



PART SIX

Space

Chapter 24

SPACE ENVIRONMENT

Space. The Final Frontier. These are the voyages of the Starship Enterprise. Its continuing mission—to explore strange new worlds, to seek out new life and new civilizations, to boldly go where no one has gone before!

Gene Roddenberry, Introduction to Star Trek, The Next Generation

Space is the final frontier. Though we are a long way from building our first starship, we get closer every day. There are many reasons why we seek to explore and exploit space. From space we get a global view of the Earth and we can see the universe more clearly. Space also holds the promise of abundant resources such as solar energy and minerals from other planets. Finally, space provides a unique environment that is useful in making new materials.

The higher you are, the more you can see. Throughout history people have sought high places from which to observe the terrain around them. Armies have fought great battles to win the high ground to enable them to see, control and defend the land below.

Landowners built great towers from which they could survey the condition of their fields and to spot the approach of strangers and potential threats. Space offers the ultimate high ground above Earth. From space we can see large parts of the Earth's surface and orbiting satellites allow us to see the entire planet.

The universe is more visible from space. When we view the stars through Earth's atmosphere, they appear to twinkle or scintillate. This scintillation is caused by turbulence in the atmosphere that alters the light from the stars. The atmosphere also blocks some of the light. By placing observatories in space, we can get a clear view of the universe without atmospheric interference.

Exploitation of space offers new sources for minerals and energy. Scientists speculate that vast sources of minerals exist on the planets, Moons and asteroids in our Solar System. The Moon for instance, is rich in aluminum. Lunar soil is also rich in oxygen that might be used to sustain operations in space by providing breathable atmosphere. The oxygen in the soil might also be used as a rocket propellant. Energy from the Sun, unobstructed by the Earth's atmosphere, currently provides limitless power for spacecraft and may one day provide power for colonies in space.

Finally, the unique environment in space allows production of new metal alloys that are difficult, if not impossible, to produce in Earth's gravity. Objects orbiting around the Earth are actually constantly falling toward the Earth, but the path of their fall exactly matches the curvature of the Earth (see illustration). Because there is nothing to stop their fall, they are said to be in free-fall. And, with no opposing force, the object experiences weightlessness. We can experience the principles of this effect if we descend a tall building in a high-speed elevator. As we begin to descend, we briefly experience a sense of reduced weight. If the elevator descended fast enough, we would experience weightlessness.

It is this weightless condition that is so important to manufacturing new alloys. Combining different metals in exact proportion produces these alloys. Because the metals have different weights per given volume (also known as density), gravity tends to pull the higher density ones to the bottom, thus preventing a uniform mixture. In a



Imagine a cannon firing a projectile horizontally from a tower high above the Earth. The projectile will follow a curved path as it falls back. If we progressively increase the power of the cannon shot, we will reach a point where the curved path of the falling projectile will match the curvature of the Earth. At that point, the projectile will have attained orbital velocity.

Picture credit: Astronomy 161, The Solar System

weightless environment, they all weigh the same so they can combine evenly.

While the space environment provides some unique advantages, it also presents some big challenges, as we shall see. There are millions of interesting objects in space. Astronomers look at them all and many are the subjects of our space programs. We will discuss many of the manned and unmanned programs, past, present, and proposed.



Objectives

- List** four reasons to explore and exploit space.
- Define** the lower limits of space.
- Define** cislunar space.
- Describe** the contents of cislunar space.
- Describe** interplanetary space.
- Describe** interstellar space.
- Describe** the characteristics of the Sun.
- Describe** the solar magnetic field.
- Identify** two solar cycles.
- Identify** the divisions of the Sun's atmosphere.
- Identify** three solar phenomena.
- Define** solar wind.
- Identify** three categories of solar emissions and their sources.
- Describe** the Earth's ionosphere.
- State** the causes of ionization.
- Identify** types of ionospheric behavior.
- Define** atom and ion.
- Describe** the general characteristics of the magnetosphere.
- Explain** the effect of solar wind on the magnetosphere.
- Describe** cosmic rays.
- Describe** the structure of the Van Allen radiation belts.
- Identify** the content and cause of the belts.
- State** the hazards identified with the belts.
- Describe** the characteristics of magnetic storms.
- Identify** the effects of the space environment of communications.
- Identify** the effects of the Earth's atmosphere on spacecraft.
- Identify** the effects of vacuum on spacecraft.
- Describe** the electrostatic charging that affects spacecraft.
- Explain** the dangers from collisions in space.
- Identify** the effects of the space environment on manned operations.



Definition of Space

What is space? Space is a place that extends infinitely in all directions and contains all of the stars, planets and galaxies in the universe. This is true, but is not a very good definition. The big question is “where does the Earth’s atmosphere end and space begin?” There are several definitions of space but the most widely accept level is 62 miles above the Earth. When the Ansari family offered a \$10,000,000 prize for a privately-funded aerospace craft to go in to and return from space, a parameter of 62 miles, or 100 kilometers was established as space. On the other hand, NASA awards astronaut wings to persons who fly above 50 miles altitude. Another phrase that has been used for years is outer space. The academic community defines this as the space beyond Earth’s atmosphere to the ends of the known universe. The minimum altitude required for a satellite to sustain a stable orbit is approximately 100 miles above the Earth. Most shuttle missions require ranging from 115 to 250 statute miles. A one-way trip to the Moon is ruffly a quarter of a million miles.



Cislunar Space

Description

The dimensions of cislunar space, the space between the Earth and the Moon, vary from month to month since the Moon’s orbit about the Earth is elliptical, with its closest distance (perigee) being 221,600 miles, and its farthest distance (apogee) 252,500 miles (values are close approximations).



This would be the same as traveling from New York to California 75 times. Since the Moon rotates around the Earth, the actual space that forms the sphere of ... diameter of this sphere averages about 474,000 ... with a circumference averaging approximately 1,489,000 miles. Thus, the Moon travels this distance in its orbit around the Earth as it establishes the outer border of cislunar space.

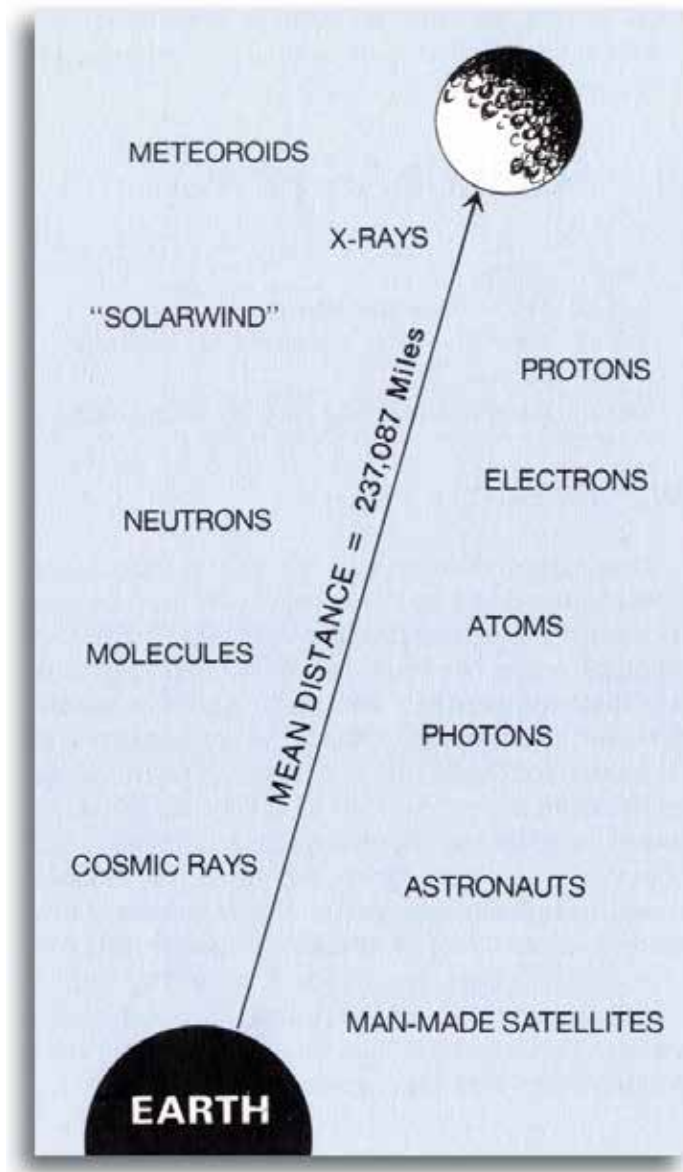
Cislunar Space—Is it a void?

What would an astronaut find in this area called cislunar space? It is certainly not the void as portrayed in science fiction movies. The Earth's magnetosphere extends thousands of miles outward through cislunar space and onward to the Sun. The Sun's solar wind presses the magnetosphere and its contents beyond the Moon's orbit. So, a portion of Earth's magnetosphere is found within cislunar space. The magnetosphere also contains mass in the form of protons and electrons.

Magnetic lines of force from both the Earth and the Sun emanate into cislunar space. These magnetic lines of force are added to the Moon's very weak, but measurable magnetic field.

Besides the radiation storms emanating from the Sun, which bathe all of cislunar space, there are cosmic rays. These tiny charged particles cannot be seen, but the photons of the visible light spectrum generated by the Sun are visible. The Sun's photons can also be seen as some are bounced back through cislunar space after striking the Moon's surface. Photos from other stars in our Milky Way Galaxy travel through cislunar space to reach Earth.

Meteoroids, asteroids, comets and spacecraft, can all be found in this space. So it is not a void, it's just that most of its contents are invisible to the unaided eye.



Dimensions and Occupants of Cislunar Space

Interplanetary Space

Interplanetary space is that region of outer space that extends spherically from the Sun past the outermost planet to what is known as the heliopause (defined as the region where the Sun's influence is no longer dominant). According to data sent back by the Voyager 1 space probe, the heliopause has been located at approximately 11 billion miles out from the Sun. Within the region of interplanetary space are the Sun, the known planets and their moons, a huge belt of asteroids, minor planets (to include Pluto), charged particles, magnetic fields, cosmic dust, and more.

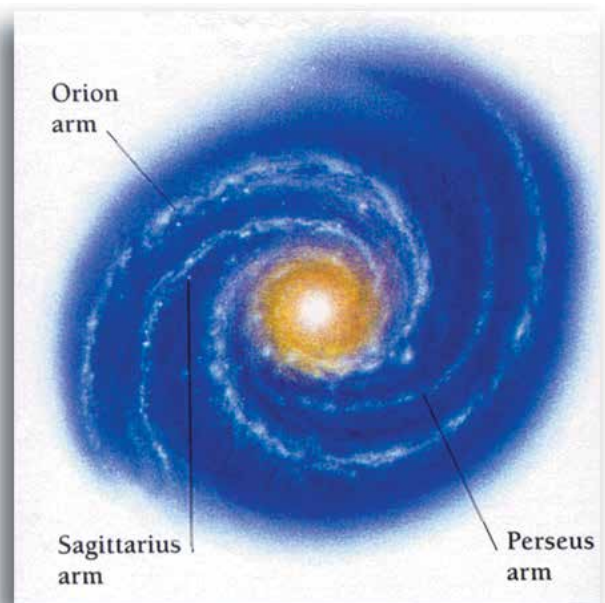
Interstellar Space and Beyond

On clear nights, nights free of clouds and air pollution, the Milky Way is visible. This is a common name for the galaxy in which we reside, along with about 100 billion other Solar Systems and stars. The distance between the extent of one Solar System and the beginning of another Solar System is called interstellar space.

Distance between the stars and/or Solar Systems varies and involves such high numbers of miles that the imagination is staggered. In this case, distance is thought of in light years and parsecs instead of astronomical units (a single unit being the mean distance between the Sun and the Earth). A light year is the distance a photon can travel in one of Earth's calendar years. This amounts to 5 trillion 878 billion statute miles (5,878,000,000,000 miles). When the number of light years gets very large, parsecs are used; one parsec is 3.26 light years, or 19.2 trillion miles.

So, how far into this interstellar space would a person travel to find another Sun and/or Solar System? Astronomers believe a person would have to travel $4 \frac{1}{3}$ years at the speed of light to reach it. However, this would be a nearby Solar System. Other stars and Solar Systems are much farther away.

Beyond Interstellar space is the realm of intergalactic space, or the space between the galaxies. It is the term that describes the broadest spatial dimensions used in astronomy. It is considered to contain the "emptiest" parts of the Universe, with very little cosmic dust or debris. Scientists have calculated that there is probably only one hydrogen atom per cubic meter (nearly a perfect vacuum).



Overhead view of our galaxy. Seen face-on, the Milky Way's central bulge of stars is surrounded by spiral arms.

Sun

Characteristics of Our Sun

The force at the center of our Solar System is the Sun. Although the Sun is only a medium-size star, its dimensions, power, composition, temperature and other factors stagger the imagination. The Earth has a diameter of a little less than 8,000 miles; the Sun's diameter is 864,000 miles. The Sun is the



strongest gravitational force in the Solar System. Its gravity controls the orbital paths of all the objects in the Solar System. The Sun emits enormous amounts of energy. How does the Sun do what it does? No one has all the answers as to exactly how all the pieces of the solar puzzle fit together. It is generally accepted that the Sun is a giant thermonuclear reactor. Thermonuclear reaction is the nuclear fusion of atoms under pressure and heat into different atoms. This fusion process releases tremendous energy.

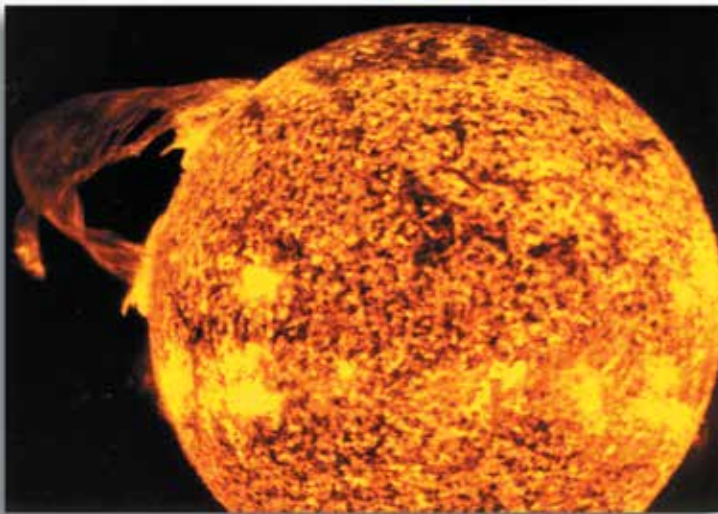
In the Sun, the fusion process is carried on as hydrogen atoms are fused into helium by the pressure and heat of the Sun's great mass. This helium may exist for only a billionth of a second before its protons disengage themselves with another release of energy. This process occurs over and over with each activity producing and absorbing energy.

The core of the Sun is so hot that no solid or liquid molecules can exist. Virtually, all atoms remain in a plasma state. The energy released within the core has to make its way to the surface, atom by atom. It's theorized if the Sun's fusion reaction were to suddenly halt, it would take more than 100,000 years before any effect would show on the surface.

While the Sun's gravity and energy emissions directly affect the space environment, the Sun's magnetic field affects it indirectly. Magnetic activity on the Sun affects how energy is released from the Sun.

The Sun's magnetic field is at least 100 times stronger than the Earth's. Unlike the Earth's magnetic field, the Sun's magnetic field lacks definite structure. The Earth's field flows between the North and South Poles. The Sun's is the net result of many small surface fields and the magnetic networks surrounding surging surface plasma. The Sun's rotation then alters these magnetic fields.

Because the Sun is plasma and not a solid body, its surface rotates at different rates. The generally accepted average time for one rotation is 27 days, but the Equator rotates 30% faster than the poles. Depending on where you measure, the Sun requires between 25 and 40 days to complete one rotation. These different rates cause the magnetic field lines to get twisted and sheared. The result is an increase in field strength and areas of stored energy. These areas are called active solar regions. **Sunspots, filaments, prominences, and flares** are solar phenomena associated with these active regions.



Solar Prominences

In addition to the 27-day rotation cycle, the activity of the Sun follows an 11-year cycle. Commonly called the Sunspot cycle, its actual length can vary between 8 and 15 years. These cycles are very important to space operations because they allow us to predict when solar phenomena may occur. During these occurrences, the Sun's stored up energy can be released suddenly and explosively. These sudden bursts can produce damaging amounts of particles and electromagnetic waves.

By compiling all the solar wind data gathered in the space age, NASA scien-



tists have concluded that even though the solar magnetic field is constantly changing, it always returns to its original shape and position. Scientists now know that the Sun's magnetic field has a memory and returns to approximately the same configuration of each 11-year solar cycle.

The solar wind is composed of charged particles ejected from the Sun that flow continuously through interplanetary space. The solar wind carries part of the Sun's magnetic field into space. Before completing this research, scientists knew that features of the solar wind reaching the Earth tended to repeat about every 27 days. The new information pinpoints the repetition interval at 27 days and 43 minutes, and shows that the Sun has kept this steady rhythm, much like a metronome, for at least 38 years.

This pattern escaped previous detection because it is a very subtle statistical effect. There are many larger variations in the solar wind that come and go, which largely mask the underlying pattern. This repetitive behavior can't be seen if these data are examined for only a few months or years, but it was revealed through several decades of observation.

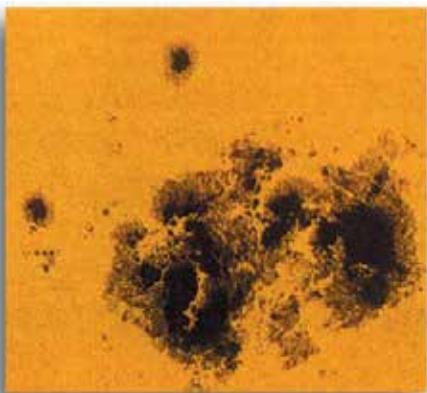
Unfortunately, not all phenomena are cyclic. Flares, potentially the most dangerous phenomena, are non-cyclic. The particles emitted during flares can harm satellites, ground systems, spacecraft and astronauts. We monitor the Sun's activity closely so we can react quickly when flares occur. The less dangerous electromagnetic radiation from a flare will reach Earth in less than 9 minutes. The more dangerous high-energy particles may take 15 minutes to 3 days to get here. Spacecraft operators must be prepared to act quickly.

Solar Atmosphere

The solar atmosphere consists of the photosphere, the chromosphere and the corona. Each has its own characteristics.

Photosphere. The portion of the Sun which gives light is a very thin shell called the photosphere. This is the portion of the star that exists in a gaseous form that is familiar to people. This shell is composed mostly of hydrogen and helium, and is very hot. Its temperature is more than 10,000° F, but its density is less than that of Earth's near-surface atmosphere.

Photographs of the Sun's photosphere depict a granular appearance. Each of these granules has a diameter of several hundred miles. The granules are massive clouds of super-heated gases that rise and fall



Sunspots

with changing temperatures. Their brightness is also dependent on the temperature. Their motion can be generally equated with the rough seas produced by the winds of a hurricane, since these gases behave more like a boiling liquid than our terrestrial gases.

Sunspots are a phenomena associated with the photosphere. These spots are enormous areas where the photosphere is dark—somewhat like looking into a hole through the photosphere. Sunspots appear dark because they are cooler than the surrounding plasma.

There are many hot spots that show as bright blotches on ultraviolet pictures of the photosphere. Sometimes ionized gases condense and flow down magnetic field lines. What these gas flows are called depends on your perspective. When seen against

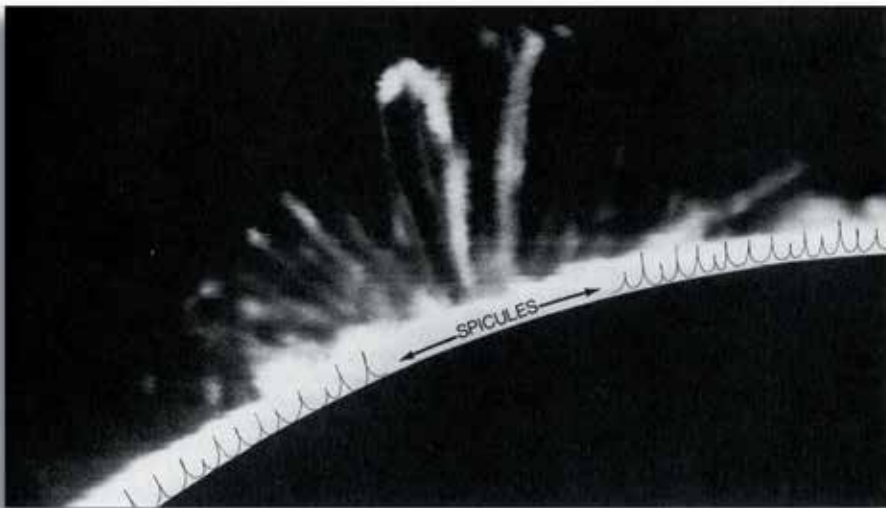


the black background of space, they are prominences. Against the solar disk, where they appear darker because they're cooler than the hot plasma of the solar disk, they are called filaments. Bursting from the surface are occasional solar flares. These phenomena extend through the Sun's chromosphere and into its corona.

Chromosphere. Above the photosphere is the chromosphere (sphere of color). It extends to about 15,000 miles. Considering the Sun's diameter of almost a million miles, you can see that the chromosphere is indeed a very minor shell. It is characterized by spicules that apparently jet straight up from the area of the granules described above. Astronomers believe that these spicules are part of the convective action taking place within the granules. At first, these hair-like spicules were thought to go only outward from the photosphere. However, later observations found some of them to be descending. This pink fringe of spicules has been described as appearing like blades of grass.

Corona. The next division of the Sun's atmosphere is called the corona (crown). The corona cannot be seen unless the solar disc is eclipsed (covered). This is also true for the chromosphere. Today,

there is no need to wait for a natural eclipse to take place because astronomers have instruments, which contain an opaque disc for eclipsing the Sun. The corona is an enormous area of faint white light that visibly extends outward from the Sun's surface. It extends outward for 3 million miles during normal solar activity and more than 4 million miles when Sunspot activity is high.



Solar Prominences and Spicules

Remember that this is visible light—that part of the electromagnetic spectrum that can be detected with the eye. There are other types of emissions from the Sun besides visible light. These electromagnetic emissions can be steady, cyclic or non-cyclic. We've already discussed the non-cyclic emissions generated by solar flares. Steady emissions are usually called solar wind and are made up of many different types of atoms and ions generated within the Sun. Solar wind is an extension of the Sun's corona into interplanetary space. Traveling at speeds from 300-1000 km/sec, its average speed near Earth is 400 km/sec.

Solar winds are also affected by the Sun's 11-year cycle. When strong localized magnetic fields build up, they sometimes extend out from the Sun. When this happens, they drag and accelerate particles away from the corona. This leads to areas of lower density in the corona, known as corona holes. These holes are the source of high speed solar winds. Because they follow magnetic lines of force, these high-speed winds cannot mix with other solar winds. The differing speeds create shock waves, which impact Earth and cause disturbances in Earth's magnetic field.

Our main source of information for learning about the Sun is SOHO, the Solar and Heliospheric



Observatory, launched in December 1995. The SOHO project is jointly operated by NASA and the European Space Agency (ESA). SOHO was designed for a nominal mission lifetime of two years. Because of its spectacular successes, the mission was extended five times (in 1997, 2002, 2006, 2008, and 2010). This allowed SOHO to cover an entire 11-year solar cycle (#23) and the rise of the new cycle 24. At the time of this publication, SOHO was currently approved for operation through the end of 2012. Source: ESA SOHO Fact Sheet. During the maximum sunspot occurrence of ... were also responsible for disrupting voice and other telecommunications on a global scale. Today, we are even more dependent on satellites and computers. Advanced microchips are more vulnerable to the Sun's electromagnetic effects and particles.

Located 1.5 million kilometers out in space, SOHO is the world's chief watchdog for the Sun. From its vantage point where the Sun never sets, the spacecraft can continuously observe solar activity. Images are sent to regional warning centers of the International Space Environment Service, which in turn alerts engineers responsible for power systems, spacecraft and other technological systems of impending effects on Earth's environment.



Earth

One of the most surprising discoveries resulting from SOHO observations was the occurrence of tornadoes on the Sun. Images and data collected from SOHO observations include at least a dozen tornadoes with steady wind speeds of 15 kilometers per second and with gusts up to 10 times faster. These tornadoes occur most frequently near the North and South Poles of the Sun and are almost as wide as the Earth. Hot gases in the tornado spiral away from the Sun and gather speed. Scientists are now studying the phenomena to determine how solar tornadoes might relate to observations of the fast solar wind farther out in space.

Space Environment Around the Earth

Ionosphere

Throughout history, people have wondered about the aurora borealis and the aurora australis. The aurora borealis (or northern lights) flashes brilliant colors in varying patterns across the northern skies. The aurora australis presents a similar display in the Southern Hemisphere. Observers have determined that these displays occur at heights ranging from 60 to 600 miles above the surface of the Earth.

It was only recently that people learned that these and other events may be associated with a zone of electrically conductive layers in the upper atmosphere called the **ionosphere**.



The ionosphere is a part of the atmosphere divided by its electrical activity. It gets its name from the gas particles that are ionized or charged.

Discovery of the ionosphere came with the invention of the radio early in the twentieth century. When radio waves were transmitted beyond the horizon, scientists theorized that a layer of atmosphere could act as a mirror to bounce waves back to Earth.

In the 1920s and later, a long series of observations provided a picture of the ionosphere. It was learned that the ionosphere contains reflecting layers. The lowest of these reflects long-wave radio transmissions, such as those of the standard commercial radio broadcast bands in the United States. Higher layers reflect short-wave transmissions. The higher the reflecting layer, the farther a signal can travel because it bypasses more of the Earth's curvature. Thus, short-wave radio can be used for international broadcasting and long-wave radio is preferred for local commercial broadcasting. However, long-wave stations may have ranges to approximately 1,000 miles, depending on power.

Characteristics of the Ionosphere. It is essential to examine the electrical peculiarities of the ionosphere. Why is the atmosphere at times ablaze with northern lights or other spectacles? Why are there reflecting layers that aid people in long-distance radio communications? Why are there black outs or garbled radio communications? Why do magnetic compasses spin instead of point steadily at the magnetic north? To understand both normal ionospheric behavior and sudden ionospheric disturbances, or SIDs, certain facts must be understood.

The Atom. An atom contains almost all of its mass in a central body or nucleus, which is a tight cluster of smaller particles called neutrons and protons. Neutrons have no electrical charge; protons carry a positive electrical charge. Around this central body, negatively charged electrons whirl in all directions. These electrons are so tiny that scientists formerly believed that they had no mass—that they were mere sparks of energy. Now, it is generally agreed that an electron has mass, approximately 1/1900 that of a proton or neutron.

Electrically speaking, however, the proton and electron are equal and opposite in charge; one charge balances the other. A normal atom is electrically neutral because the number of electrons exactly equals the number of protons. For example, a nitrogen atom has a nucleus containing 7 protons and 7 neutrons, giving it an atomic weight of approximately 14 and an atomic number of 7. The atomic number refers to the number of protons. Seven electrons revolve around the nucleus.

The Ion. An ion is an atom that carries a positive or negative electrical charge as a result of losing or gaining one or more electrons. The name is also sometimes given to a free electron, proton or other charged subatomic particle (particle smaller than an atom). Therefore, the ionosphere includes those zones of upper atmosphere and near space in which there are many charged or ionized atoms and numerous free electrons and other charged subatomic particles. These ions concentrate in certain layers to reflect radio waves of a given range or frequency.

Causes of Ionization. What causes ionization? In the ionosphere, the main causes are the powerful ultraviolet radiation of the Sun and the ultra-high-frequency cosmic rays from the stars of outer space. Above the shielding effect of the thicker atmosphere at lower levels, this radiation bombards the scattered atoms and molecules of nitrogen, oxygen and other gases, and knocks some of the electrons out of the outer rims of the atoms.

Ionospheric Behavior. Sunspots, solar flares and other disturbances on the surface of the Sun produce fluctuations in the output of the Sun's rays. These, in turn, produce SIDs and other variations in



the behavior of the ionosphere. The normal rhythm of nights and days also affects the behavior of the ionosphere. SIDs, for example, will produce excess electrons in the atmosphere, and these will absorb radio waves. The magnetic forces of the Earth also have an effect on the behavior of the ionosphere. It is the interaction of solar radiation and the Earth's magnetism that produces the aurora borealis and aurora australis. Particles traveling swiftly toward the Earth's two magnetic poles produce these glowing displays.

The ionosphere is generally regarded as extending to more than 250 miles above Earth's surface, well beyond the altitude where most of the atmosphere exists. One name applied to space beyond the Earth's atmosphere is **exosphere** (outside sphere). The ionosphere blends into the exosphere, which must not be considered a dead vacuum. It contains atomic and subatomic particles. This is especially true of the Van Allen belts.

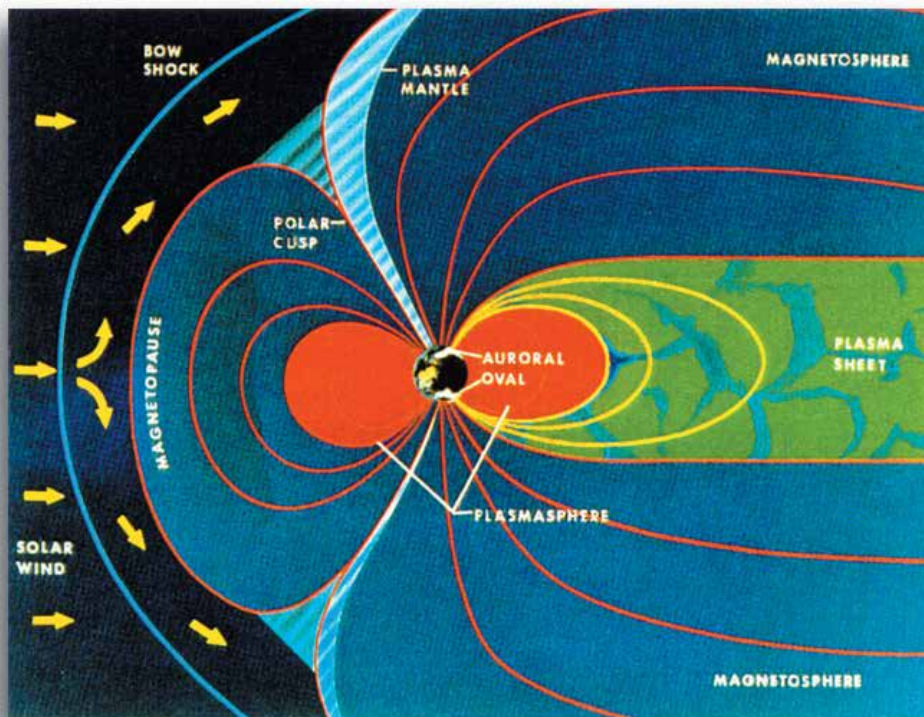
Magnetosphere and Solar Wind

Before studying the Van Allen belts in detail, a look at the Earth's magnetosphere and the effects upon it by the solar wind is essential. This is due to the Van Allen belts being closely related to the behavior of the magnetosphere.

Magnetosphere. The region of the Earth's atmosphere where ionized gas plays a big part in the dynamics of the atmosphere and where the geomagnetic field plays an important role is called the **magnetosphere**. The magnetosphere begins about 217 miles above the Earth's surface and extends 10 or 15 Earth

radii to the boundary between the atmosphere and the interplanetary plasma.

Earth, like most other planetary and stellar bodies, is surrounded by a tremendous magnetic field. Remember the experiment where a bar magnet is placed beneath a piece of paper on which there are iron filings? If the magnet is close enough for its magnetic field to affect the filings, they take on the shape of the magnetic field—that

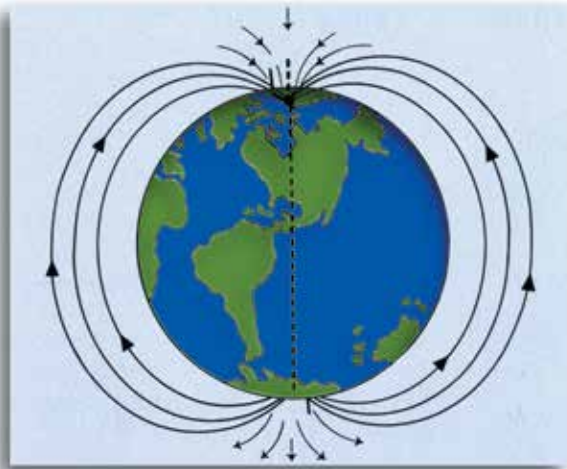


Regions of the Magnetosphere



is, they align with the field of force. The filings sweep toward the magnet's North and South Poles, concentrating more or less at the poles and leaving relatively few filings toward the Equator of the magnetic force field.

If the bar magnet and the iron filings could be suspended in three dimensions, instead of the paper's two dimensions, the iron filings would probably, at least for a short time, form a sort of cloud around the magnet. This cloud would surround the magnet, but would leave a very deep depression at each of the poles as the magnetic lines of force swept downward carrying filings toward each of the poles (see picture at the left).



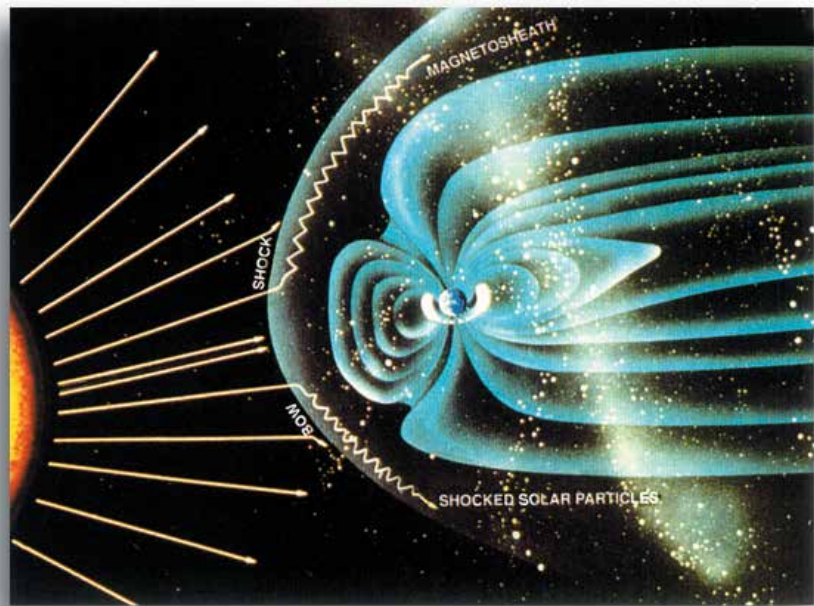
Earth's magnetic lines of force without outside forces acting upon them.

Earth acts as if it had a large bar magnet going through its center surfacing at the magnetic poles. The north and south magnetic poles are near the north and south celestial poles, which are sometimes referred to as the rotational axis. If the magnetic field could be seen, and if it were not for the effects of many other forces, Earth's magnetosphere would look something like the diagram to the left. However, forces such as the solar wind alter the patterns of the magnetic lines.

If a way could be found for space travelers to see

Earth's total magnetosphere, it would probably look like a comet with an extended tail that always points away from the Sun. This pointing away from the Sun, of course, is caused by the pressure of solar radiation pushing outward from the solar sphere.

Solar Wind. The normal solar wind, or solar plasma, strikes the Earth's magnetosphere with considerable collective force. This force is such that it forms a bow shock wave where the magnetic lines of force of the magnetic field are struck by the solar plasma. The resulting bow shock wave distorts Earth's magnetosphere. The extent of the



Magnetosphere

distortion of the magnetosphere by the solar wind is not precisely known, but it is known that it sweeps the magnetosphere beyond the orbit of the Moon.



Actual, solid knowledge about the total magnetosphere and the solar wind continues to be received as the data is returned from satellites and other instruments. However, in 1958, a University of Iowa physicist, James A. Van Allen, announced the discovery of a large zone of space filled with electrically charged particles extending far beyond the limits of the ionosphere. This discovery was made with instruments of *Explorer 1*, the first US Earth satellite. Numerous other satellites and sounding rocket probes and scientific studies of the so-called Van Allen radiation belts have been made since then.

Van Allen Radiation Belts

Cosmic Rays

Energetic charged particles from all over the galaxy and beyond continuously rain down upon the Earth. These atomic particles, mostly electrons and the nuclei of atoms, are called cosmic rays. Even though they travel at nearly the speed of light, their flow is greatly reduced by solar wind. When solar wind is at a minimum, more cosmic rays enter into the magnetosphere. This increase in cosmic rays can disrupt spacecraft operations. Cosmic rays entering the atmosphere collide with atmospheric molecules and create secondary cosmic rays. While the cosmic rays coming from outer space are a concern to spacecraft, they rarely have enough energy to affect ground systems. However, secondary cosmic rays can be a major concern to ground systems.

Van Allen Radiation Belts

Like the ionosphere, the Van Allen radiation belts are filled with charged particles. Also like the ionosphere, the Van Allen belts are the product of interaction between the Sun and the Earth. Thus, some scientists regard these belts as an extension of the ionosphere, but the Van Allen particles are different from those prevailing at lower levels of the ionosphere. They also behave differently and fall into different patterns.

Structure of the Belts. The belts are thought to be crescent-shaped in cross section and composed of two shells. The “horns” of these crescents dip toward Earth’s magnetic poles as the charged particles follow the magnetic lines of force. The horns of the internal belt lie close to where the magnetic line of force dips downward toward Earth’s 45° latitude in both the Northern and Southern Hemispheres. The outer or external zone converges above Earth’s surface between latitudinal lines 55° and 67°, with maximum concentration located at 62° latitude.

Content and Cause of the Belts. What is in these belts and what causes them? Primarily, the cause is the Sun. The Sun constantly emits charged particles that sweep outward in all directions and extend for unknown distances. These particles are mainly protons and electrons traveling at a million miles per hour as a plasma (a plasma is of much thinner consistency than a gas and is a conductor of electrical activity). However, this speed of a million miles per hour increases considerably when the Sun is active.



The Sun is considered to be active when solar flares and other solar disturbances are occurring. When these charged particles encounter Earth's magnetic field, many of them are trapped and bounce back and forth between the Northern and Southern Hemispheres.

Some say that both Van Allen belts are caused by solar activity with some influence by cosmic rays. Others believe that the outer belt is the result of solar activity while the inner belt has a different origin. The theory here is that the more powerful cosmic rays come into the upper layers (primarily the mesosphere) of the Earth's atmosphere where they are stopped when they collide with atmospheric molecules.

These collisions result in the release of neutrons, some of which travel outward from Earth. These neutrons decay into protons and electrons, which then become trapped by Earth's magnetic field. Thus, you can see that science is not positive as to exactly how the magnetosphere was formed or continues to function.

Radiation Hazards. Going outward from Earth's surface at the geomagnetic Equator (as opposed to the geographic Equator), radiation from the Van Allen belts begins to increase rapidly above 600 miles and then falls away rapidly near 30,000 miles out. This radiation increase goes up to about 10,000 counts per second (a measure of charged particles) and returns to 10 counts per second beyond what we might say is the outer fringe of the Van Allen belts. The maximum count (10,000 per second) occurs within the internal belt at the geomagnetic Equator and between 1,400 and 3,000 miles altitude.

Correcting this number of counts to roentgens, scientists tell us that the effect is between 10 and 20 roentgens per hour. The safe or maximum dosage of radiation is 0.3 roentgen per hour, so it is clear how lethal the internal belt would be to human habitation.

Actually, the combined energy possessed by one-radiation particle enables it to penetrate the human body and destroy or disturb a human body cell. Sustained exposure to these high-energy particles within the outer belt would kill too many body cells for the exposed person to survive.

Therefore, the concentrations of radiation within the Van Allen belts pose a hazard to astronauts. If it were justified to keep a manned space vehicle within this portion of the magnetosphere for any length of time, the occupants would have to be protected by heavy shielding.

During the Apollo Program, astronauts had to pass through both Van Allen radiation belts on the way out and on the return trip, but the exposure time was very short and insignificant. Orbits of manned spacecraft, such as Russia's Soyuz and the US Space Shuttle, are beneath the internal Van Allen belt because its altitude of 600 miles is much greater than the usual orbit.

What would happen, though, if a manned spacecraft were in polar orbit? Recalling that the radiation belts dip downward toward the surface of Earth, each orbit might involve flight through the four crescents. This could, in turn, build into a dangerous level of accumulated radiation effects on the astronauts' bodies even though they would be flying through a radiation-free zone near each of the Earth's magnetic poles.

The intense amount of radiation found within the Van Allen portion of the magnetosphere can be damaging even to satellites. However, satellites that are in synchronous equatorial orbit (22,300 miles altitude) are on the fringe of the outer Van Allen belt, so they remain functional for many years before replacement is necessary.

Effects of Solar Disturbances

Much of what affects the ionosphere, magnetosphere and Van Allen belts stems directly from solar activity. Most of the effects of solar activity on these regions occur during solar disturbances, a period when the Sun is active. These disturbances cause strange effects on the magnetosphere and in the ionosphere during what we call magnetic storms.

Magnetic Storms. Magnetic storms (also called electromagnetic or radiation storms) are characterized by a sudden onset of radiation bursts in which the magnetic field undergoes marked changes in the course of an hour or less. This is followed by a very gradual return to normalcy, which may take several days. Magnetic storms are caused by solar disturbances, although the exact nature of the link between the solar and terrestrial disturbances is not yet understood.

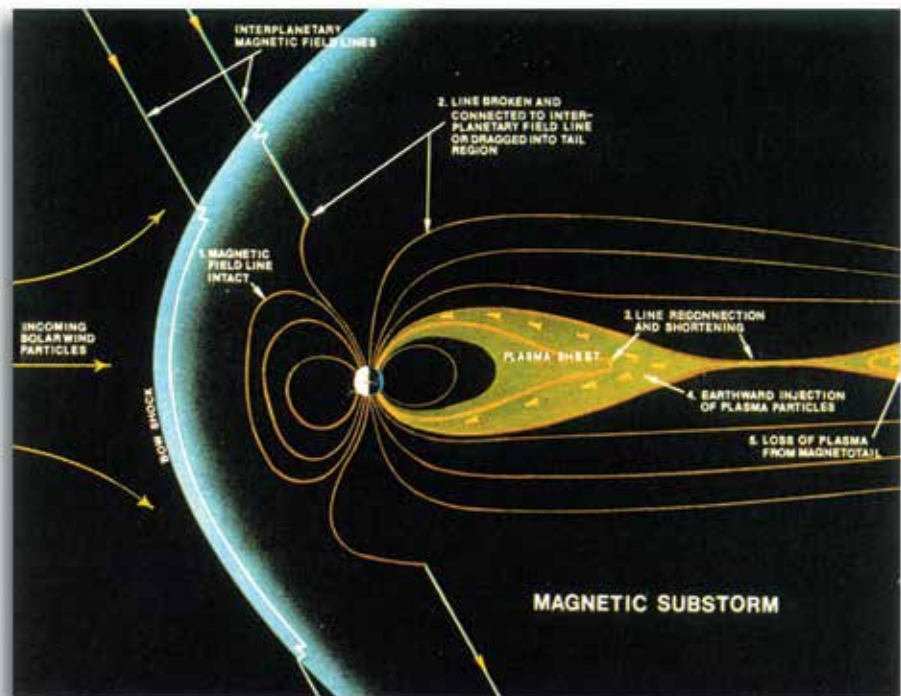
Magnetic storms are more frequent during years of high Sunspot activity and can sometimes be linked to a particular solar disturbance. In these cases, the time between the solar flare and onset of the magnetic storm is about one or two days. This suggests that a cloud of particles thrown out by the Sun carries the disturbance to the Earth.

Magnetic storms interfere with the reflectivity of the ionosphere and cause it to actually absorb radio transmissions rather than reflect them. Everything from telescopes to satellites monitor the Sun's activity

on a 24-hour, around-the-world surveillance system. When one of these solar storms occurs, it is detected immediately and word is sent out so that those who work with electronic communications can prepare for the effects of the storm.

In 1960, a solar outburst of great intensity took place. At 2:37 p.m. on November 12th, an astronomer discovered it. Approximately 6 hours later, this finger of hydrogen plasma (which was 10 million miles across) collided with Earth's magnetosphere and atmosphere. For over a week, there were interruptions and disruptions of electromagnetic functions on Earth.

The intensity of this solar outburst affected communications around the world. It blacked out long-distance radio communications for hours and made magnetic compasses spin erratically. This



Process Involved in a Magnetic Storm



was a very serious blow to aviation since the magnetic compass is the primary reference for direction of flight.

To illustrate how powerful magnetic storms can be, during this outburst even the teletype machines printed nonsense instead of the messages sent. In northern areas of the country, electric lights flickered as if electrical storms were taking place; however, the sky was clear.

Solar outbursts of this intensity do not happen frequently, but when they do, similar effects occur. Even the transmission of electricity and telephone messages can be disrupted by such energy. It is now believed that solar activity of sufficient magnitude may have been responsible for electrical blackouts in the past. Solar activity has been known to induce currents in telephone circuits and cause automatic switching devices to open and close at the wrong time. So, when an outburst of solar energy strikes Earth, it temporarily affects many of the processes of civilization. The long-term effects on plant and animal life are unknown, but it seems certain that some are produced.

Earth does not receive the force of all solar outbursts. The Sun spins rapidly on its axis and has a tremendous magnetic field. When these outbursts or flares of energy occur, the net effect is a relatively narrow streaming out of plasma that may follow a curved trajectory (path). An example can be found with the common lawn sprinkler. Imagine cutting or separating a segment of the stream of water coming from the whirling sprinkler; this is what a stream of solar storm plasma is believed to be like. If Earth is in the path of this plasma stream's trajectory, communication and other problems arise and the auroras will be activated.

Polar Magnetic Storms. When the solar disturbances are observable only in the polar areas, they



Aurora Borealis



are termed polar magnetic storms. These polar magnetic storms produce sporadic radiant emissions from the upper atmosphere over middle and high latitudes. The visible emissions are called aurora borealis in the northern latitudes and aurora australis in the southern latitudes and appear as colored lights.

According to various theories, auroras are related to magnetic storms and the influx of charged particles from the Sun. The nature of the exact mechanisms involved is still being investigated, but it seems that the trapped particles from the Van Allen belts apparently play an important part. The protons and electrons dashing about within the Van Allen belts spill into Earth's upper atmosphere where the belts dip toward the magnetic poles. This spillage involves billions of collisions between the charged particles and the atoms that, in turn, cause the upper atmosphere's gases to glow and shimmer in different colors.

For example, radiation striking atomic oxygen at a certain altitude produces a green color. If atomic oxygen is struck at a higher level, where the oxygen atoms are less dense, a reddish glow will result. When molecular nitrogen is struck, a reddish glow different from oxygen red is produced. Occasionally, the green-glow oxygen bands will be fringed at the bottom edge by nitrogen red.

The auroras are brightest when the Sun is highly active. Long ago, the appearance and intensities of the auroras were discovered to be linked to solar activity. When a solar flare occurs, for example, people in latitudes from which the auroras can be seen are in for a spectacle. However, the spectacular nighttime visual displays are overshadowed by the problems caused, particularly on the Sun side of Earth, during the magnetic storms discussed earlier.

Environmental Effects on Space Operations

Communications

In addition to the problems caused by magnetic storms, several other environmental factors affect communications. First, not all radio frequencies are useable for uplink/downlink ground to satellite communications. The ionosphere absorbs low frequencies and water vapor absorbs high frequencies. Frequencies between 300 megahertz (wavelength = 1 meter) and 300 gigahertz (wavelength = 1 millimeter) are generally acceptable.

A second problem is scintillation. Electron density variations in the ionosphere cause rapid changes in radio signals. The effect is the same one mentioned earlier, which causes stars to twinkle. Three options exist to lessen the effects of scintillation. One is to only transmit when conditions permit such as during night hours. Obviously this limits the usefulness of the communication system.

The second option is to avoid transmitting in regions, such as the Equator and the poles, where scintillation is particularly strong. Again, depending on the satellite's orbit, this might not be a useful solution. The last option is to use a very high frequency to minimize the effects of scintillation. The problem with this option is the potential effects of water vapor we mentioned earlier.

A final environmental effect that hurts radio communications is caused by solar flares. Solar flares release large amounts of radio energy. The effect is referred to as "solar radio burst." It usually only lasts a few minutes, but during that time radio waves are effectively jammed.



Spacecraft

The space environment can be very hostile to spacecraft. The atmosphere, vacuum of space, charged particles and space debris all take their toll.

Atmosphere. Whenever a spacecraft passes through the Earth's atmosphere, it can be affected in two ways. The first effect is called drag, which slows the spacecraft down. This is the same force you feel pushing on your hand when you stick it out the window of a moving car. The second effect is oxidation from free oxygen atoms.

The most familiar type of oxidation occurs when iron is exposed to water. The oxygen atoms in water break away and combine with the iron. The result is rust. When oxygen atoms are free, the reaction is much faster. Normally, oxygen atoms exist as parts of molecules.

In the upper atmosphere, molecules are widely spaced. When radiation or high energy particles collide with these molecules, the atoms break apart. Often they are too far apart to recombine. The result is free oxygen atoms. These react with spacecraft surfaces to weaken components, change thermal properties and degrade sensors.

Fortunately, many free oxygen atoms find each other and form groups of three. These molecules are called ozone. Ozone is very effective at blocking radiation from reaching the Earth.

Satellites rarely orbit at a uniform distance from Earth. Instead they follow elliptical paths that bring them closer at one point, known as perigee, and farther away at another point, known as apogee. It is at perigee that the greatest effect from the atmosphere is felt. Any spacecraft perigee below 1,000 km will be affected. Temperature and atmospheric density determine the extent of the effect. However, the effect is fairly predictable and spacecraft designers plan for it.

Unplanned drag can occur when the atmosphere heats unexpectedly. When heated, it expands outward toward the spacecraft. Both electromagnetic radiation from solar events and particle bombardment that occurs during magnetic storms can heat up the atmosphere and create more free oxygen. Low Earth orbits and polar orbits are most affected.

Vacuum. Beyond the atmosphere, space is a vacuum. The emptiness of a vacuum can cause problems for spacecraft. Materials used in spacecraft can contain tiny bubbles of gas. Under atmospheric pressure, they stay where they are. Removing the pressure by exposing them to a vacuum can be like opening a can of soda. Eventually, the soda goes flat because all the bubbles escape. This is called outgassing.

We don't care about the spacecraft losing the bubbles, but sometimes the outgassing molecules settle on spacecraft surfaces. When these surfaces are delicate sensors and lenses, they can be damaged. Spacecraft, which might have this problem, must be placed in a vacuum chamber prior to flight to bleed off the gas.

Another problem the vacuum environment can cause is called cold welding. This occurs when moving parts fit with only a tiny air space between them. In a vacuum the tiny amount of air which kept them separated escapes and they weld together. Using a lubricant to maintain the space will solve the problem.

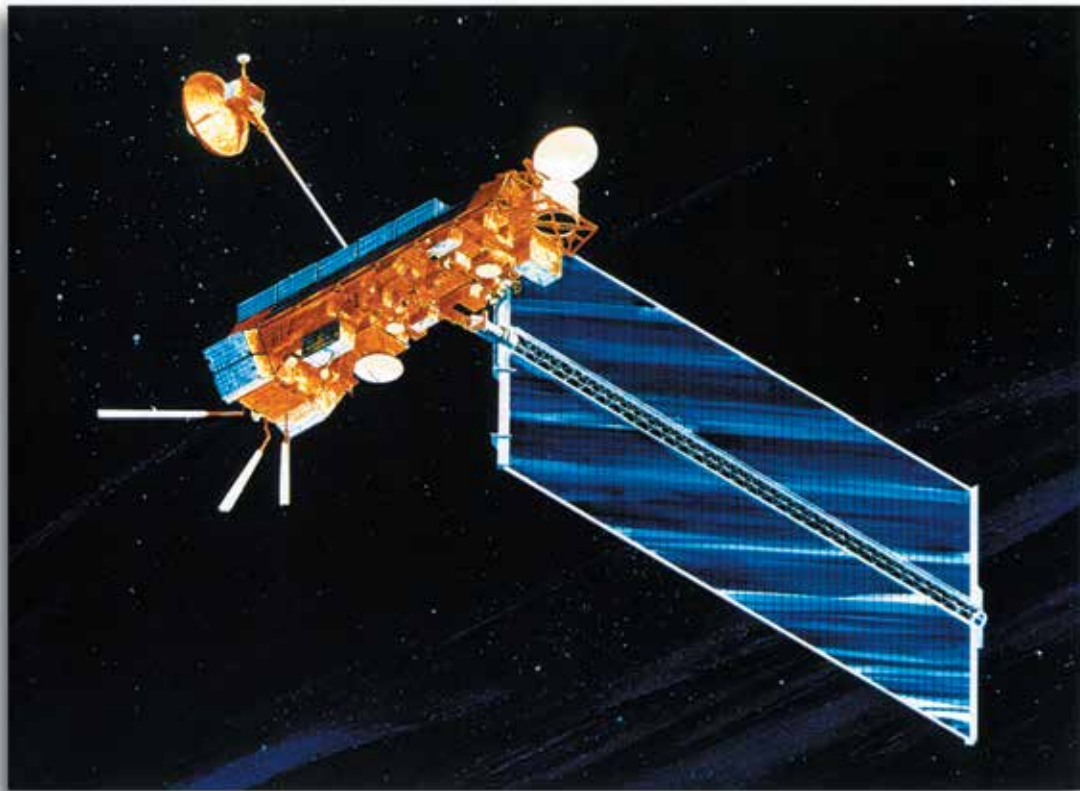
However, we must be careful to select a lubricant that won't outgas, freeze or evaporate in the vacuum of space. Dry graphite, like the lead in a pencil, is a good choice.

Electrostatic Charging. Electric charging, by itself, is not always a problem for spacecraft. But



anyone who has ever scuffed across a carpet and then touched grounded metal can tell you how painful discharging can be. The small electronic parts of a spacecraft, particularly computer data bits, can be badly shocked. Spacecraft charging can be either “absolute” or “differential.”

Absolute charging occurs when the whole craft is charged. It only becomes a problem if two spacecraft of different charges come together. Opposite charges cause a discharge. An example might be the shuttle retrieving a satellite. If it’s charged up, it could discharge on contact with the shuttle.



Polar Orbiting Platform

Absolute charging often occurs as a spacecraft passes through fields of plasma, such as solar wind. This plasma imparts a negative charge on the entire satellite.

Differential charging occurs when one part of a spacecraft gets charged and has a different charge than another part of the craft. One of the prime causes of this type of charging is called the photoelectric effect. It occurs when the Sun’s electromagnetic radiation liberates electrons from the spacecraft surface leaving it positively charged. Spacecraft will usually have a negative potential on shaded areas due to plasma charging and positive potential on Sunlit areas.

If the surface of the satellite is conductive, these potentials will cancel each other out. If it’s not conductive, they can build up to a point where they are much like the shoe scuffing example given earlier. This is very dangerous for the satellite. Unexpected discharges can cause total system failures, or “flipped bits,” which can include false commands and memory changes.



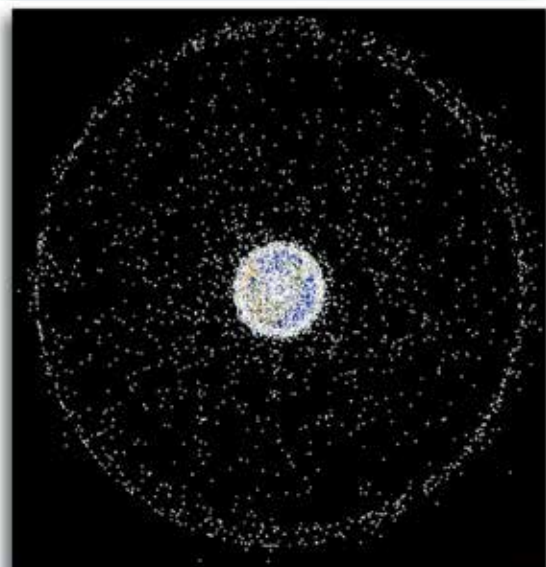
Many designs have been used to counter the impact of electrostatic discharge. They include shielding to prevent charging, part selection to cancel it out, redundant systems, error detection and correction systems, and systems to intentionally discharge affected systems at regular times.

Collisions. You might think the most dangerous collisions in space are caused by meteoroids or perhaps other spacecraft. You would be close. Any object big enough to be seen would cause a lot of damage if it collided with a spacecraft at orbital speed. However, the vastness of space makes the risk of colliding with naturally occurring objects very low. Colliding with another spacecraft is also unlikely. There just aren't that many of them. But, getting hit by space garbage, now that is another story.

The space around Earth is full of junk left behind by previous space missions. The North American Aerospace Defense Command (NORAD) tracks more than 8,000 orbiting pieces of trash including broken satellites, booster parts and even an astronaut's lost glove. But, NORAD can only track objects baseball sized and larger. There may be as many as 40,000 golf-ball-sized objects and billions of much smaller pieces. Traveling at terrific speeds these tiny objects can hit with more energy than a rifle bullet. Even so, the odds of colliding with any of this debris are still fairly low.

The most common collisions are with high-energy particles from solar flares and cosmic rays. High-energy particles can cause direct damage to spacecraft surfaces and cause false sensor readings. Cosmic rays penetrate deep into spacecraft and ionize atoms as they pass through. This ionization is called deep charging and can disrupt electrical systems. They can also cause direct damage to internal parts. Protecting spacecraft from particle collisions isn't feasible because the necessary shielding is much too heavy. Designing triple redundant systems and doing recurring error detection and correction are the most effective solutions.

Space debris includes discarded hardware, abandoned satellites and released spacecraft items like separation bolts, lens caps and auxiliary motors. The three pictures illustrate the distribution of both operational satellites and space debris from different distances and perspectives.



Manned Operations

Human beings were not designed to live in space. We need air to breathe, the right temperature range, gravity and protection from radiation. In addition, living in isolation can be mentally taxing. We've already talked about the effects of radiation and we know we need to bring air and control the temperature. What can be done about weightlessness or the psychological effects of space?

Free Fall. Our skeletons, muscles and connective tissue all serve to support us against the pull of gravity. In space, we are still subject to gravity, but we don't experience the pull. We and our spacecraft are falling freely with nothing to resist our fall. We are in free fall and so is everything inside us. The inside parts of our bodies suffer from free fall. Our body's fluids shift, we experience motion sickness and all those tissues designed to support us in gravity get weaker.

On Earth, gravity pulls our body's fluids into our legs. In free fall, these fluids spread out evenly with less than normal in the legs and more than normal in the upper body. This causes several problems. First, the kidneys react to the increase in fluid in the upper body and eliminate it. This can cause dehydration so astronauts need to drink several quarts of liquid prior to returning to Earth.

Second, the heart doesn't have to work as hard and tends to weaken. Third, the downward shift of fluids when gravity is returned can cause us to black out or have the same feeling you sometimes get when you stand up quickly after sitting a long time.

Have you ever wondered why you get dizzy after spinning around in circles? It's because your internal balancing system gets confused. Normally, your eyes establish reference points to where you are, while tiny hairs inside your inner ear sense movement. By putting the two together, you are able to balance and sense where you are. When you spin around, your inner ear cannot react quickly enough and gets out of sync with your eyes.

This is what happens in space, only worse. Your inner ear is calibrated and takes gravity into account when it senses movement. In free fall, the calibration is wrong. What your inner ear senses doesn't match up with what your eyes see. You'll be motion sick until your inner ear can recalibrate.

Astronauts train for free fall by riding in NASA's "Vomit Comet." It's an airplane that flies as high as it can and then dives straight down putting its passengers in free fall for almost a minute.

The same faulty calibration, which affects your inner ear, also affects the rest of your body.



NASA's "Vomit Comet"

Without the constant pull of gravity, your muscles and bones don't get exercised and atrophy. Muscles lose mass and weaken. Bones lose calcium and weaken. Vigorous exercise can help prevent muscle loss, but bone loss is still a problem. Long trips in space will probably require some sort of artificial gravity.

Psychology. When we first started sending astronauts into



space, they didn't stay there a long time. We needed them to get as much done as possible, so we designed very rigorous work schedules.

As missions got longer, the costs increased, so schedules continued to be grueling to get the most for our money. Eventually, even the best crews got exhausted. The crew of one United States *Skylab* mission got so frustrated they went on strike for a day to protest. The Russians have experienced similar problems aboard the *MIR* space station.

Extreme isolation and living in close quarters with the same people can cause problems as well. On long missions, we can expect individuals to experience bouts of depression, flaring tempers and periods of poor team performance. Mission planning must include breaks for the crew and provide diversions such as music or games. On long missions, frequent contacts with loved ones are necessary to combat isolation. Teams will need to be selected for compatibility.



Key Terms and Concepts

- space
- interplanetary space
- cislunar space
- the Milky Way
- light year
- solar flares
- solar winds
- Sunspots
- sudden ionospheric disturbance
- ion
- radiation hazards
- magnetic storms
- polar magnetic storms
- uplink/downlink
- scintillation
- solar radio burst
- atmosphere
- photosphere
- meteoroid
- chromosphere
- corona
- magnetosphere
- ionosphere
- exosphere
- aurora borealis
- aurora australis
- vacuum
- outgassing
- cold welding
- electrostatic charging
- absolute charging
- differential charging
- free fall
- NASA's "Vomit Comet"
- Van Allen belts
- cosmic rays

? Test Your Knowledge ?

MATCHING

1. Match the terms with their definitions:

- | | |
|------------------|---|
| a. photosphere | (1) composed mostly of hydrogen and helium |
| b. chromosphere | (2) electrically conductive zone in upper atmosphere |
| c. corona | (3) characterized by spicules |
| d. ionosphere | (4) ionized gas and magnetic field play an important role here |
| e. magnetosphere | (5) enormous area of white light emanating from the Sun's surface |

2. Match the terms with their definitions:

- | | |
|-----------------|--|
| a. Sunspot | (1) Steady emissions made up of many different types of atoms and ions |
| b. spicules | (2) Areas of lower density in the Sun's "crown" |
| c. solar flares | (3) Cooler area that appears dark on the photosphere |
| d. solar winds | (4) Hair-like phenomena that characterizes the chromosphere |
| e. corona holes | (5) Non-cyclic eruptions that can harm space assets |

SELECT THE CORRECT ANSWER

3. **(Interstellar/Interplanetary)** is defined as the space between the extent of one Solar System and another.
4. The Sun's **(gravity/energy emissions/magnetic fields)** affect the space environment in our solar system. (Circle all that apply).
5. It is estimated that there are 100 **(thousand, million, billion, trillion)** other Solar Systems just in our galaxy.
6. A parsec is defined as roughly **(two/three/five/ten/twenty)** times the distance of a light year.
7. Astronomers think it would take just over **(2 / 4 / 6 / 10)** light years to reach the nearest solar system in our galaxy.
8. The diameter of the Sun is more than **(ten/one hundred/one thousand)** times the diameter of Earth.
9. Appropriately, the Sun's magnetic field is also more than **(ten/one hundred/one thousand)** times the strength of Earth's magnetic field.



FILL IN THE BLANKS

10. _____ is the space between the Earth and the Moon.
11. USAF administratively defines _____ as beginning at _____ miles above the Earth because that is where it awards _____.
12. Others define _____ as beginning at _____ miles above the Earth because _____.
13. The _____ is the name given to our galaxy.
14. A _____ is defined as the distance a photon can travel in 365 Earth days. It is 5.878 (**thousand, million, billion, trillion**) miles.
15. The surface of the Sun rotates at different rates, varying from _____ days at the Equator to _____ days at the poles, but it is generally accepted that the average is _____ days.
16. The _____ cycle also varies. It can vary between _____ and _____ years, but usually follows close to a/an _____ year cycle.
17. The less dangerous electromagnetic radiation from a _____ can reach the Earth in as little as _____ minutes. The more dangerous high energy particles may take any where from _____ minutes to _____.
18. The _____ begins 217 miles above the Earth's surface and extends 10 or 15 Earth radii to the boundary between the atmosphere and the interplanetary plasma. When struck by _____, it is formed into a bow shock wave, distorting it and pushing it out past the _____.
19. _____, made up mostly of _____ and _____, travel at nearly the speed of light, but have their flow greatly reduced by _____.
20. The _____ are thought to be _____-shaped and composed of _____ shells. Their most significant threat to astronauts is _____, which may be as high as 65 times the safe exposure.
21. _____ are characterized by a sudden onset of _____ in which the _____ field undergoes marked changes in an hour or less.
22. _____ is caused by electron density variations in the _____ and results in rapid changes in radio signals.
23. _____ is when tiny bubbles of gas escape from the materials of the spacecraft due to the _____ of space.
24. Dry graphite may be used as a lubricant to prevent _____, which occurs when the tiny amount of air escapes from between two surfaces of the spacecraft and they fuse.
25. _____ occurs when one part of a spacecraft gets charged and has a different charge than another part of the craft.



TRUE OR FALSE _____

26. *There is strong agreement that space begins 82 miles above the Earth's surface.*
27. *The solar atmosphere consists of the core, photosphere, chromosphere and corona.*
28. *The Sun's output is fairly consistent and any variance does not impact space operations.*
29. *Short-wave radio is used for local broadcasting, while the long-wave radio is used for international broadcasting because it bounces off the ionosphere better.*

SHORT ANSWER _____

30. *List four reasons to explore and exploit space.*
31. *What are the main causes of ionization?*
32. *What is the primary cause of the Van Allen radiation belts?*
33. *List some of the characteristics of the Sun.*
34. *Describe an atom.*
35. *Describe an ion.*