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Glossary

Acceleration--the speeding-up of motion (or in general, any change of velocity, in magnitude and/or direction). Fast electrons in the aurora, charged particles in the radiation belt , cosmic rays etc., all require an acceleration process to provide their high energy. More about auroral acceleration, here.

Adiabatic invariant--An **invariant** of a motion is a quantity which does not change as time advances. For instance, the **energy** of a system is often an invariant (for a swinging pendulum, or a planet and the Sun), and knowing that it stays constant is a great help in calculating the motion.

Adiabatic invariants are quantities associated with **approximately** periodic motions. They **almost** do not change, and thus also help in calculating the motion, to a very good degree of accuracy. They are often important in calculating the way ions and electrons move in a magnetic field.

Alpha particle--A type of fast **ion** emitted by many types of heavy radioactive nuclei, such as uranium. Actually, the nucleus (atom stripped of all electrons) of the gas helium.

Ampere--see electric current.

Argus (project)--A 1958 experiment by the US military, to create artificial radiation belts by exploding small nuclear bombs above the atmosphere.

Astronomical unit (AU)--The mean Sun-Earth distance, a unit of distance widely used in expressing distances in the solar system. 1 AU = 149,600,000 km = 92,957,000 miles.

Attitude(of a satellite)--The direction in which the satellite is oriented in space.

AU -- acronym for Astronomical Unit, mean distance to the Sun.

Aurora (short for polar aurora)--A glow in the sky, often observed in a ring-shaped region around the magnetic poles ("auroral zone") and occasionally further equatorward. The name comes from an older one, "aurora borealis," Latin for "northern dawn," given because an aurora near the northern horizon (its usual location when seen in most of Europe) looks like the glow of the sky preceding sunrise. Also known as "northern lights," although it occurs both north and south of the equator.

The aurora is generally caused by fast electrons from space, guided earthward by magnetic field lines, and its light comes from collisions between such electrons and the atoms of the upper atmosphere, typically 100 km (60 miles) above ground.

Aurora, diffuse --see diffuse aurora

Aurora, discrete--see discrete aurora

Auroral acceleration--The process by which auroral electrons acquire their energies, typically 1-10 keV. May be associated with parallel voltage drops or with an interaction between particles and plasma waves, and may be related to magnetic reconnection in the plasma sheet.

Auroral electrojet--see electrojet, auroral

Auroral kilometric radiation--intense radio waves whose wavelength is of the order of a kilometer, emitted from regions above the ionosphere where the aurora is (apparently) accelerated. Since the waves are even longer than those of the AM radio band, they are stopped by the ionosphere and do not reach the ground, but they are readily observed from spacecraft.

Auroral oval--the region in which aurora appears at the same time, corresponding to the "ring of fire" around the magnetic pole, often observed by satellite cameras. It resembles a circle centered a few hundred kilometers nightward of the magnetic pole, and its size varies with magnetic activity. During large magnetic storms it expands greatly, making auroras visible at regions far from the pole, where they are a rare occurence.

Auroral zone--the region on Earth where auroras are common--a smeared-out average (over time and distance from the magnetic pole) of the auroral oval. Typical magnetic latitude is 63-65 degrees.

Barium release --the firing from a rocket or spacecraft above the atmosphere of a charge of barium, evaporated by a thermite process. Usually produced shortly after sunset, when the sky is already dark but sunlight still reaches the high altitude where the release occurs. The barium atoms are released as a vapor, they spread rapidly and are readily ionized by sunlight. The ion cloud then moves with the local plasma and is therefore a useful tracer of plasma flows.

Birkeland currents --electric currents linking the Earth´s ionosphere with more distant regions, flowing along **magnetic field lines**. Named for Kristian Birkeland, a pioneer of auroral research who first proposed such currents around 1900, these currents are often associated with the polar aurora and with substorms.

Boundary layer --a transition layer between two neighboring regions in the magnetosphere. The plasma sheet boundary layer (**PSBL**) is the transition from the plasma sheet and the tail lobes. The low latitude boundary layer (**LLBL**), just inside the magnetopause, is the transition between the equatorial magnetosphere and the solar wind (more accurately, the magnetosheath, solar wind slowed down by passage through the bow shock).

Bow shock --a sharp front formed in the solar wind ahead of the magnetosphere, marked by a sudden slowing-down of the flow near Earth. It is quite similar to the shock forming ahead of the wing of a supersonic airplane. After passing near Earth, the slowed-down flow gains speed again, to the same value as the surrounding solar wind.

Chromosphere--a reddish layer in the Sun´s atmosphere, the transition between the photosphere and the corona

Convection (magnetospheric)--large-scale plasma flow, circulating in the magnetosphere and driven by the solar wind. Plasma physics requires such circulation to be associated with an electric field. Assuming that the electric field propagates along magnetic field lines (as it would along good conductors of electricity) and reaches the polar ionosphere, corresponding electric fields should be observed above the polar caps, and such fields exist.

In the view proposed in 1961 by Axford and Hines, plasma near the flanks is dragged tailwards by the adjoining solar wind flow, through the action of "viscous-like forces"; in the view suggested that same year by Dungey, plasma travels tailward on "open" field lines following reconnection. Evidence suggests both processes contribute. In both models the plasma returns earthward in the plasma sheet near midnight, a process which could be not continuous but intermittent, associated with substorms.

Corona--see solar corona.

Coronal mass ejection (CME)--a huge cloud of hot plasma, occasionally expelled from the Sun. It may accelerate ions and electrons and may travel through interplanetary space as far as the Earth´s orbit and beyond it, often preceded by a shock front. When the shock reaches Earth, a magnetic storm may result.

Cosmic rays --A steady drizzle of high energy ions arriving at the solar system from the distant universe. Their energies are enormous, ranging from 1-2 billion electron volts to perhaps 100,000,000 that much, though the

higher energies are rare. Their total energy flow is comparable to that starlight. The origin of their huge energies is uncertain, but may come from expanding shock fronts created by supernova explosions.

Crab nebula --a cloud-like nebula observed in the Crab constellation, the remnant of a supernova explosion observed in China in 1054. It contains a very rapidly rotating (and hence, young) pulsar, which is probably the remnant of the supernova. The emissions of radio waves and light from this nebula suggest the presence of high energy particles.

Cusps (of the magnetosphere)--two regions of weak magnetic field, on the sunward boundary of the magnetosphere, one on each side of the equator. They separate magnetic field lines closing on the front from those swept into the Earth´s magnetotail.

Diffuse aurora--a spread-out glow often covering much of the auroral oval. It is not seen by the eye but can be observed quite well by satellite cameras. See discrete aurora.

Dipole--a compact source of magnetic force, with two magnetic poles. A bar magnet, coil or current loop, if their size is small, create a dipole field. The Earth´s field, as a crude approximation, also resembles that of a dipole, located near the Earth´s center.

Discrete aurora (or "auroral arcs") are the typical ribbon-like structures of aurora observed from the ground. From space they may appear as brighter spots in the diffuse aurora.

Drift--A magnetically trapped ion or electron moves as if it were attached to a magnetic field line. Drift is one of the features of such motion, namely its slow shift from one guiding field line to its neighbor. In the Earth´s magnetic field, such drifts gradually move particles all the way around Earth. Viewed from far above the north magnetic pole, ions drift around the Earth clockwise, electrons counter-clockwise, resulting in an electric current circling the Earth, the ring current.

Dynamo process--the generation of an electric currents by the flow of an electrically conducting fluid through a magnetic field. For instance, the magnetic field originating inside the Earth is believed to come from a dynamo process involving the flow of molten iron in the Earth´s hot core. The energy required to create the current is obtained from the motion of the flow.

Earth radius (RE)--the average radius of the Earth, a convenient unit of distance in describing phenomena and orbits in the Earth´s neighborhood in space. 1 RE = 6371 km = 3960 miles, approximately.

Edison effect--the flow of an electric current through a laboratory vacuum, between two metal wires, one of which is heated. The current flows only

when the heated wire is more negative, because it is due to free electrons released from the wire by heat. The Edison effect made possible "vacuum tubes" used in radio and television equipment before the invention of the transistor.

Electric charge--that which causes electrons and ions to attract each other, and to repel particles of the same kind. The electric charge of electrons is called "negative" (-) and that of ions "positive" (+). Materials such as glass, fur and cloth acquire an electric charge by rubbing against each other, a process which tears electrons off one substance and attaches it to the other. Electric charges (+) and (-) may also be separated by a chemical process, as in an electric battery. About Ben Franklin's role in studying and naming electrical charges, click here.

Electric current--a continuous flow of electrons and/or ions, through a material with conducts electricity. A currents usually flows in a closed circuit, without beginning or end. In daily life currents are generally driven through wires by voltages produced by batteries or generators. In space plasmas, some currents may be produced this way, but many are inherent to the way ions and electrons move through magnetic fields, e.g. their **drifts.**

Electric field--the region in which electric forces can be observed, e.g. near an electric charge. As a field, it may also be viewed as a region of space modified by the presence of electric charges.

Electrojets, auroral--two intense electric currents, flowing around the auroral oval from the day side towards the night side and meeting somewhat west of midnight. Associated with Birkeland currents and caused by the unusual electric conductivity properties of ionospheric plasma, the electrojets are responsible for practically all of the magnetic disturbance observed on the ground due to substorms. Their magnitude (derived by analyzing such disturbances) often serves as a convenient gauge of the intensity of substorm activity.

Electromagnet--a magnet powered by an electric current. Usually the current flows in a coil, which may or may not contain a core of iron or of some other magnetic material.

Electromagnetic field (EM field)--the regions of space near electric currents, magnets, broadcasting antennas etc., regions in which electric and magnetic forces may act. Generally the EM field is regarded as a modification of space itself, enabling it to store and transmit energy.

Electromagnetic wave--a combination of oscillating magnetic and electric field, spreading in wavelike fashion through space at a speed of about 300 000 km.sec. James Clerk Maxwell´s theory in 1864 suggested that light was such a wave, and today we know that such waves include all forms of light--also infra-red and ultra-violet, as well as radio waves, microwaves, x-rays

and gamma rays.

Electron--a lightweight particle, carrying a negative electric charge and found in all atoms. Electrons can be energized or even torn from atoms by light and by collisions, and they are responsible for many electric phenomena in solid matter and in plasmas. (About the discovery of the electron in 1897, click here.

Electron volt (ev)--a convenient unit of energy applied to ions and electrons, equal to the energy gains when such particles "fall" across a voltage difference of 1 volt. Gas molecules at room temperature have about 0.03 ev, on the Sun´s face about 0.6 ev, typical electrons of the aurora 5000 ev, typical protons in the inner radiation belt 20,000,000 ev, typical cosmic ray protons near Earth 10,000,000,000 ev, and the highest energies of cosmic rays may reach up to 10,000,000,000 times more.

Electroscope--a simple instrument, indicating the presence of electric charge by the spreading-apart of two leaves of metal foil, hanging next to each other inside a glass jar. The rate at which an electroscope in dry air loses its charge is a rough indicator of the prevailing level of ionizing radiation.

Energetic particles--charged atomic particles moving rapidly, often at a significant fraction of the speed of light. They can penetrate matter, ionize the material which they traverse and emit energetic photons (e.g. of x-rays). See also radiation belt, cosmic rays, solar energetic particles.

Energy--loosely, anything that can cause a machine to move. For example, energy is contained in moving water, water raised to a high place, heat or magnetic fields. The energy of fast ions and electrons (measured in " electron volts") is a measure of their speed, and it enables them (for instance) to penetrate matter.

Explorer 1--first satellite launched by the US, around midnight of January 31, 1958. Carrying Geiger counters, Expolorer 1 and the similar Explorer 3 (launched two months later) discovered the existence of a belt of magnetically trapped energetic particles around Earth.

Field line preservation--a property of fluids which are perfect conductors of electricity (including "ideal plasmas"), by which two particles which initially share the **same** field line, continue to do so into the future. The opposite also holds for such fluids: two particles which start out on **different** field lines will **always** be on different field lines.

Frequency--the number of back-and-forth cycles per second, in a wave or wave-like process. Expressed this way, the frequency is said to be given in units of Hertz (Hz), named after the scientist who first produced and observed radio waves in the lab. Alternating current in homes in the US

goes through 60 cycles each second, hence its frequency is 60 Hz; in Europe it is 50 cycles and 50 Hz.

Flare--see solar flare

Gamma ray bursts--brief bursts of gamma rays from the distant universe, observed by satellites.

Gamma rays--electromagnetic waves of the highest frequencies known, originally discovered as an emission of radioactive substances.

GCM--guiding center motion

Geiger counter--a simple electronic detector of energetic particles. It consists of a thin straight wire at a high positive voltage (usually close to 1000 volts) relative to a cylindrical electrode surrounding it. Geiger counters can detect ("count") high-energy particles, but they cannot identify their type or distinguish their energy.

Geocorona--the outermost layer of the Earth´s neutral atmosphere, a huge cloud of hydrogen surrounding our planet. Its density diminishes with distance and it has been observed up to distances of 5-6 Earth radii.

GSM coordinates--geocentric solar magnetospheric coordinates, the system in which locations in the large-scale magnetosphere are usually given. The main axis ("noon-midnight") points at the Sun, and the plane of symmetry ("noon-mignight plane") contains the Earth´s magnetic axis, which however needs not be exactly perpendicular to the sunward direction.

Guiding center--An ion and electron in a magnetic field, of suitably low energy, is constrained to circle ("gyrate") around a local magnetic field line, while the center of its circular motion slides up or down along the line and also slowly shifts from one guiding field line to its neighbor, following certain rules. The center of that circle is known as the particle´s **guiding center** and the entire mode of mottion is called **guiding center motion**. See gyration, magnetic mirroring, drift.

Gyration--a term used in plasma studies for the circular motion of an ion or electron around its guiding center.

IMF--interplanetary magnetic field (see below).

IMF polarity--the general direction of interplanetary magnetic field lines in a certain location (e.g. near Earth), i.e. whether they head away from the Sun ("**away polarity**") or towards it ("**towards polarity**"). The IMF polarity determines which of the polar caps of the Earth is magnetically linked to the Sun and gets **polar rain** guided towards it. See interplanetary sector.

Inner magnetosphere--the region of the magnetosphere in which ions and

electrons are relatively stably trapped. Approximately the region threaded by field lines which cross the equator within synchronous orbit, i.e. within 6.6 **Earth radii**.

Interplanetary magnetic field (IMF)--the weak magnetic field filling interplanetary space, with field lines usually connected to the Sun. The IMF is kept out of most of the Earth´s magnetosphere, but the interaction of the two plays a major role in the flow of energy from the solar wind to the Earth´s environment.

Interplanetary shock--the abrupt boundary formed at the front of a plasma cloud (e.g. one from a coronal mass ejection) if it pushes its way through interplanetary space much faster than the rest of the solar wind. See bow shock. For an article about the impact of a large shock on the magnetosphere, click here.

Interplanetary sector--a region of interplanetary space in which all magnetic field lines point **either** away from the Sun ("away sector") **or** towards the Sun ("towards sector"). The Earth´s orbit typically contains 4 sectors, but 2 or 6 are not unusual; they are caused by waviness of the current sheet separating magnetic field lines from opposite polar regions of the Sun.

Ion--usually, an atom from which one or more electrons have been torn off, leaving a positively charged particle. "Negative ions" are atoms which have acquired one or more extra electrons, and clusters of atoms can also become ions.

Ionic Theory--in chemistry, the theory (by Svante Arrhenius, 1884) which first explained the behavior of acids, alkalis (bases) and salts when dissolved in water. By the ionic theory, each molecule of such materials consists of molecular or atomic groupings charged with positive or negative electricity ("ions"), held together by their mutual electrical attraction. In water these electrical forces are greatly weakened, the groupings often get separated, and if an electric current flows, positive and negative ones migrate with it in opposite directions.

Ionization--the process by which a neutral atom, or a cluster of such atoms, becomes an ion. This may occur, for instance, by absorbtion of light ("photoionization") or by a collision with a fast particle ("impact ionization"). Also, certain molecules (such as table salt or sodium chloride, NaCl) are formed by natural ions (like Na+ and Cl-) held together by their electric attraction, and they may fall apart when dissolved in water (which weakens the attraction), enabling the solution to conduct electricity.

Ionosphere--a region covering the highest layers in the Earth´s atmosphere, containing an appreciable population of ions and free **electrons**. The ions are created by sunlight ranging from the ultra-violet to x-rays. In the lowest

and least rarefied layer of the ionosphere, the D-layer (around 70 km or 45 miles), as soon as the Sun sets the ions and electrons recombine, but in the higher layers, collisions are so few that its ion layers last throughout the night

Lagrangian point--in a system dominated by two attracting bodies (such as Sun and Earth), a point at which a third, much smaller body (such as a satellite) keeps the same position relative to the other two. Theoretically, the Sun-Earth system has 5 Lagrangian points, but only two are important: L1 (L-one), on the sunward side of Earth, about 4 times the distance of the Moon, and L2 at approximately the same distance on the midnight side.

LLBL--low latitude boundary layer. See **boundary layers**.

Magnetic field--a region in which magnetic forces can be observed. See "electromagnetic field," a more general field also including electric forces.

Magnetic field lines--lines in space, used for visually representing magnetic fields. At any point in space, the local field line points in the direction of the magnetic force which an isolated magnetic pole at that point would experience. In a plasma, magnetic field lines also guide the motion of ions and electrons, and direct the flow of some electric currents.

Magnetic latitude--geographic latitude of a location, in a system of latitudes and longitudes whose axis is **not** the rotation axis of the Earth but the magnetic axis, i.e. the axis of the dipole at the Earth´s center which best fits the internal magnetic field. The auroral zone, for instance, is near magnetic latitude 65 degrees. See magnetic local time.

Magnetic lines of force --Michael Faraday´s original term for what is now widely called magnetic field lines.

Magnetic local time (MLT)--in the a system of latitude and longitude whose axis is the dipole axis, magnetic local time is the **longitude**, measured not in degrees but in hours (1 hour = 15 degrees).

The zero of this longitude is **not** fixed relative to Earth (the way the Greenwhich meridian is for geographic longitude), but rather relative to the Sun: the line of magnetic longitude facing the Sun always has MLT = 12 hours ("magnetic noon"), and the opposite one has MLT = 0 or 24 hours ("magnetic midnight"). See magnetic latitude

Magnetic mirroring--the process by which an ion or electron, constrained by its guiding center motion to follow a magnetic fields line, slows its advance down that line as it enters a region of stronger magnetic field, and is ultimately turned back ("mirrors") at a certain "mirror point."

Mirroring is what makes possible long-term trapping of ions and electrons in the Earth´s radiation belts. In the inner magnetosphere, ions and electrons are confined between two mirror points, one north of the equator and one

south of it. These turn them back before their motion along the guiding field line reaches the atmosphere, where they might otherwise have been lost by colliding with molecules of air.

Magnetometer--intrument for measuring magnetic fields. Spacecraft often carry fluxgate magnetometers, which measure components of the magnetic field (3 of them are combined to give its strength **and** direction) but need to be calibrated. Rubidium-vapor and similar instruments measure only the strength, but their reading is absolute, related to atomic constants.

Magnetic poles --A term with two meanings:

- (1) the points on the surface of the Earth towards which the compass needle points. (Several slightly different definitions exist, because the field is not exactly that of a dipole.)
- (2) A concentrated source of magnetic force, e.g. a bar magnet has two magnetic poles near its ends.

Magnetic reconnection--In a plasma, the process by which plasma particles riding along two different field lines can be made to share the same field line (see field line preservation). For instance, following reconnection, solar wind particles on an interplanetary field line, and magnetospheric ones on a field line attached to Earth, may find themselves sharing the same "open" field line, which has one end anchored on Earth and the other extending to distant space.

Magnetic reconnection can occur when plasma flows through a neutral point or a neutral line at which the intensity of the magnetic field is zero and its direction is not defined. It is an important concept in the theories of energy transfer from the solar wind to the magnetosphere and of energy release in substorms.

Magnetic storm--A large-scale disturbance of the magnetosphere, often initiated by the arrival of an interplanetary shock originating at the Sun.

A magnetic storm is marked by the injection of an appreciable number of ions from the magnetotail into the ring current, a process accompanied by increased auroral displays. The strengthened ring current causes a world-wide drop in the equatorial magnetic field, taking perhaps 12 hours to reach its greatest intensity, followed by a more gradual recovery.

Magnetometer--an instrument for measuring magnetic fields. Spacecraft often carry fluxgate magnetometers, which measure components of the magnetic field (3 of them are combined to give its strength **and** direction) but they need to be calibrated.

Rubidium-vapor and similar instruments measure only the field strength, but their reading is absolute, related to atomic constants.

Magnetopause --The boundary of the magnetosphere, separating plasma attached to Earth from the one flowing with the solar wind.

Magnetosheath--the region between the magnetopause and the bow shock, containing solar wind which has been slowed down by passage through the bow shock. As the magnetosheath plasma streams away from the bow shock, it gradually regains its former velocity.

Magnetosphere--The region around Earth, bounded by the magnetopause, whose processes are dominated by the Earth´s magnetic field.

Magnetotail--The long stretched-out nightside of the magnetosphere, the region in which **substorms** begin. It starts about 8 Earth radii (RE) nightward of the Earth and has been observed to distances of at least 220 RE. See plasma sheet, tail lobes,

NENL--near-earth neutral line (see below).

Neutral point --A **point** at which the magnetic intensity is zero. Plays an important role in magnetic reconnection.

Neutral line (NL)--A **line** along which the magnetic intensity is zero. Like a neutral point, a NL can play an central role in magnetic reconnection, but because of physical reasons, it may be a more likely setting for the actual reconnection process.

Neutral line, near-earth (NENL)--a neutral line which many believe forms in the plasma sheet during magnetic substorms.

Neutral line, distant --A neutral line in the distant magnetotail where (by Dungey´s theory) interplanetary field lines which were split apart by magnetic reconnection when they first encountered the magnetosphere are once more re-united.

There is little doubt such re-uniting takes place: what is unclear is the exact manner in which it happens.

Northern lights--an older name for the polar aurora.

Orbit--the line followed by a spacecraft or a celestial body. See Sun synchronous orbit, synchronous orbit.

Parallel voltage drops ("parallel electric fields")--voltage drops along magnetic field lines.

Particle--in general, a charged component of an atom, that is, an ion or electron.

Photon --colloquially, a "particle of light." Although light spreads as an electromagnetic wave, it can be created or absorbed only in discrete amounts of energy, known as photons. The energy of a photon is greater the shorter the wavelength--smallest for radio waves, larger for visible light, largest for x-rays and gamma rays.

Photosphere--The layer of the Sun from which all visible light reaches us. The Sun is too hot to have a solid surface and the photosphere consists of a plasma at about 6000 degrees centigrade.

Planetary magnetospheres --the magnetospheres of planets, especially of Jupiter, Saturn, Uranus and Neptune, all of which have dipole-like magnetic fields stronger than the Earth´s. Mercury has a weak magnetic field, Mars and the Moon are magnetized in patches (probably on their surfaces) and Venus, although non-magnetic, has its own interaction with the solar wind, by means of its thick ionosphere.

Plasma --a gas containing free ions and electrons, and therefore capable of conducting electric currents. A "partially ionized plasma" such as the Earth´s ionosphere is one that also contains neutral atoms.

Plasma physics --the study of plasma phenomena--in the laboratory, where it may one day help extract energy from hydrogen fusion, in the Sun and the distant universe, in the Earth´s ionosphere and in the magnetospheres of Earth and other planets.

Plasma sheet --a near-equatorial layer of denser plasma in the tail of the Earth´s magnetosphere. It separates the two tail lobes, the two bundles of magnetic field lines connected to the regions around the Earth´s magnetic poles.

Plasmasphere --A region of relatively dense but cool plasma, surrounding Earth, extending to distances of about 5 Earth radii (RE). The plasmasphere is the upward extension of the Earth´s ionosphere, getting less and less dense with increasing distance, and it shares the Earth´s rotation.

Polar caps --in magnetospheric usage, the regions around the Earth´s magnetic poles, inside the auroral oval. The field lines in these regions extend into the tail lobes of the Earth; they reach great distances and do not close in the magnetosphere.

Polar orbit --a satellite orbit passing over both poles of the Earth. During a 12-hour day, a satellite in such an orbit can observe all points on Earth.

Polar rain --a drizzle of electrons observed inside the polar caps, apparently from the high end of the energy distribution of solar wind electrons. Its origin in the solar corona is revealed by the fact that in general only one polar cap receives it at any time--the one which (depending on IMF polarity) is linked to the Sun.

Proton --an ion of hydrogen and one of the fundamental building blocks from which atomic nuclei are made.

Radiation --a term with two broad meanings:

- In the narrow sense, some type of electromagnetic wave: radio, microwave, light (infra-red, visible or ultra-violet), x-rays or gamma rays are all types of radiation.

- Colloquially, the full term is "**ionizing radiation**" and means any spreading emission which can penetrate matter and ionize its atoms. That includes x-rays and gamma rays, but also high-energy ions and electrons emitted by radioactive substances, accelerated by laboratory devices or encountered in space (e.g. the "radiation belt" and "cosmic rays," also known as the "cosmic radiation").

Radiation belt --The region of high-energy particles trapped in the Earth´s magnetic field.

Radioactivity --Instability of some atomic nuclei, causing them to change spontaneously to a lower energy level or to modify the number of protons and neutrons they contain. The 3 "classical" types of radioactive emissions are (1) alpha particles, nuclei of helium (2) beta-rays, fast electrons and (3) gamma-rays, high-energy photons.

Radio Astronomy--the observation of radio waves from the Sun, planets and the distant universe. In many cases these are signature of energetic particles.

Radio waves--Electromagnetic waves of relatively low frequency.

Reconnection--see "Magnetic reconnection"

Ring current--A very spread-out electric current circling around the Earth, carried by trapped ions and electrons.

Shock--A sudden transition at the front of fast flow of plasma or gas, when that flow moves too fast for the undisturbed gas to move out of its way. Also occurs when a steady fast flow hits an obstacle.

Solar corona--the outermost layer of the Sun´s atmosphere, visible to the eye during a total solar eclipse; it can also be observed through special filters and best of all, by X-ray cameras aboard satellites. The corona is very hot, up to 1-1.5 million degrees centigrade, and is the source of the solar wind

Solar energetic particles--high energy particles occasionally emitted from active areas on the Sun, associated with solar flares and coronal mass ejections. The Earth´s magnetic field keeps them out of regions close to Earth (except for the **polar caps**) but they can pose a hazard to space travelers far from Earth.

Solar flare--a rapid outburst on the Sun, usually in the vicinity of active sunspots. A sudden brightening (only rarely seen without special filters) may be followed by the signatures of particle acceleration to high energies--

x-rays, radio noise and often, a bit later, the arrival of high-energy ions from the Sun.

Solar wind--hot solar plasma spreading from the solar corona in all directions, at a typical speed of 300-700 km/sec. It is caused by the great heat of the corona.

Space tether--see tether, space

Space Weather--the popular name for energy-releasing phenomena in the magnetosphere, associated with magnetic storms, substorms and interplanetary shocks.

Substorm--a process by which plasma in the magnetotail becomes energized at a fast rate, flowing earthward and producing bright auroras and large Birkeland currents, for typical durations of half an hour.

Sun--the star at the center of our solar system. The Sun keeps Earth warm and sustains life on it, and it also emits the solar wind and occasional bursts of solar energetic particles.

Sunspot--An intensely magnetic area on the Sun´s visible face. For unclear reasons, it is slightly cooler than the surrounding photosphere (perhaps because the magnetic field somehow interferes with the outflow of solar heat in that region) and therefore appears a bit darker. Sunspots tend to be associated with violent solar outbursts of various kinds.

Sunspot cycle (or solar cycle)--an irregular cycle, averaging about 11 years in length, during which the number of sunspots (and of their associated outbursts) rises and then drops again. Like the sunspots, the cycle is probably magnetic in nature, and the polar magnetic field of the Sun also reverses each solar cycle.

Sun-synchronous orbit --a near-Earth orbit resembling that of a polar satellite, but inclined to it by a small angle. With an appropriate value for the inclination angle, the equatorial bulge causes the orbit to rotate during the year once around the polar axis. Such a satellite then maintains a fixed position relative to the Sun and can, for instance, avoid entering the Earth´s shadow.

Supernova--a large explosion at the end of the evolutionary process of many stars. (Strictly speaking, all that follows applies to a "type II" supernova.)

A star such as the Sun is kept "puffed up" to its apparent size by the heat which nuclear reactions create in its core. Once its nuclear fuel is used up, the pull of gravity overcomes all other forces and makes the star contract to a very small size. The star´s atoms or even its nuclei are then crushed, and the process may turn it into a pulsar or black hole.

An enormous amount of energy is released in this last collapse, blowing

off the star´s outer layers as a rapidly expanding cloud of gas. It is widely believed that powerful shock fronts form ahead of this cloud´s advance, and through them some ions get accelerated to the very high energies of cosmic rays.

Synchronous orbit --a circular orbit around the Earth´s equator, at a distance of 6.6 Earth radii. At this distance the orbital period is 24 hours, keeping the satellite "anchored" above the same spot on Earth. This feature makes the synchronous orbit useful for communication satellites: a satellite transmitting TV programs to the US, for instance, will always be in touch with the US if "anchored" above it, and receiving antennas on the ground only need to point to one fixed spot in the sky.

Tail lobes--the two bundles of nearly-parallel magnetic field lines which stretch into the magnetotail, on opposite sides of the plasma sheet. The northern lobe contains field lines **entering** the north polar region of Earth, while the southern lobe contains lines **emerging from** the southern polar region.

Terrella--a small magnetized sphere, used as laboratory model of the Earth. About Birkeland's terrella experiments (1896), here

Tether, space--an experiment in which a satellite was released from the space shuttle at the end of a long insulated cable. The plan was for the dynamo process due to the motion of the tether through the Earth´s magnetic field to generate a large current in the cable.

Ultraviolet (UV)--electromagnetic radiation resembling visible light, but of shorter wavelength. UV cannot be seen by the eye, and much of it is absorbed by ozone, a variant of oxygen, at altitudes of 30-40 km. Satellite telescopes, however, can and do view stars and the Sun in UV, and even in the extreme UV (EUV), the range between UV and X-rays.

Vector--a physical quantity having both magnitude (= strength or intensity) and direction. The magnetic field observed at any point in space is a vector; other examples are velocity, acceleration, force and the electric field, which maps the electric force acting on ions and electrons. Equations involving vectors tend to be more complicated, as they have to describe three-dimensional structure.

Voltage--a sort of "electric pressure," gauging the electric force acting on ions or electrons (or more accurately, the amount of energy they might obtain from that force). In electric devices such as are used in the home, increasing the voltage increases the current--just as increasing the pressure driving water through a pipe increases its flow rate. (The scientific term is "potential" or "potential difference".)

X-rays--electromagnetic waves of short wavelength, capable of penetrating

some thickness of matter. Medical x-rays are produced by letting a stream of fast electrons come to a sudden stop at a metal plate; it is believed that X-rays emitted by the Sun or stars also come from fast electrons.

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Spanish translation by ***J. Méndez***

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#8. *Positive Ions*

(Files in red–history)

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- **8 Positive Ions**
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  - 9H. Poincaré, 1896

Matter is made of atoms. Each atom, in its turn, is made of electrically charged components:

- a positive central **nucleus**, where most of the atom's mass is concentrated, and
- one or more negative electrons.

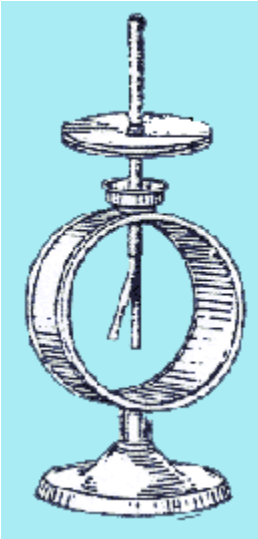
Nucleus and electrons are held together by the electric attraction between positive (+) and negative (-) charges. In any atom, the two charges are exactly balanced, so that to the outside world the atom is electrically neutral.

Ions help gases conduct electricity

When an atom is hit by a fast-moving particle, like those emitted by radioactive materials, or absorbs light, an electron may be torn off. What is left is an electrically charged atom or "**ion,**" carrying a positive charge, and the process is known as "**ionization.**"

When such processes occur in air, they produce there free ions and electrons, which can move and carry an electric current, something neutral atoms cannot do. Air is usually an excellent electrical insulator, but with ionization present,

electric charges can leak through it.



The Electroscope

This leakage was used, around 1900, to detect radioactive emissions and measure their intensity. The drawing below shows a simple instrument for performing such measurements. It is called an **electroscope** and contains two parallel leaves of metal foil, protected from wind inside a metal box with transparent windows and attached to a metal rod insulated from the box and leading outside (drawing).

When the plate at the end of the rod is electrically charged (e.g. by rubbing it with a dry cloth), the leaves spread wide apart, since both carry electric charges of the same sign and repel each other. However, when a radioactive substance is brought close, the electric charge leaks to the box and the leaves gradually drop down again.

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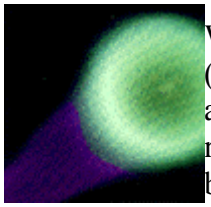

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Ion types

Hydrogen, the simplest atom, has one electron. When that electron is removed, we get the simplest positive ion, the "**proton**"; like the electron, it is a fundamental particle, but 1836 times heavier. The chemical symbol for hydrogen is H, but for the proton it is H+.

The next heavier atom is that of **helium** (chemical symbol He) and it contains two electrons. Its nucleus consists of two protons and also two **neutrons**, particles similar to the proton but with no electric charge. The Sun gets its energy by combining protons (some of which convert to neutrons in the process) into helium, deep in the Sun's core; since the helium nucleus is an unusually stable combination of particles, energy is released in the process.

The completely ionized helium atom He++, missing both electrons, is also known as the "alpha particle" (see history section). Just as in the Sun and in most stars, hydrogen is the most abundant element with helium next, so the solar wind consist mostly of protons, with 5% alpha particles and small numbers of heavier ions.

A somewhat similar composition exists among **cosmic rays**, a very thin drizzle of ions moving close to the speed of light and bombarding the Earth from all directions; they probably fill our galaxy and their origin is uncertain.

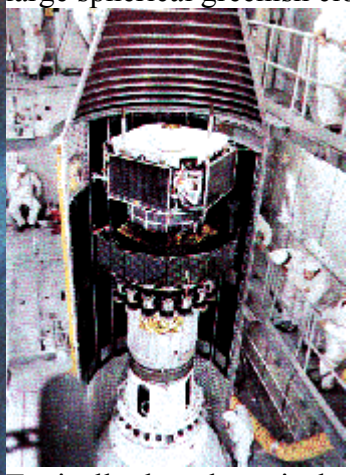
It may be mentioned that in addition to such atomic ions, there also exist molecular ions of either sign, formed when intact molecules lose or gain an electron. Such ions occur in ionospheric processes.

Clouds of barium ions

An atom can become ionized by the absorption of light. The atom of barium is particularly easy to ionize, because its outermost electron is very loosely bound. If a mass of barium is vaporized in space, producing a barium cloud, much of the barium becomes ionized by sunlight within less than a minute. The cloud then moves in response to electric forces in space, and can be used to study the electrical field in space.

In practice the barium is packed into canisters with copper oxide, and these are released from rockets or satellites and ignited. The resulting chemical reaction produces great heat, but more barium is packed into the canister than can combine chemically, and some the excess is vaporized to form a

large spherical greenish cloud.



Typically the release is done after sunset or before sunrise, so that while the canisters explode in full sunlight, observers on the ground can watch the cloud against the dark sky: soon a bluish ion cloud separates from the green one, usually elongated or striped in the direction of the magnetic field lines, which guide the ions.

The AMPTE Charge Composition Explorer (CCE) satellite

Some barium releases are conducted far from Earth and are tracked by telescopes. The AMPTE mission (Active Magnetospheric Particle Tracer Experiment), launched in 1984, released barium clouds near the "nose" of the magnetosphere and in the magnetospheric tail.

The AMPTE mission included three spacecraft, shown here stacked up during launch. Click here for a full size version of this image.

In addition it released a barium cloud in the solar wind to produce an "artificial comet". Soon after the cloud formed, the magnetic field embedded in the solar wind picked it and made it share the wind's flow, a process similar to the one which creates the ion tails of comets (see solar wind, history).

Questions from Users:

*** How are ions produced?

Further Exploring:

This section starts with the words "**Matter is made of atoms.**" Actually it took about a century, many experiments and some clever deductions to arrive at that conclusion! It would be completely impossible to tell the entire

story here, but you might want to look at a brief sketch of the steps which led to the atomic theory, part of material prepared for teachers in a different course.

Next Stop: #8H. Positive Ions--History

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Timeline **Expanded timeline** **Glossary**

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Site Map

Some Dates in the Exploration of the Magnetosphere

Dates in red are from the basic timeline of events related to "Exploration of the Earth's Magnetosphere".
Dates in black are from the history of society and technology, and are meant to provide a broader context for the dates in the basic list.

If connected to the internet, **click here** for a similar but broader chronology on astronomy and space, extending from antiquity to 2004. If using a CD, go to folder "stargaze" and open there "Stimelin.htm" .

- **~1000--Magnetic compass** discovered in China

- **1000-1400** Age of **feudal lords** in Europe: castles, knights, religious fervor, only very rudimentary science and technology. Also the age of the **Vikings**, some of whom sailed as far as Greenland and America. **Mongols** overrun and subjugate southern **Russia**.

- **1095-1291 Crusades**

- **1460** Johann Gutenberg invents the **printing press** with movable type. Combined with **paper** (another Chinese invention which gradually reached Europe and displaced parchement), the printed book is a major force in a cultural and technical growth spurt, the **Renaissance** (French for "rebirth").

- **1492** Columbus discovers **America**, followed by Spanish (and some Portugese) explorers. The main powers in Europe are **Spain, France, England, Turkey** and a confederation of **German** princes ("Holy Roman Empire.").

- **1543** **Copernicus**, a Polish cleric, publishes his theory that the Earth is a planet revolving around the Sun.

- **1588** The "**Spanish Armada**," a fleet attacking Britain, is destroyed by the British navy and by storms. For the first time Britain is able to claim part of the American continent.

- Europe and Asia are introduced to American crops--potatoes, tomatoes, corn. Europe´s diet is also gradually enriched by sugar, oranges and pepper, originating in India.

- **1600 William Gilbert** publishes in London "De Magnete" ("on the magnet"). His explanation of the compass: the Earth is a giant magnet.

- **1609---Galileo Galilei** builds in Italy the **first astronomical telescope** and observes mountains on the Moon, **sunspots** (also discovered independently by Christopher Scheiner and Johann Fabricius), 4 moons around Jupiter and a crescent-like Venus, changing its shape the way the Moon does. His observations convince him that Copernicus was right.
  That same year **Johann Kepler** in Prague formulates his first two laws--that planets move in ellipses, and that they speed up as they approach the Sun according to a certain formula; these are shown by **Isaac Newton** in 1684 to be a direct result of Newton's law of gravitation.

- After a failed attempt (1586) to establish a colony on Roanoke Island, Virginia (now part of N. Carolina), Jamestown is founded in Virginia in 1607, and the first English settlers land in Massachussetts Bay in 1620 (the "**Pilgrims**").

- A century after Martin Luther broke away from the Roman church, religious wars sweep Europe. The **30 years' war** (**1618-1648**) devastates Germany and establishes Sweden as a major military power. In the civil war in England, parliament suspends monarchy 1645-1660, king beheaded 1649.

- The**Turkish** army reaches Vienna (**1683**) but is repelled; among the booty the victors discover **coffee**, develop a taste for it. Englishmen begin smoking tobacco, an American plant.

- **1708**---Abraham Darby begins extensive iron production in England, based on roasted coal (coke). As firewood gets scarce, **coal** becomes England's choice fuel and coke replaces charcoal in iron production. To run the pumps that keep coal mines dry, Newcomen in 1712 invents a crude steam engine.

- **1712**---Russia's king (czar) Peter the Great "opens a window to the West" by founding a new capital, which he names **St. Petersburg** and which becomes Russia's main port on the Baltic sea.

- **1741**--Hiorter and Celsius note that the polar aurora is accompanied by a disturbance of the magnetic needle.

- **Britain's colonies in America** achieve a growing degree of self-

sufficiency. Benjamin Franklin prints books in Philadelphia, also demonstrates (1749) that lightning is an electrical phenomenon. Later (**1775-1783**) the colonies rebel against Britain, win their independence and form a confederation. In 1787 they write a constitution and form a federal republic.

- **1769**---James Watt in Britain invents a greatly improved **steam engine**; In 1807 Robert Fulton uses steam to run the first commercial paddlewheeler on the Hudson river;

- **1777 Charles Augustin de Coulomb** in Paris builds a sensitive magnetometer, using a magnet suspended by a long flexible string. Using this, he proves that the magnetic attraction (and also the electric one) decrease like the inverse square of the distance.

- **1781**---William Herschel, a German musician settled in Britain, discovers the **planet Uranus** with a mirror telescope he had constructed.

- **1783**---The Montgolfière brothers in France, owners of a paper factory, build the first **hot air balloons**; balloons lifted by hydrogen follow.

- **1789**---The **French Revolution**: France rebels against its king, who is later deposed and executed. The French follow the US example and set up a republic, but a military officer, Napoleon Bonaparte, gradually gains power. From **1798 to 1815** France under Napoleon fights a series of wars and for a while rules or controls most of the European continent.

- **1793**---Alexander Mackenzie **crosses Canada** from coast to coast. After the **1803** US purchase of **Louisiana** from Napoleon, **Meriwether Lewis** and **William Clark** cross the continent with their exploration party, from St. Louis to the mouth of the Columbia River.

- **1796**---Edward Jenner in Britain introduces **vaccination** against smallpox.

- **1803**---John Dalton, a chemist, argues that observations in chemistry require matter to be composed of **atoms**.

- **1820**--Hans Christian Oersted discovers electromagnetism. André-Marie Ampére deduces that magnetism is basically the force between electric currents.

- The Industrial revolution: George Stephenson in Britain (**1825**) and Peter Cooper in the US (**1830**) found successful **railroads**, run by steam. Mass production of fabric and paper. **Henry Bessemer** in 1856 finds way to mass-produce steel.

- **1826**---crude **photography** by L.J.M. Daguerre, greatly improved in decades that follow.

- 1829--Joseph Ressel (a Czech forester employed by the Austrian Navy in Trieste) builds and tries out a simple **ship's propeller**. Later in 1836 John Ericsson patents the propeller and develops it further.

- **1837**--Samuel Morse invents his **telegraph**; 1844 first commercial telegraph line opens, by 1866 undersea telegraph cables link Europe and America.

- **1846**---**Anesthesia** by ether is introduced by William T. Morton in Boston.

- **1849**---California **gold rush**.

- **1851**--Samuel Schwabe, a German amateur astronomer, announces the discovery of the 11-year sunspot cycle.

- **1856**---Commodore Perry and a US fleet open up **Japan** to western culture and technology; rapid modernization follows, enabling Japan to defeat Russia in war less than 50 years later.

- **1859**--Richard Carrington in England observes a violent and rapid eruption near a sunspot; 17 hours later a large magnetic storm begins.

- **1859**---Charles **Darwin** publishes "Origin of the Species"

- **1859**---Edwin Drake extracts **petroleum** from an oil well in Titusville, Pennsylvania. Beginning of a world-wide effort to find and extract oil, refine it and use its constituents for light, heat and later to run gasoline and diesel engines.

- **1861**---**Italy** unified under the king of Piedmont; 1850-70, **Germany** unified under Prussian leadership..

- **1860-65--US Civil War**

- **1865**---Joseph Lister introduces antiseptics to surgery, cutting its risks.

- The **Industrial revolution** continues: bicycles are introduced (high-wheelers, then "safety models"), mass production of fabrics, also Brooklyn Bridge (**1883**), Statue of Liberty (**1886**), Eiffel Tower (**1889**)

- **1985-1900**---After the introduction of electric train engines, the construction of **subways** begins in the major cities of Europe (starting with London, then Budapest) and the US (starting with Boston, then New York).

- **1870**---**Suez Canal** opens, a shortcut between Europe and Asia.

- **1870**---**Railroad across the US**. In **1891-1905**, the trans-Siberian railroad is built.

- **1876**---**Telephone** invented

- **1879**---Edison invents the electric **lightbulb**, initially using a fragile carbon filament.

- **1882**---**Electric power stations** in London and New York. Large scale refrigeration.

- **1884**---Charles Parsons invents his **steam turbine**, which ultimately becomes the preferred power plant of electric power stations and ships. Diesel engine introduced by Rudolf Diesel in 1897.

- The beginning of **automobiles** (Marcus 1864 in Austria; Benz, 1887 in Germany; Duryea, 1893 in the US).

- **1890**---Nitrocellulose photographic **film** introduced (George Eastman of Kodak, Rochester NY), making possible the first "movies."

- **1892**--George Elery Hale introduces the spectroheliograph, observing the Sun in the light of a single spectral line such as H-α. Using it he observes a solar flare and confirms the connection between flares and magnetic storms.

- Age of exploration and colonization in Africa.

- **1900-3**--Kristian Birkeland experiments with beams of electrons aimed at a magnetized sphere ("terrella") in a vacuum chamber. The electrons hit near the magnetic poles, leading him to propose that the polar aurora is created by electron beams from the Sun.
- Birkeland also observes magnetic disturbances associated with the aurora, suggesting to him that localized "polar magnetic storms" exist in the auroral zone.
- **1902**--Marconi successfully sends radio signals across the Atlantic Ocean. Oliver Heaviside suggests that the radio waves found their way around the curving Earth because they were reflected from electrically conducting layer at the top of the atmosphere.

- **1903---Wright brothers** fly at Kitty Hawk, North Carolina.

- **1906**---Lee De Forest invents the **triode**--the vacuum-tube device (based on the Edison effect) by which weak electric signals can be greatly amplified . It makes possible radio, sound films, loudspeakers and later a whole generation of electronic devices.

- **1909**---L.H.Baekeland introduces "bakelite", first mass-produced **plastic** material. It is widely used as electrical insulator.

- **1904-1914**---**Panama canal** is built.

- **1911**---Amundsen reaches **South Pole**.

- **1912**---Emperor overthrown in **China**, republic proclaimed.

- **1914-1918**---**World War I**. The main opponents are Germany, Austria and Turkey, lined up against Russia, France, Britain, Italy. In 1917 Russia withdrew, defeated, and the Czar was overthrown by Communist workers (Russian Revolution) but the US entered to help Britain, whose side prevailed. A very large, destructive war, the first in which technology played a major role, including airplanes, tanks, machine guns, submarines and poison gas.

- **1916**---Robert Goddard designs the first modern **rocket** motor; in 1926, launches first liquid-fuel rocket.

- **1926**--Gregory Breit and Merle Tuve measure the distance to the conducting layer in the high atmosphere, the one from which radio waves are reflected, by measuring the time needed for a radio signal to bounce back from it.
- R. Watson-Watt proposes naming the layer "ionosphere."

- **1927---Charles Lindbergh** flies solo from the US to Paris.

- **1929**---The New York stock market crashes, beginning a long economic **depression**, in the US and across the world.

- **1922 to 1925**---**Fascism**, the creed of a strong, all-controlling government, gains power in Italy under Benito Mussolini. In Russia in 1924, Communist leader V.I. Lenin, dies; after that Joseph **Stalin** gradually gains power, kills or exiles all his rivals and institutes a reign of terror.

- **1930**---In Germany, hard-hit by the economic hardships following WW-I and by the world-wide depression, the Fascist **Nazi party** under Adolph Hitler is 2nd in the polls in 1930, takes power 1933.

- **1930-1931**--After Birkeland's "electron beam" theory is disproved, Sydney Chapman and Vincent Ferraro in England propose that magnetic storms are caused when plasma clouds ejected from the Sun envelop the Earth.

- **1927-1930---Talking films** (black and white). "The Wizard of Oz" (1939)

pioneers color movies, but more than 10 years pass before color films become prevalent.

- **1932**---Sulfa drugs, first new anti-bacterial weapon. Penicillin follows during World War II, and other **antibiotics** are developed after the war.

- **1936**---The **DC-3**, the first modern airliner, can reach 210 mph with 21 passengers.

- **1939-1945 World War II**. A world-wide conflict is started by Hitler's Germany, whose army annexed Austria and Czechoslovakia, then attacked Poland. Germany was allied with Italy and after December 1941 with Japan, which launched its own war of expansion (it had invaded China years before that). A war with unsurpassed destruction and cruelty, including Hitler's attempt to exterminate the Jewish people, of whom about 6 million were killed in a deliberate plan. Technology played an even greater role than in World War I, including long-range bombing raids, improved submarines, jet engines, radar and towards the end, large military rockets and nuclear bombs. Opposing Hitler were France (which fell to the Germans), Britain, Russia and after 1941, the United States: 1941-3 the Germans became bogged down in brutal winter fighting in Russia, in 1943 the US and its allies invaded Italy and forced its surrender, then in 1944 they invaded France and in 1945 first Germany and then Japan surrendered. In 1945 in San Francisco, the victors formed the "**United Nations**", an international union whose major role was to ensure peace and arbitrate conflicts.

- **1943**---Oswald Avery at the Rockefeller Institute in New York proves that **DNA**, a hitherto unexplained substance in all nuclei of living cells, carries the genetic information.

- **1947**---**India** becomes independent, along with a great number of colonies (especially in Africa), as Britain and France dismantle most of their empires. **Indonesia** is established in 1949.

- **1948-1949**---The "**cold war**" between the western allies (Britain, France and the US) and the Soviet Union begins with a blockade of Berlin by the Soviets, who try to force out the western allies. Contact is maintained for a year by a massive airlift.

- **1947**---**Transistor** invented, compact solid-state device that replaces the triode and is much more durable. In 1956 Bardeen, Brattain and Shockley are awarded the Nobel prize for this.

- **1949**--A sudden increase in cosmic rays is traced to an eruption on the Sun. A much larger event occurs in February 1956.

- **1949**---The X-1 rocket airplane of the United States exceeds the **speed of sound**.

- **1949**---A million **TV** receivers (black-and-white) in the US; two years later the number reaches 10 million.

- **1949**--Britain puts the first **jet airliner** into service, the Comet. It is later withdrawn because of structural faults, but by 1958 the French Caravelle and the larger Boeing 707 jets enter service. Gradually jets begin dominating air transport, while travel by ocean liners declines sharply.

- **1950**---The "**Marshall Plan**" of US general George C. Marshall revitalizes the European economy by providing extensive but judicious aid.

- **1950**---**North Korea** invades South Korea. The US army stops the invasion and after a while enters North Korea, but a major intervention by China's army forces a stalemate.

- **1951**--UNIVAC, first large electronic **computer**, built by Sperry-Rand.

- **1953**--Owen Storey proves that "whistler" radio waves are produced by lightning and are often guided through distant space along field lines of the Earth's magnetic field.

- **1952**---United States explodes "Mike", the first **hydrogen** bomb, perhaps 500 times more powerful than the nuclear "atomic" bomb.

- **1953**---Edmund Hillary and Tenzing reach the top of **Mt. Everest**.

- **1954**--Meredith, Gottlieb and Van Allen use a rocket in the auroral zone to detect radiation from the aurora.

- **1954**---Following a supreme court ruling, the US government **outlaws Black/White segregation** in public schools.

- **1955**--Radio emissions from Jupiter are detected, mystify observers.

1955---Jonas **Salk** develops vaccine against polyomyelities, followed (1960) by the Salk oral vaccine; diseases is effectively eradicated.

- **1953-1958**---Watson and Crick show that DNA is a **double helix** and its mode of replication is established. By 1966 the "genetic code" is revealed, by which specific proteins are created. The beginning of modern molecular biology.

- **1956**--Soviet army crushes attempt of **Hungary** to break away from Communist block.

- **1956**---First large commercial **nuclear power** station, at Calder Hall, opens in Britain.

- **1957**-- -Sputnik 1 launched by the Soviet Union, the first artificial satellite.
- **1958**--Explorer 1, launched by the US January 31, observes the radiation belt; Explorer 3, launched in March, comes up with the first clear evidence for its existence. Sputnik 3, in May, also observes the radiation.
- Eugene Parker (Chicago) proposes the theory of the solar wind.
- Pioneer 3 observes the outer radiation belt.
- "Project Argus", 3 small nuclear bombs above the south Atlantic Ocean, creates (3 times) artificial radiation belts, lasting about 2 weeks. The project also creates artificial aurora.

- **1958---Interstate highway** network in the US started.

- **1958**---**NASA** established by President Eisenhower.

- **1959**--Thomas Gold proposes the name "Magnetosphere".
- **1961**--James Dungey in Britain proposes a mechanism for transmitting solar wind energy to the magnetosphere by direct magnetic linkage between the two.
- Ian Axford and Colin Hines (Canada) raise an alternative possibility, of energization by fluid friction at the boundary between the two.
- **1962**--The magnetopause, boundary between magnetosphere and the solar wind, is observed by Explorer 12.

- **1962, 20 February**---John Glenn becomes first American in orbit.

- **1962**--In July, an H-bomb test ("Project Starfish") by the US above the central Pacific Ocean creates a radiation belt of high-energy electrons, parts of which remain until 1967. The new belt creates aurora at Samoa and unexpectedly knocks out 3 artificial satellites.

- **1962**---The placing of Soviet Missiles on **Cuba** produces international crisis, which ends when the missiles are withdrawn.

- **1963**---President J.F. **Kennedy** assassinated in Dallas, Texas.

- **1963**---Nuclear **test ban** treaty

- **1964**--IMP-1 (Interplanetary Monitoring Platform 1) reports a large bow shock formed in the solar wind ahead of the magnetosphere, and a long magnetic tail on the night side of the Earth.
- Syun-Ichi Akasofu (Japan-US) and Sydney Chapman revive and expand Birkeland's notion of a "polar magnetic storm", now named "magnetospheric substorm."

- **1969, 20 July**---Apollo 11 astronauts **land on the Moon**.

- **1971**--Ionospheric oxygen ions found among energetic particles trapped in the Earth's magnetic field, evidence that O+ ions are pulled out of the ionosphere and accelerated (Ed Shelley et al., Lockheed).
- **1973**--Observations of the diffuse aurora are reported, made by the Canadian Isis-2 spacecraft.
- **1974**--A large-scale pattern of extensive electric currents flowing from space into the polar cap and out again is traced by Alfred Zmuda and Jim Armstrong of the Johns Hopkins U. Applied Physics Lab, using the Navy's "Triad" satellite.

- **1975---Viet Nam** war ends.

- **1975**---Steve Jobs and Stephen Wozniak create the first **personal computer**, the "Apple"

- **1976**---NASA´s "Viking" **soft-lands on Mars**, marking the US bicentennial.

- **1977**--The S3-3 satellite of the U.S. Air Force observes the upward acceleration of O+ ions, related to the downward acceleration of electrons in the polar aurora.
- **1981**--High resolution images are obtained by Lou Frank's group in Iowa of the entire auroral zone, using the Dynamics Explorer satellite.

- **1981---AIDS** begins spreading in the US.

- **1983**--ISEE-3 (International Sun-Earth Explorer 3) explores the distant magnetotail, before heading for comet Giacobini-Zinner.
- **1985**--An "artificial comet" is produced by a cloud of barium ions, released by the German IRM (Ion Release Module) satellite, part of the AMPTE mission. Meanwhile another AMPTE spacecraft, CCE (Charge Composition Explorer) observes mass and energy distribution in the ring current, including its peak energies around 65 keV.
- **1991**--Severe solar-produced shock wave hits the magnetosphere, producing an additional (temporary) inner radiation belt.
- **2004**--the HESS telescope array in Namibia maps a circular source of high-energy gamma rays, evidence for the origin of cosmic rays in supernovas.
- **27 December 2004**--a powerful gamma ray burst arrives, apparently from a "magnetar" in our own galaxy.
- **16 December 2004**--Voyager 1 apparently crosses the termination shock of the solar wind, at which it slows down below the Alfven speed (magnetic equivalent to sound velocity). That shock is the first sign of resistance to the solar wind by the interstellar plasma.

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