere), provide a clear indication of the rotation rate. Single spots, or families of spots, rotate about the sun at a rate proportional to the latitude. Equatorial sunspots, for example, travel the fastest, overtaking spots at higher latitudes. By careful timing, the rate was established by observers as early as 1610.

Physically, the spots are relatively cool areas on the surface of the photosphere; sunspots exhibit very strong magnetic fields, thus providing order to the local molecules and hence cooling them. In addition to providing evidence of solar rotation, the number of spots is also strongly correlated to the overall output of solar radiation. At times of minimal activity (which includes historical cases of no observed sunspots), the radiation emanating from the sun is also at a minimum. As the number of sunspots or sunspot groups increases, so does the number of flares, prominences, and overall radiation. Because of this clear correlation, depicted in Figure 4, these times are called *Solar Minimum* and *Solar Maximum*, respectively.

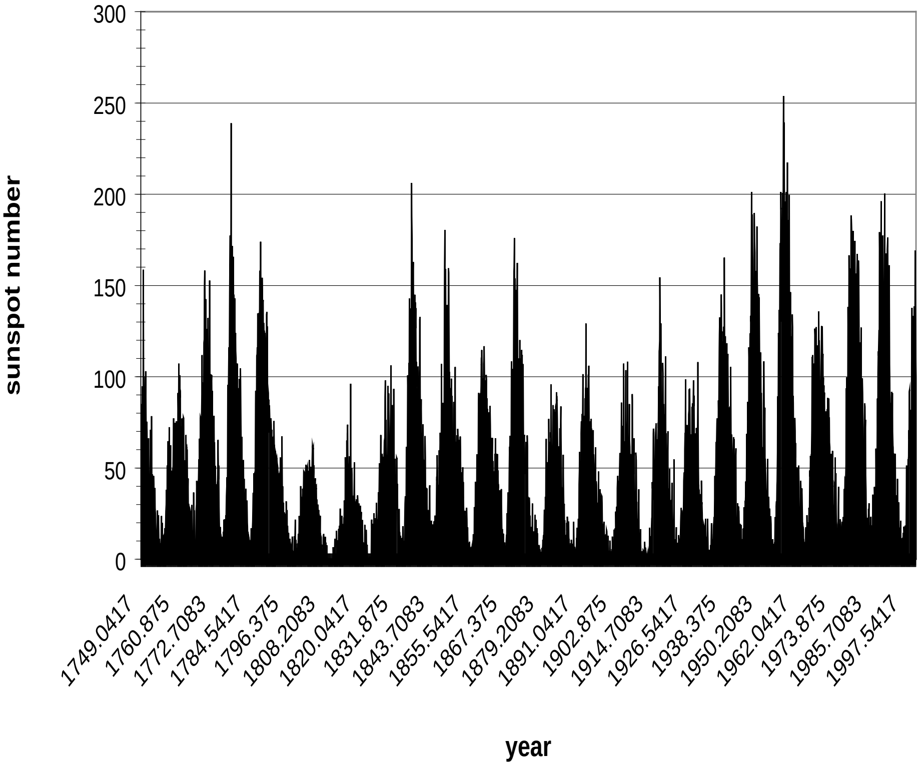


Figure 4. Solar sunspot activity. *Note.* Original numerical data from the National Geophysical Data Center (www.ngdc.noaa.gov).

Prominent among the data portrayed in Figure 4 is the regular periodicity of the sunspot cycle. This cycle, approximately 11 years from Solar Maximum to Solar Maximum, is well known. However, a 22 year cycle is also evident, and longer period cycles (on the order of 80 years) may exist as well. Consequences of this cycle vary. For example, during the period of the “Maunder Minimum” (1645-1715), few if any sunspots were noted. This corresponds to the so-called “Little Ice Age” evident in Europe at that time. More recent data indicate that times of Solar Maximum exhibit significantly enhanced periods of auroral phenomena and a disturbed geomagnetic field, a denser atmosphere at high altitudes, and periods of enhanced or crippled radio communication. The reader should note that, despite the apparent regularity of the sunspot cycle, efforts to predict solar activity have demonstrated only limited and short term viability.

The Solar Wind

The solar wind, also correlated with the solar cycle, is composed primarily of protons (hydrogen nuclei) and electrons. Helium nuclei (composed of two protons and two neutrons, also known as alpha particles) are occasionally observed. Being a continuous stream of particles emanating from the chromosphere and corona, the term “wind” is particularly apt. This wind travels outward from the sun at speeds of up to 800 km per second and has a typical density, at the Earth’s orbit, of five (5) protons and electrons per cubic centimeter. However, dense structures capable of transporting segments of the sun’s magnetic field (termed the sun’s magnetic field being “frozen into” the wind) are occasionally observed.

The Earth’s magnetic field (the geomagnetic field) both deflects and traps solar wind particles. In deflecting the solar wind, the geomagnetic field is compressed towards the surface of the Earth, leading to the “bow shock” phenomena (similar to the bow wake created by a ship). Compression of the geomagnetic field on the sunlit side of the Earth also compresses the ionosphere below it, as manifested by reduced ranges for AM radio stations during daylight hours. As the solar wind “flows” over the surface of the geomagnetic field, some particles are funneled down into the north and south geomagnetic poles. This flow of particles replenishes the Van Allen radiation belts and create the auroral phenomena visible at high latitudes. Particularly severe solar activity can sometimes produce aurora as far south as New Mexico and Texas due to an increase in the number of solar wind particles.

Particles and Fields

The term “radiation”, as used to describe solar output, is perhaps too general. This term refers both to physical particles as well as electromagnetic traveling waves/particles. The former are sometimes termed “corpuscular radiation”, while the latter are best represented by photons and wave phenomena. Photons, best known as “light particles”, exhibit both wavelike and particle-like properties; hence, they are sometimes termed “wavicles”. Photons also carry electromagnetic radiation from X-rays (high energy) to radio waves (low energy). Magnetic fields affect both the trajectory and energy of particles and photons. Therefore, an overview of these physical phenomena is presented below.

Radiation Transport

The interaction of radiation with matter and fields is manifested in a variety of ways. In this section we’ll examine several radiation transport mechanisms, including ballistic-thermal motion, force field motion, scattering, absorption and re-emission, and reflection/refraction.

Ballistic motion is motion under the influence of gravity. An example is provided by the motion of a cannon ball fired from the surface of the Earth. Neglecting air drag, the projectile will move in a parabolic path from cannon muzzle to impact point. Large (macroscopic) particles ranging from micrometeoroids to planets exhibit ballistic motion. Thermal motion is influenced by ambient heating conditions and, referring to a previous section, is a function of local particle density. Neutral particles, such as molecules and neutrons, may undergo ballistic motion, thermal motion, or a combination of the two.

Force field motion is characterized by particles under the influence of a local force field; as such, ballistic motion is a subset of force field motion. In a more general sense, the field may be electric, magnetic, or both. Charged particles such as protons and electrons are deflected by local magnetic fields and may even be trapped by them. The Earth's radiation belts are examples of trapped radiation.

Scattering may occur as a special case of force field motion. In gravitational scattering, a planet may "sweep out" small particles in a region of space due to its gravitational attraction. Charged particles may also scatter from each other. In the case of particles of like charge, the particle will experience a repulsive force which grows stronger as they approach each other. In the case of particles of like charge, the particles will experience an attractive force which increases in magnitude as they approach each other. The latter case is identical to gravitational scattering.

Capture and re-emission describes the action of photons on matter. During capture phase, a photon increases the energy of an atom by promoting orbital electrons to higher quantum energy levels. The excited electron may then fall back to a lower energy state by emitting a photon of equal or lesser energy.

Conservation of energy requires that energy is not lost in transport. Energy lost by one particle is transferred to other particles during collisions, as is well known. Less appreciated, perhaps, is conservation of energy that occurs during the interaction of photons with matter or, in general, wave phenomena crossing the interface or boundary between different materials. This conservation may be summarized as:

Incident energy = (reflected energy) + (absorbed energy) + (transmitted energy).

This simple relationship is applicable to small scale phenomena, such as light transiting a pane of window glass, as well as large scale (planetary) phenomena. An example of the latter is provided by the Earth's *radiation budget*. This "budget" refers to the total amount of incoming solar energy and its disposition in the atmosphere and at the surface. For example, incoming photons may be absorbed in the atmosphere, reflected from the surface (in the case of high albedo—reflectivity—portions of the surface, such as snow and ice), or absorbed by the surface (in the case of low reflectivity structures such as tarmac and buildings, or forests). This topic shall be addressed in much more detail in the text, as it is of fundamental importance in many environmental processes.

The Electromagnetic Spectrum

The electromagnetic spectrum comprises photonic radiation of various energies and wavelengths. As discussed in Topic 1, entitled "An Introduction to Science", energy is directly proportional to frequency and inversely proportional to wavelength. The spectrum is presented in Figure 5.

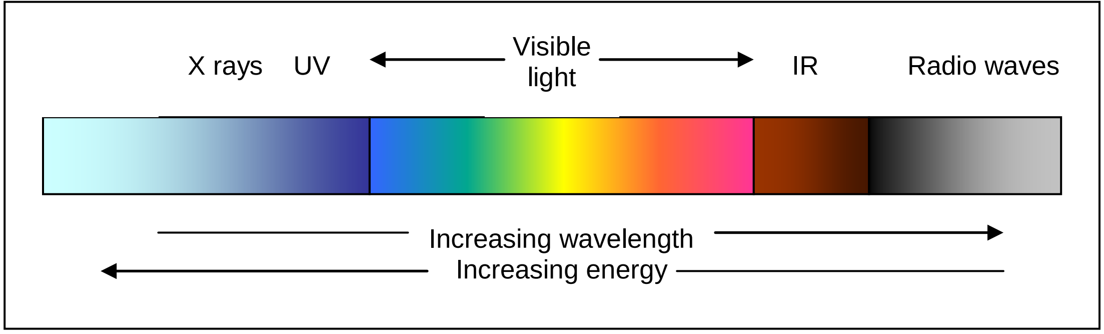


Figure 5. The electromagnetic spectrum.

Solar output is primarily in the visible light portion of the electromagnetic spectrum. However, the high energy portion of the sun's spectrum is of interest because of its environmental effects. For example, the ultraviolet portion of the spectrum is responsible for heating the upper atmosphere.

Particles

Macroscopic Particles

Macroscopic (large) particles, in this context, are particles ranging in size from several molecules to planets. In terms of numbers, smaller particles obviously predominate. These particles may be left over from the formation of the solar system, have been liberated from the surface of a planet, comet, or moon due to impact, or be scattered into the solar system from interstellar space. In general, these "smaller large" particles are referred to as micrometeoroids.

Meteoroids are classified by their constituent material and in general fall into the iron, stone, or stony-iron categories. Each category has several subcategories based on exacting mineralogical standards. For example, consider stony meteoroids. Composed of silicate materials, they may be further described as being chondrites (*i.e*. containing chondrules, spherical bodies that appear to have their origin in molten droplets) or achondrites (*i.e*. those lacking chondrules in their structure). Iron meteoroids are composed mostly of alloys of iron and nickel. Stony-iron meteoroids are composed of silicates and metals in approximately equal amounts. Various hypotheses also characterize these particles according to their supposed origins amongst the asteroids, comets, impact ejecta, interstellar dust, *etc*.

Microscopic Particles

In the context of this overview, microscopic particles are those of atomic sizes and smaller. These include two main categories. The first category are the fundamental particles that serve as building blocks for atomic structures. The second are elemental atoms referred to as *cosmic rays*.

Fundamental Particles

This class of particles include neutral particles (neutrons) as well as charged particles and even assemblages of the two types. Charged particles, the basic constituents of atomic structure, are the electron (negative electrical charge) and the proton (positive electrical charge). Electrons are sometimes referred to as "beta particles" or "beta radiation". "Alpha particles/radiation" refers to a combination of two protons and two neutrons, a structure identical to a fully ionized helium nucleus. The term "fully ionized" indicates that the particle is at its maximum electrical charge state, in this case +2. This state is achieved by removing all of the helium's electrons. A partially ionized helium would be at a +1 charge state, as only one (of two) electrons had been removed. Atomic helium is electrically neutral, as are all other un-ionized (neutral) atoms.

Cosmic Rays

Cosmic rays are not "rays" *per se* (as this leads one to suspect a photon ray, such as a beam of light), but instead are ionized elemental atoms. Due to their very high energies, they are sometimes treated as high-frequency matter. Cosmic rays are classified into two categories according to their source: the sun or the galaxy as a whole.

Solar cosmic rays (SCRs) consist primarily of high-energy protons or alpha particles. Energies are typically on the order of 1 MeV to 1 GeV per nucleon (1 electron volt [eV] = 1.6021×10^{-19} J, a large amount of energy for a single, microscopic particle). The flux of SCRs generally follows solar activity, being greatest around Solar Maximum. The Earth's magnetosphere provides shielding to a limited extent. Galactic cosmic rays (GCRs) consist of approximately 2 % electrons with the remainder consisting of either protons or ionized nuclei up to and including ionized nickel atoms. Particles with nuclear mass greater than nickel are rare. The energy range for GCRs is between approximately 10 MeV to more than 10^{16} eV per particle. GCRs appear to emanate from all directions of the celestial "sky".

Energy and Momentum

Energy determines the ability of radiation to penetrate materials and is proportional to radiation damage. In the case of non-relativistic particles, the kinetic energy of particles is given by:

$$E = ½\cdot m\cdot v^2 \quad ,$$

where the variables are as defined previously. In the case of photon radiation, energy is expressed by:

$$E = h\cdot f = h\cdot c/\lambda \quad ,$$

where h is Planck's constant, f is the frequency of the photon, c is the speed of light, and λ is the wavelength of the photon. Long wavelength radiation, such as radio waves, therefore exhibit lower energy than shorter wavelength radiation such as, for example, ultraviolet photons.

Momentum is generally a measure of mass and velocity. For non-relativistic corpuscular radiation, we may express the particle's momentum by:

$$p = m\cdot v \quad .$$

In the case of photon radiation, energy and momentum are related by:

$$E = p\cdot c \quad .$$

Penetration of particles or photons can produce a force on a object, produce radiation damage, or cause the re-emission of a photon. A force is created a particle being decelerated inside a material, and is proportional to the distance over which the particle is brought to a stationary state. Alternately, a force is created by the rate of change of momentum over some time. Photon re-emission is caused by the excitation of an atom struck by a photon and the subsequent release of this stored energy.

Gravitation

Gravitation is a property of matter and, as previously discussed, manifests itself as a force capable of acting over distances on the order of universe in size. Two Gravitational Theories exits. The *Newtonian Theory* is predicated upon the force acting between two bodies, each possessing mass. In contrast, the *Theory of General Relativity* treats gravity as a distortion in the space-time continuum. In this Theory, gravity may be visualized as the displacement of a hammock (space-time) by an occupant (a mass). In an earlier section we discussed the

Newtonian gravitational force acting between central and orbiting bodies. In this section we'll examine in greater detail the gravitational fields of the Earth and moon.

Higher fidelity gravitational field models are usually presented in terms of a gravitational potential. This potential includes terms determined from both survey and space probe data, and accounts for asymmetries in the Earth's field due to body tides (*q.v.*), the continental mass distributions, the flattening of the Earth at the poles, the slight pear shape of the Earth, *etc*. The Newtonian gravitational force (or any force in general) is derived from the potential by calculating the rate of change of the potential as one moves closer or further away from the gravitating body, *i.e*. the gradient of the potential.

The gravitational field of the moon is significantly more complex due to the presence of mass concentrations, or *mascons*, in the moon's internal structure. Mascons appear to be not far beneath the Lunar surface. The field has been mapped by Lunar satellites, whose orbital lifetimes are generally short due to being perturbed into the moon's surface by the gravitational field.

Geomagnetism

Magnetic fields appear to be a property typical of bodies with active cores. The Earth, the sun, and Jupiter all possess magnetic fields of varying strength, while space probes have detected only weak, at best, magnetic fields for the moon, Venus, and Mars. In this section we'll provide an overview of the Earth's magnetic field, or the geomagnetic field.

In its simplest form, any magnetic field may be described as a dipole ("two pole") field. This is because all magnets possess a north and south magnetic pole, whether discussing laboratory bar magnets or the sun itself. In any of these cases, the cross-sectional shape of the magnetic field is as shown in Figure 6. In the dipole field, the magnetic field is always considered to emanate from the magnetic north pole and to return into the magnetic south pole. Field strength is strongest at the poles, weakest at the equator, and generally decreases in strength as one moves farther away from the poles.

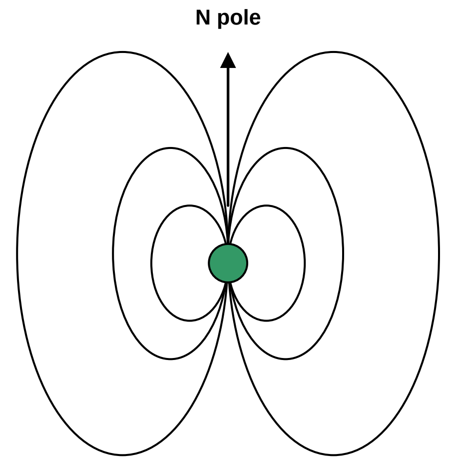


Figure 6. The dipole magnetic field.

The most popular hypothesis as to the origin of planetary magnetic fields is the "dynamo model". This model is predicated upon the circulation of electrical currents in the liquid metal core of the Earth. These currents create corresponding magnetic fields which are sustained by the continuing circulation of these currents. In this sense, the model portrays the spinning core of the Earth as being similar to an electrical generator or dynamo.

A property of planetary and solar magnetic fields is pole reversal. In the case of the sun, this takes place approximately 1-2 years after sunspot minimum. In the case of the Earth, reversals occur on the time scale of hundreds of thousands of years. At the current time, the geomagnetic field strength is in decline (decreasing approximately 5 % over the last century) and a reversal is generally deemed overdue. The time period during which the geomagnetic field decreases to zero and then re-orients itself is not well understood. During that time when the field is very weak or near zero strength, the solar wind and the majority of solar cosmic rays will not be deflected and could impart energy to the upper atmosphere directly, as they do the Lunar surface. The ecological and environmental effects of such a bombardment are not understood. Efforts to correlate historical environmental events, such as mass extinctions, have not proven conclusive.

The geomagnetic field, as measured by space probes, extends at least to 100 Earth radii in the direction opposite the sun. This stretching is caused by the impact of the solar wind against the sunlit side of the field and is a corollary of the sunlit side's "bow shock". As explained previously, this shock is responsible for compressing the Earth's magnetic field down towards the surface of the planet. Thus, Figure 6's symmetric shape becomes distorted into a (near) tear-drop shape, with the point in the opposite direction of the sun. The shape is qualified because the "funnels" still exist at and near the poles of the magnetic field.

Resources

A large number of INTERNET websites provide both general and specialized information regarding the topics discussed. Some of these site's URLs are (as of October 2000):

www.swpc.noaa.gov, the Space Environment Center site;

www.ngdc.noaa.gov, the National Geophysical Data Center site, maintained by the National Oceanographic and Atmospheric Administration;

http://science.nasa.gov/, a Space Science home page for NASA; and

Books dealing with the topics discussed include basic texts in physics, astronomy, and geology. Many atlases also contain information related to Earth in Space in their introductory sections. More specialized and in-depth coverage is offered by books such as:

Moore, P., and Hunt, G., (1983) *Atlas of the solar system*, Rand McNally.

and

Bowers, R., and Deeming, T. (1984) *Astrophysics* (two volumes). Jones & Bartlett.

Many specialized journals also exist. Preeminent among them are:

- Icarus, the journal of solar system studies, and
- The various parts of the Journal of Geophysical Research.