

# *Glossary*

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## Glossary

**Aberration**--A shift of direction (or location) from the one predicted by a simple calculation. **Abberation of starlight**--a small shift in the observed position of stars, due to the Earth's orbital velocity.

**Absolute temperature**--temperature in degrees centigrade (also known in this case as "degrees Kelvin"  $K^{\circ}$ ) measured from the absolute zero of  $-273.1^{\circ} C$ , the temperature at which all atomic and molecular motions are expected to cease.

**Absorption lines** Dark lines interrupting a continuous color spectrum, caused by a cool gas between the light source and the observer. Cool gas absorbs light in the same frequencies as it emits when hot, e.g. double yellow line of sodium. Such dark lines in the Sun's spectrum were discovered by Joseph Fraunhofer.

**Acceleration** -- Rate at which velocity changes (negative acceleration--slowing down--is also known as deceleration). Acceleration is a **vector** quantity.

**Adiabatic invariant** A quantity conserved in periodic motion--a bit the way energy is conserved, but here it is just approximate. Adiabatic invariants of electrons orbiting nuclei were once thought to be subject to quantum rules, but that turned to be a false lead. Later however adiabatic invariants (on a larger scale, not atomic) turned out to be important in radiation belt physics.

**Algebra** A branch of mathematics. Originally (and still in high school context), it refers to the art of calculating with unknown quantities, represented by letters. Modern algebra has expanded this to manipulating symbols represented by letter, following certain rules which may differ from the ones applying to numbers, e.g. vector algebra, matrix algebra etc.

**Algebraic equation** A relation involving unknown numbers, which is satisfied only for a certain value (or values) of those numbers. Finding those values is "solving the equation."

**Algebraic expansion** As used here, representing an algebraic expression involving a small quantity by a sum of terms which rapidly decrease. By omitting the small term, an approximate solution may be obtained. In an **iteration**, the procedure is repeated again and again, increasing the accuracy.

**Algebraic formula** A relation between undefined quantities, each representing a variable. For instance, after  $t$  seconds, the velocity  $v$  of a stone thrown vertically with velocity  $u$  is, in meters/second, (neglecting air resistance)  $v = g * t + u$  where  $*$  marks multiplication and  $g = 9.81$  is the acceleration due to gravity. Unlike an equation, the formula has no specific solution: but if you replace  $g$ ,  $t$  and  $u$  by the appropriate numbers, it will give the value of  $v$ .

**Algebraic identity** A relation between symbols (usually letters) representing unknown numbers, which is always correct, regardless of the numbers the symbols represent. For instance, if  $a^2$  is the second power ( $a$  squared) and  $*$  denotes multiplication, then  $(a^2)-(b^2)=(a+b)*(a-b)$ . Sometimes distinguished by replacing the symbol  $=$  with one containing three parallel lines.

**Alpha radioactivity**, The radioactive decay of heavy nuclei by emission of an alpha particle, a nucleus of helium. Made possible by [quantum tunneling](#). See also [radioisotopes](#).

**Angle of attack**--in the theory of airplane wings, the angle between the wing profile (roughly, measured along its bottom) and the wing's motion relative to the surrounding air.

**Angular momentum** A measure of the momentum associated with rotation around an axis; a vector, its direction determined by the axis. For a mass  $m$  rotating around the axis at distance  $r$  with velocity  $v$ , the angular momentum is  $mr v$ . Angular momentum can only assume certain discrete values ("is quantized") in the quantum theory of atoms.

**Anomaly** -- in orbital motion, one of the angles which gauges the motion of a planet or satellite around its orbit, increasing by  $360^\circ$  every revolution. The **true anomaly**  $f$  equals the polar angle  $\phi$  in **polar coordinates** with origin at the center of the motion (e.g. Sun or Earth). The **mean anomaly** is a related angle which increases in direct proportion to the time elapsed (the true anomaly does not--the motion is faster near the center). The **eccentric anomaly** is an auxiliary angle used in relating true anomaly (which is observed) and mean anomaly (which is calculated).

**Aphelion** -- the point in a planet's orbit furthest from the Sun (Helios is Greek for Sun). See **perihelion**, **apogee**.

**Apogee** -- the point in a satellite's orbit furthest away from Earth (see **perigee**, **aphelion**).

**Apollo** (project)--the US mission to land humans on the Moon and bring them back safely.

**Apparent motion** -- The observed motion of a heavenly body across the celestial sphere, assuming the Earth is at the sphere's center and is standing still.

**Astronomical unit** (AU). Mean Sun-Earth distance, used as scaling distance in the solar system. Using Kepler's laws, it is easy to derive distances in this system as measured in astronomical units. Independent measurement of one distance in that system then fixes the magnitude of all the rest.

**Atlas** -- An early liquid-fueled rocket, used by US astronauts and still in use for unmanned launches. Because of its lightweight construction it needs no

staging to achieve Earth orbit, but only drops two of its engines.

**Atom** A fundamental constituent of matter. All substances consist of atoms, usually combined chemically into molecules.

**Aurora, polar** Light emitted around an altitude of 100 km by atoms of the upper atmosphere hit by [fast electrons arriving from space](#), usually at near-polar latitudes. Most observed auroral light comes from oxygen atoms, elevated to relatively long-lived "excited" energy levels.

**Azimuth and elevation** -- Two angles which give the direction of a surveyor's telescope (theodolite). Azimuth is the rotation angle of the telescope around a vertical axis, measured from due north, clockwise from above; that is, the directions (north, east, south, west) have azimuth (0°, 90°, 180°, 270°). Elevation is the angle the telescope is lifted above the horizontal plane.

[In 3-dimensional polar coordinates centered on the instrument, azimuth is  $360^\circ - \varphi$  (since  $\varphi$  is measured counterclockwise), elevation is  $90^\circ - \theta$ , the direction of straight up has elevation  $90^\circ$  but  $\theta = 0$ ].

**Ballistic pendulum** -- A device often used for measuring the energy of motion of a bullet, adapted by Goddard to measure the thrust of small rockets with various nozzles. For a bullet is a heavy block of wood or sand-filled box, hanging by a string; the bullet is weighed, then fired into the pendulum, and the distance the pendulum rises allows the bullet's velocity to be deduced.

**Balmer series** . A series of 4 visible colors emitted by glowing hydrogen, appearing as a series of 4 "lines" in the spectrogram of hydrogen light (additional lines can be observed by instruments, beyond the range of the human eye). Johann Balmer, a high-school teacher, discovered in 1885 a simple but accurate formula connecting the wave frequencies of these colors, which provided the first clues to processes inside atoms, starting a process which ultimately led to quantum physics.

**Big Dipper** A prominent constellation in the northern sky. Because it is close to the north pole of the sky, it rarely sets below the horizon and is visible on most clear nights.

**Binding energy of an atomic nucleus.** The energy holding a nucleus together, balancing the attraction of the strong nuclear (attractive) force and the electrical repulsion of a large number of positive protons, confined together in a small space.

**Binomial Theorem**--A formula first derived by Newton, giving  $(1+z)^a$ , the result of raising  $1 + z$  to an arbitrary power  $a$ , as a sequence of form

$$(1+z)^a = 1 + A_1z + A_2z^2 + A_3z^3 + \dots$$

where the terms  $A_i$  ( $i = 1,2,3,\dots$ ) are given by the formula and where  $a$  can be positive, negative, fractional or whole. When the magnitude of  $z$  is less than 1, the higher powers get smaller and smaller and the formula can be made as precise as one wishes by including enough of them (for  $z$  of small magnitude, 1-2 terms are sufficient), although the result is never exact. For magnitudes of  $z$  equal to 1 or more, the formula only holds for values of  $a$  which are positive whole numbers. In that case, for any  $z$ , the result is exact and the sum of terms with powers of  $z$  does not go on arbitrarily but ends

with  $z^a$ .

**Black body radiation**--light or other [electromagnetic radiation](#) emitted due to heat by a solid, liquid or dense gas, with no color of its own (hence "black"). Distinguished by a continuous distribution of spectral color, with its peak of emission shifting towards shorter wavelengths as the temperature increases--e.g. infra-red for a warm hand, red for a hot iron bar, yellow for the glowing filament in a lightbulb.

The spectrum of black body radiation created serious theoretical difficulties at the turn of the 20th century. They were only resolved after Max Planck in 1900 proposed the spectrum could be explained, if the energy of emitted radiation was [limited to "quanta" of energy](#) whose size increased with the frequency of the radiation. His theory marked the beginning of quantum physics.

**Black hole**--an extremely compact object, collapsed by gravity which has overcome electric and nuclear forces. It is believed that stars appreciably larger than the Sun, once they have exhausted all their nuclear fuel, collapse to form black holes: they are "black" because no light escapes their intense gravity. Material attracted to a black hole, though, gains enormous energy and can radiate part of it before being swallowed up. Some astronomers believe that enormously massive black holes exist in the center of our galaxy and of other galaxies.

**Bohr model of the hydrogen atom.** The first model of the atom explaining the [hydrogen spectrum](#) by imposing "quantum conditions" by which angular momentum in an atom had to equal a multiple of Planck's constant  $h$ . Later expanded by Sommerfeld to explain many qualitative features of atoms and their spectra, but quantitative calculations were only possible after [wave mechanics](#) was introduced.

**Boyle's law** A fundamental law in the behavior of ideal gases: if temperature is kept constant, the density  $D$  of a gas varies proportionally to its pressure  $P$ . Actual gases usually approximate ideal ones pretty well as long as the temperature is far above their boiling point, e.g. nitrogen and oxygen in ordinary air.

**Bradley's aberration.** An apparent motion observed in all stars, shifting their celestial position around a small ellipse with a 1-year period. Discovered by the British Royal Astronomer James Bradley, it can be viewed as the result of the vectorial addition of the velocity  $v$  due to Earth's orbital motion and the velocity  $c$  of light. This is a "first order effect" involving  $v/c$  (not its square) and as such does not contradict relativity.

**Bulge of the Earth** The extra extension of the Earth's equator, caused by the centrifugal force of the Earth's rotation, which slightly flattens the spherical shape of the Earth. The Earth's bulge causes the planes of satellite orbits inclined to the equator (but not polar) to slowly rotate around the Earth's axis.

**Buoyancy**--The lifting force acting in a fluid on bodies and regions less dense than their surroundings. The buoyancy of hot air--the force that also lifts hot-air balloons--is the main cause of weather-related flows in the Earth's atmosphere. Also see [convection](#).

**Calendar** -- A system of marking days of the year, usually devised in a way to give each date a fixed place in the cycle of seasons.

**Calorie** -- Unit used in measuring the energy of heat or chemical energy. A "small" calorie is the heat needed to warm up one gram of water by 1 degree centigrade and equals about 4.18 **joule**. A "kilocalorie" or "big calorie" equals 1000 calories and is the unit usually used in describing the energy content of food.

**Cartesian coordinates** -- A system of uniquely marking the position of a point on a plane [or in 3-dimensional space] -- by 2 [3] numbers (its "cartesian coordinates") giving its distances from 2 [3] mutually perpendicular lines ("cartesian axes"). The distances and the axes to which they are parallel are usually marked (x,y) in a plane and (x,y,z) in space; the "origin" is the point at which the axes intersect.

**Celestial coordinat**es -- see "right ascension and declination."

**Celestial pole** -- One of the two points in the sky around which the celestial sphere seems to rotate.

**Celestial sphere** -- An immense sphere surrounding Earth, to which the fixed stars seen at night appear to be attached. Although strictly speaking such a sphere does not exist, it is often used as a convenient tool for mapping the position of stars and other heavenly bodies. In a similar way, although it is clear that the apparent rotation of the celestial sphere is really due to the Earth rotating around its axis, that rotation is often used for convenient description of apparent motions such as the rising and setting of stars.

**Center of gravity** -- (CG), also known (more precisely) as **center of mass**. In a distributed mass, an appropriately defined "average location" of its parts. If the mass is a rigid (=undeforming) body subject to the earth's gravity, then if it is supported at the CG, it will stay balanced and not tilt to any side.

In a system subject only to internal forces, the center of gravity always stays in the same spot; hence the Earth-Moon system rotates around its mutual center of gravity (**not** around the Earth's center), and a rocket flies forwards when it ejects a high-speed stream of gas backwards.

**Centrifugal force** -- A force which must be included in the calculation of **equilibria** between forces in a rotating frame of reference (e.g. rotating carrousel, rotating space station, rotating Earth). In the rotating frame, the forces on a body of mass  $m$  are in equilibrium (as evidenced by the body staying at the same place) only if all forces acting on it, **plus** a "centrifugal force"  $mv^2/R$  directed **away** from the center of rotation, add up to zero. See **Coriolis force**.

**Centripetal acceleration** -- The acceleration associated with motion around a circle, directed **to** the center of the circle.

**Centripetal force** -- The force making a motion in a circle possible, always directed to the center of the circle. To make a (small) object of mass  $m$  move with velocity  $v$  around a circle of radius  $R$ , a centripetal force of magnitude  $mv^2/R$  must be applied.

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

CME--see **coronal mass ejection**.

**Chronometer** An accurate clock used to derive the local longitude from the position of the Sun in the sky.

**Circulation** (atmospheric, also known as "global circulation"). Large scale flows of air in the atmosphere, distributing to higher latitudes (and ultimately returning it to space via radiation) the heat deposited by sunlight near the equator (ultimately returning it to space via radiation).

**Climate** The average pattern of weather variation at a certain location, throughout the year.

**Color**--a quality of light, depending on its wavelength. **Spectral color** of an emission of light is its place in the rainbow spectrum. **Perceived color** (or visual color) is the quality of light emission as conveyed by the human eye, combining the impressions of 3 types of light-sensitive cells which the eye contains. Perceived color can be the response to certain combinations of spectral colors, e.g. brown responds to green and red (or blue, yellow and red).

**Comet**--a body of dust, frozen water and gases falling sunward from the outer regions of the solar system. Comets become visible when they approach the Sun, as sunlight evaporates their upper layers and creates long tails of dust and ions. Comets are believed to be remnants of the formation of the solar system; some of them (like Halley's comet) are diverted by the attraction of planets into orbits of relatively short periods around the Sun.

**Component of vector**--When a vector is **resolved** into a sum of vectors in specified directions, each of those vector is the **component** of the given vector in the specified direction.

**Conic Sections** -- The family of curves generated by planes intersecting with a cone. Several cases are distinguished, depending on the angle between the plane and the axis of the cone. Precise definitions exist for each, but in general terms, when the plane is:

--Perpendicular to the axis, the curve is a **circle**.

--Moderately inclined to the axis, the curve is an **ellipse**.

--Parallel to one of the straight lines which generate the cone, the curve is a **parabola**.

--Even more steeply inclined, the curve is a **hyperbola**.

**Conservation of Energy** A fundamental law of physics (and chemistry): the total sum of energy in a "closed system"--one which does not interact with others around it--stays unchanged as time advances.

**Conservation of momentum**--A fundamental law of motion, equivalent to Newton's laws: in a system of bodies (=objects), the (vector) sum of all momenta cannot change due to any internal interactions.

**Constellation** -- A named grouping of fixed stars, e.g. Orion or the Big Dipper.

**Convection** A circulating flow in a fluid, carrying heat away from its source. Convection in the atmosphere carries heat from the sun-warmed ground to higher layers, where it is radiated away into space; the lower levels do not radiate efficiently because of the **greenhouse effect**. Atmospheric convection is the engine that drives the Earth's weather. Convection is also believed to occur in a certain depth range below the Sun's

surface, helping carry away heat from the Sun's core region.

**Coordinates** Numbers which define the position of a point on a surface (two numbers) or in space (three).

**Copernican System** -- A theory of planetary motions, proposed by Copernicus, according to which all planets move in circular orbits around the Sun, the ones closer to the Sun moving faster, with the Earth itself a planet orbiting between Venus and Mars.

**Coriolis force** -- A force which must be included in the calculation of **motion** in a rotating frame of reference, if the body moves in such a way that its rotation velocity changes. In general, it tends to preserve that part of its velocity. The Coriolis force is responsible for the swirling of hurricanes and large weather systems--for air flowing into a region of low pressure, counterclockwise north of the equator, clockwise south of the equator (reverse directions for air flowing **out** of a high pressure region). See **centrifugal force**.

**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](#)

**Coronal hole**--an area in the Sun's corona that appears dark when viewed in the far UV or in the long-wavelength end of the x-ray range. Coronal holes seem associated with sources of fast solar wind, probably because their field lines do not curve back to the Sun. Over most of the Sun their shapes are changeable and irregular, but the Sun's polar regions seem to contain "permanent" coronal holes.

**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.

**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.

**Crater** (impact crater). A generally round depression created by the impact of a large compact mass on a planet or moon. Impact craters mark the Moon, also Mercury and Mars, and many satellites in the solar system. Notable ones on Earth include Meteor Crater in Arizona and Manicougan lake in Canada.

**Cross staff** A cross-shaped device to measure the elevation of the Sun or a star above the horizon, or the angle between the directions of two heavenly objects. The staff is aimed halfway between the objects, then the cross-piece is slid until aiming points at its end cover the two objects. Widely used for navigation at sea in the 15-17th century, later displaced by the more convenient sextant.

**Date line (international)** An imaginary line across the Pacific Ocean, with dates on its west side one day ahead of those to its east. To simplify time

keeping, the globe is divided into **time zones** at whose boundaries local time (usually) jumps by one hour. A date line had to be instituted to limit time gain or loss from crossing such boundaries to less than 24 hours. Much of it follows longitude 180° across empty ocean, deviating to make the date in the Aleutian islands the same as in Alaska, and that in Fiji, Tonga and some smaller islands the same as in New Zealand.

**Deceleration** (spell with one "c"!) Negative acceleration, slowing down of motion.

**Declination** -- One of the two angles uses to specify location on the celestial sphere. Declination is like latitude, but unlike latitude, it is measured from the north pole. The pole has declination 0, the equator 90 degrees, the southern celestial pole 180 degrees. See **right ascension and declination**

**De Laval nozzle** -- A device for efficiently converting the energy of a hot gas to kinetic energy of motion, originally used in some steam turbines and now used in practically all rockets. By constricting the outflow of the gas until it reaches the velocity of sound and then letting it expand again, an extremely fast jet is produced.

**Diffraction grating** A flat optical surface, transparent or reflecting, ruled with many parallel grooves at precisely spaced distances. The active parts are not the grooves but the flat sections left between them, which act like a large number of precisely spaced slits. The light waves passing those slits resonate with each other in a way which depends on wavelength, causing different wavelengths to be steered in different directions. The overall effect on light containing different wavelengths is like that of a glass prism: the intensity of the light deflected is much smaller than with a prism, but the ability to separate close colors is much better.

**"Dirty bomb"**. Name given by the press to a possible terrorist weapon, a load of nuclear waste from a nuclear power station, combined with an ordinary explosive charge. Set off in some public site, such a bomb would cause few or no casualties, but considerable disruption, by contaminating the area in which it is set off. That area would have to be sealed off and would need an expensive clean-up effort, giving the terrorists the publicity and exposure which they seek.

**Drag**--the air resistance encountered by a moving object. Drag is one of the four forces sensed by an airplane, the others being **lift**, **thrust** and **weight**.

**Duality**. The property of light (and other electromagnetic radiation), also of atoms, to behave as waves in some situations and as particles in others.

**Earthshine** The faint glow which dimly illuminates the dark part of the new moon (seen as a narrow crescent). The Moon at that time observes a "full Earth," completely illuminated by the Sun, and that is the source of earthshine light. Earthshine has been used to monitor the amount of sunlight reflected by the Earth.

**Eccentricity** -- Number between 0 and 1, gauging the elongation of elliptic orbit. The eccentricity  $e$  of the orbital ellipse is one of the "orbital elements" characterizing it.

**Eccentric anomaly** See **anomaly**.

**Ecliptic** -- A line around the middle of the celestial sphere, connecting the

points occupied by the Sun over the year. The moon and the visible planets also appear to move very close to that line, which cuts the celestial equator at an angle of about  $23.5^\circ$ . See **plane of the ecliptic**.

**Einstein's law**. A fundamental relation proposed by Einstein in 1905, according to which light of frequency  $\nu$  cycles/second transmits its energy only in chunks of energy ("photons") equal to  $h\nu$ , where  $h$  is **Planck's constant**

**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. See also (below) "electromagnetic wave" and **magnetic field**.

**Electromagnetic wave** or "electromagnetic radiation"--a combination of oscillating magnetic and electric fields, 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](#).)

**Elevation of Sun**. The angle between the position of the Sun's center in the sky and the point nearest to it on the horizon.

**Ellipse** -- A closed curve resembling a flattened circle (the shadow of a circle tilted towards the light is an ellipse). May be defined:

1. As the collection of points whose distances ( $R_1, R_2$ ) from two given points (the foci of the ellipse--in singular, focus) add up to the same sum.
2. Or else, in **polar coordinates** ( $r, \phi$ ), as the curve whose points satisfy a relation  $r = a(1 - e)/(1 + e \cos\phi)$  where  $a$  is the semi-major axis, half the width in the direction through the two foci. One of the foci is then at the origin and  $e$  is the eccentricity, a number ranging from 0 (circle) to 1 (parabola).
3. Or else, in cartesian coordinates with the origin halfway between the foci, as the curve of all points ( $x, y$ ) whose coordinates satisfy  $(x/a)^2 + (y/b)^2 = 1$

**El Niño**. A disruption of usual global wind flows, caused by unusually warm sea temperature in the western Pacific Ocean. Occurs irregularly at intervals of several years.

**Energy** -- Ability to perform work, i.e. to advance against resistance, for instance lift a body against gravity, or drag it against friction. See also **Work**.

**Epicycle** -- A circle around a point which (in the simplest form of **Ptolemy's system**) moved steadily around the celestial sphere. Greek astronomers proposed that planets moved along epicycles around the Sun or around other points which circled around the sky; later additional corrections were added.

The theory of epicycles was the earliest explanation for the irregular apparent motion of the planets--prograde (forward), then **retrograde**

**Equatorial axis** -- Among the two mutually perpendicular axes of a telescope, the one that points at the celestial pole. To keep a star in view, the telescope must be rotated around this axis at the same rate as the Earth turns.

**Equilibrium (of forces)** -- A situation when more than one force acts on a body, but because the sum of forces is zero, no motion results.

**Equinox** -- the time of the year (around March 21 and September 23) when the position of the Sun in the sky (following the ecliptic) crosses the celestial equator. To a good approximation, the length of the day and night are then equal, and the Sun rises exactly in the east and sets exactly in the west. . Equinox is viewed as the beginning of spring and fall.

The term is also used for each of the two points on the celestial sphere at which the ecliptic and the celestial equator intersect, i.e. the points occupied by the Sun at equinox.

**Ethiopian calendar** The calendar of Ethiopia, containing 12 months of 30 days plus a short month of (usually) 5 days.

**Explorer 1** -- The first US artificial satellite, launched 31 January 1958 by a 4-stage modified military rocket. Provided the earliest observations of the Earth's radiation belt.

**(Nuclear) Fallout.** Debris containing fission fragments from a nuclear explosion, lifted high in the atmosphere by the rising heat of the explosion. It may later come down hundreds of kilometers from the site of the explosion. With a large nuclear bomb, the nuclear radiation dose from fallout may stay at lethal levels for a week or more, requiring those in its path to seek shelter under thick barriers. Even after that, danger still remains from ingesting radioactive materials of the fallout.

**Fast (nuclear) fission** Nuclear fission caused by fast neutrons, directly after they are released by the fission of a heavy nucleus. Unlike "thermal fission" used in most nuclear reactors, where neutrons are first slowed down by multiple collisions, this process will produce a chain reaction only in relatively pure uranium-235 or plutonium. Fast fission makes atomic bombs possible; their fuel must be assembled very rapidly, to let the chain reaction produce many fission events before the explosive release of energy blows everything apart. "Fast" nuclear reactors using fast fission have also been built; they have some important advantages, but pose a technical challenge of rapid removal of great amounts of heat from a small volume.

**Field** The region in which a particular type of force can be observed; depending on the force, one can thus speak of a gravity field, magnetic field, electric field (or when the two are linked by fast oscillations, electromagnetic field) and nuclear field. The laws of physics suggest that fields represent more than a **possibility** of force being observed, but that they can also transmit energy and momentum, e.g. a light wave is a phenomenon completely defined by fields. For that reason a field is often viewed as a space which was modified by the sources of the force which the field represents.

**Field line preservation** A property of an ideal **plasma**, well approximated in real plasmas, characterizing the way the flow of plasma may deform the magnetic field in which it is embedded. The law of preservation states, "If

two particles in a flowing plasma are initially on the same magnetic field line, they continue doing so in the future."

**Firmament** -- The celestial sphere and the collection of stars whose position is fixed on it.

**First point in Aries** -- Another name for the position on the celestial sphere of the **vernal equinox**. It is called so because in ancient time that point was in Aries, a constellation of the **zodiac**. It is currently moving from Pisces to Aquarius.

**Flare** (Solar flare)--a rapid outburst on the Sun, usually in the vicinity of active sunspots. A sudden brightening (only rarely seen without special filters, isolating the red light of hydrogen) 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. Flares appear to be associated with rapid energy releases high above the photosphere, apparently from the magnetic fields of sunspots. Their link to coronal mass ejections, which may also be powered by magnetic energy, is still unclear.

**Fly-by maneuver** another name for (planetary or lunar) "gravity assist" or "**swing-by**" maneuver.

**Force** -- In mechanics, the cause of motion. It is a vector quantity, in the direction of the acceleration it causes.

**Frame of Reference** The system of coordinates (and the objects that determine it) in which motion or any physical effects are calculated or measured. Einstein's principle of relativity states that the laws of physics are exactly the same in two frames of reference moving with constant velocity along a straight line relative to each other. When one of the frames is accelerated, however, the two are not equivalent: Earth rotating around its axis fits Newtonian mechanics, the Sun going around a fixed Earth does not.

**Frequency** (Often denoted by  $\nu$  the Greek letter letter nu.) --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.

**g** -- The symbol used for the acceleration due to gravity. At the Earth's surface it averages 9.81 meters/second<sup>2</sup>, directed towards the Earth's center. In common talk, "g forces" are stresses due to acceleration, e.g. on astronauts or payloads. In the same vein, "zero g" is the condition when no acceleration is sensed, because gravity is already fully employed supplying the centripetal force which holds the object in its orbit (or alternatively from the rotating frame of reference, because gravity is fully balanced by the centrifugal force).

**Galaxy**. Originally, the large wheel-shaped collection of stars to which our sun and other stars visible to the eye belong. We view this wheel edge-on, stretching around the sky as the "Milky Way," formed by the glow of many distant stars. Later it was found that the universe contains a **huge** number of somewhat similar objects, much more distant. They are now called "galaxies" too, whereas the Milky Way is "**our** galaxy."

**Gamma rays**--electromagnetic waves of the highest frequencies known,

originally discovered as an emission of radioactive substances. See also [radioactivity](#).

**Geodesy** -- The study of the shape of the Earth, e.g. its deviations from an exact sphere.

**Global Positioning System** (GPS), a navigation system using about 20 satellites in 12-hour orbits, distributed evenly around Earth. These satellites continually broadcast their positions. and a small instrument, receiving signals of 3 or more such satellites, can calculate its position within about 10 meters. The system was created by the US military, which can get from it even more accurate positions. The Russian GLONASS system is similar.

**Gnomon** -- The part of a **sundial** which casts the shadow, usually a rod or fin pointed at the **celestial pole**.

**Gravity** (or "gravitation"), one of 4 main forces in the universe (others: electro-magnetic, and 2 types of nuclear force). Every mass exerts a gravitational pull on any other mass, inversely proportional to the square of the distance between them. This was first proposed by Newton, based on his calculation of orbits of planets and of the Moon.

**Gravity-assist maneuver** Another name for the [planetary swing-by maneuver](#).

**Gravity gradient.** The variation of gravity with location--e.g. when approaching a planet. The gravity gradient of Earth tries to make elongated objects in orbit around it make their long axis point to the Earth's center. This effect has apparently caused the Moon's rotation period to equal the Moon's orbital period, causing the Moon to present Earth with the same side. Near a black hole the gravity gradient is close enough to tear apart stars and other objects.

**Greenhouse effect** The surface of the Earth is, on the average, in a state of equilibrium between heating and cooling: that is, on the average, the rate at which sunlight heats it equals the rate at which it loses heat.

If no atmosphere existed, all that loss would take place by infra-red radiation from the surface. The Earth's atmosphere, however, absorbs infra-red, which heats it up and slows down the escape of heat. The same process occurs in glass-covered greenhouses, whose panes let sunlight in but absorb the infra-red emitted back, keeping their interior warm even in winter. For that reason, the process is known as the "greenhouse effect."

Some gases which constitute only a small portion of the atmosphere--water vapor, CO<sub>2</sub> (carbon dioxide) and CH<sub>4</sub> (methane)--are major contributors to the greenhouse effect. Burning coal and oil in the last century has markedly increased the CO<sub>2</sub> content of the atmosphere, which is why some scientists credit the warming trend experienced in the last decades of the 20th century to an increased "greenhouse effect."

**Gregorian calendar** -- Introduced in 1582 by Pope Gregory the 13th, this calendar modifies the Julian calendar for greater precision, decreeing that century years such as 1900 are not leap years, except if the number of centuries is divisible by 4 (e.g. 2000).

**H-bomb** See [Hydrogen bomb](#).

**Hadley Cell.** A scheme of global wind flow proposed by Hadley in 1735, by which warm air rises around the equator, flows poleward at higher altitude while cooling, then returns equatorward closer to the surface. It exists, but only near the equator.

**High Energy 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 [solar energetic particles](#).

**Hohmann orbit.** Also known as the "Hohmann transfer orbit," it represents the most energy-efficient orbit for transferring a spacecraft from one circular orbit to another in the same plane. This orbit is a Keplerian ellipse touching the larger orbit at its greatest distance and the smaller orbit at its smallest distance.

**Hydrogen bomb** A type of extremely large nuclear bomb, releasing fusion energy of heavy hydrogen (or in later versions, lithium) as well as fission energy of plutonium and uranium. Tests of such bombs have released 100-1000 times more energy than the nuclear bomb dropped in 1945 on Hiroshima.

**Hydrogen spectrum** The simplest [line spectrum](#) of any element, consisting of a number of separate sequences of lines, the lines of each getting closer and closer together as they approach a limit. Four lines are in the visible spectrum and belong to the [Balmer sequence](#), but other sequences also satisfy formulas like Balmer's

**Ice ages** -- Times in the geological past when great glaciers extended far into Europe, Asia and America.

**Inclination**, orbital--the angle between the orbital plane of a satellite or planet and some reference plane, usually linked to the center of attraction (e.g. Earth equatorial plane, or plane of the ecliptic). The angle between two planes is defined as the angle between their perpendiculars, at any point of their intersection. Orbital inclination is one of 6 [orbital elements](#).

**Inertia** -- The property of matter to resist acceleration or deceleration, i.e. any motion which is not in a straight line and with constant velocity

**Inertial balance** an instrument for comparing masses using only their inertia, and not relying on gravity. Examples are the [instrument](#) used for monitoring astronaut mass aboard space station "Skylab" and the [sawblade device](#) described in "Stargazers."

**Inertial force** A force which must be added to the equations of motion when Newton's laws are used in a rotating or otherwise accelerating frame of reference. Some call it a "fictional force" because when the same motion is solved in the frame of the "outside world," these forces do not appear.

**Infra-red radiation** (or infra-red light). The region of the electromagnetic spectrum adjacent to that of visible light, but with longer wavelengths (0.65-10 micrometers, typical). Infra-red radiation is emitted by hot objects and by excited molecules. See also [greenhouse effect](#).

**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.

**Ionization**--the process by which a neutral atom, or a cluster of such atoms, becomes an [ion](#). This may occur, for instance, by absorption 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<sup>+</sup> and Cl<sup>-</sup>) 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.

**Ion rocket.** A propulsion device used in long-range space missions, generating its thrust by a beam of positive ions accelerated electrically. That thrust is small (making such rocket unsuitable for launch from the ground), but the propulsion is very efficient, since the energy given to the ions comes from solar cells or a nuclear power source, and the acceleration can be maintained for a long time. Because of the separate power source, the energy each ion gets is much larger than the energy given to molecules in the jet of ordinary chemical rockets, which is limited by what the chemistry of the rocket fuel provides.

**Isotopes**--Variants found in many chemical elements, differing slightly in weight because the number of neutrons in their nuclei differ. Chemically they all behave alike, but some may be unstable and [radioactive](#)

**Iteration**--The repetition of a process of calculation again and again, each time improving the accuracy of the result. For an example of iteration (with "Kepler's Equation") [see here](#)

**Jet Propulsion Lab** -- An outgrowth of the Guggenheim Aeronautical Laboratory of Caltech, in Pasadena (near Los Angeles, California). JPL was the center of US rocket development in World War II and was founded by Theodore Von Karman and Frank Malina. Today it is the focus of NASA's exploration of the planets and of distant space.

**Jet Stream.** The core of fast air flow associated with the [westerlies](#), occurring close to the top of the [troposphere](#). Because of its high speed, it may also affect airliner schedules.

**Jewish Calendar** The calendar traditionally used to determine Jewish holidays. It is a [Metonic calendar](#) based on the motions of both Sun and Moon.

**Joule** -- (pronounced like "jewel" or "jool"). Unit of energy: the ability to overcome one Newton along 1 meter (assuming  $g = 10 \text{ meter/sec}^2$ , it is also the energy required to lift 1 kg by 0.1 meters). Named for James Prescott Joule, one of the first to measure the "rate of exchange" between mechanical energy and heat.

**Julian Calendar** -- Introduced in 46 BC by the Roman ruler Julius Caesar, this calendar assumes a year of 365.25 days, and uses a cycle in which 3 "ordinary" years of 365 days are followed by a "leap year" with 366 days. Leap years are the years whose number is divisible by 4.

**Kepler's laws** --

Three laws of planetary motion, published by Johannes Kepler using accurate observations by Tycho Brahe and shown by Isaac Newton to be a direct result of his theory of gravitation and his laws of motion:

1. Planets move in ellipses, with the Sun at one focus.
2. The line connecting the planets to the Sun sweeps equal areas in equal times.
3. The square of a planet's orbital period is proportional to the cube of its mean distance from the Sun.

**Comments:**

**1st law:** This corrected the simpler model of Copernicus, which assumed circles. More accurately, the focus is at the center of gravity of the Sun and orbiting body (discounting other planets) and non-periodic motions along parabolas or hyperbolas are also possible.

**2nd law:** The second law expresses the way a planet speeds up when approaching the Sun and the way it slows down when drawing away.

**3rd law:** The third law gives the exact relation by which planets move faster on orbits which are closer to the Sun, e.g. Venus moves faster than Earth (see **retrograde** motion). For a more precise formulation, "mean distance" should be replaced by **semimajor axis**.

**Kilowatt-hour** -- (KWH). The amount of energy supplied by one kilowatt (1000 **watt**) for 1 hour (3600 seconds), equal to 3 600 000 joule. Electric bills are usually figured by the number of KWHs consumed.

**Kinetic energy** -- Energy stored in the motion of a mechanical system--e.g. by a rolling car, or a turning flywheel.

**Kuiper objects.** A large collection of icy asteroids outside the orbit of Neptune, many with orbital periods determined by Neptune (e.g. 1.5 times longer). Some are quite large, and Pluto may properly belong to this class.

**Lagrangian points** -- In a system of two large bodies (Sun-Earth or Earth-Moon), these are the points where a small third body will keep a fixed position relative to the other two. Named for French astronomer Louis Lagrange (1736-1813) who first studied them and who showed there existed 5 such points. In the Sun-Earth system only two are important, both on the Earth-Sun line--the L1 point 236 Earth radii sunward of Earth, and the L2 point at a similar distance on the night side. The L1 point is a good "early warning" outpost intercepting shocks and particles emitted by the Sun and its vicinity has been occupied by several spacecraft. Altogether **five Lagrangian points** exist in the Earth-Sun or Earth-Moon system.

**Lapse Rate.** The rate at which temperature decreases with increasing altitude. Depends on humidity.

**Latitude and longitude** -- Two angles which specify a location on Earth. If a line is drawn from the Earth's center to the given location, then **latitude** is the angle between that line and its projection on the plane of the Earth's equator (latitude also equals  $90^\circ - \theta$ , where the "co-latitude"  $\theta$  is the angle between the line and the axis of the Earth).

To define longitude, imagine a large number of planes ("meridional planes") all of which contain the axis of the Earth. Assuming the equator is a circle, divide it into 360 degrees and fractions of degrees: then each meridional plane can be labeled by the angle at its intersection of the equator, and the **longitude** of a point is the angle  $\phi$  marking the meridional plane on which it sits. Longitude is similar to the angle  $\phi$  of 3-dimensional **polar coordinates** or to **right ascension**, but is measured from a zero longitude chosen as the longitude of the Greenwich observatory near London, Great Britain.

**Law of areas** -- Another name for Kepler's 2nd law.

**Libration** A periodic back-and-forth swing of the elongated axis of the Moon across the Moon-Earth line, apparent to a viewer on Earth. So named because it resembles the swings of two-pan scales (in Latin, "Libra") around their points of equilibrium.

This is almost entirely an *apparent* motion: actually, the Moon rotates at an almost constant rate, but by Kepler's laws, its orbital motion around the Earth is not constant. If it were, we would always see the same face of the Moon, but actually the Moon sometimes falls behind or advances ahead, allowing more to be viewed.

Because of its libration, the Moon shows Earth (now and then) areas beyond the 50% of the surface facing Earth. Other (small) effects which also expand the viewable area are included under "libration" as well.

**Lift**--the lifting force on a flying object (in particular, a wing or an aircraft), due to its motion relative to the surrounding air. Lift is one of the four forces sensed by an airplane, the others being drag, thrust and weight.

**Lightning** A sudden electric flow between a thunderstorm cloud and the ground (or another cloud), for a brief instant producing heat and light along its path (and the heat, in turn, producing a sudden expansion of air, which initiates the thunder). Lightning removes electric charge, created in collisions of freezing raindrops. Large drops fall down, while small ones, carrying charges of the opposite sign, rise up because the force of gravity pulling them down is overcome by upward-blowing winds. The work performed by separating opposite charge ends up as electric energy, at high voltages.

**Liquid fueled rockets** -- Rockets in which a liquid fuel (kerosene, liquid hydrogen) is combined in a combustion chamber with a liquid oxidizer (usually liquid oxygen, also fuming nitric acid or hydrogen peroxide). Very efficient and controllable, such rockets are generally used in spaceflight. Unlike solid fueled rockets, they can be shut off by remote command, simply by closing off their fuel line.

**"Lunar Prospector"** Small polar satellite of the Moon launched 6 January 1998, whose observations seemed to suggest possible existence of water-ice in deeply shaded lunar craters near the poles of the Moon.

**MKS system**. A consistent system of units in physics, based on distances measured in meters, mass in kilograms, time in seconds. Formulas using MKS units can be used together with no errors due to mismatch.

**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 poles** (1)Magnetic poles **of a magnet** are points near its ends, at which the magnetic force seems concentrated.

(2) The magnetic poles **of the Earth** are the point towards which a horizontal compass needle tends to point. Several alternative definitions exist, giving slightly different locations, e.g. the "dip pole" is where the

magnetic force is purely vertical.

**Magnetic polarity** Electric charges come in two varieties, denoted (+) and (-). Similarly, the poles of a magnet have different magnetic polarities, "north-seeking" (N) and "south-seeking" (S). If the magnet is freely suspended (e.g. a compass needle), the (N) end turns to face north, the (S) turns to face south. Like electric charges, poles of the same kind repel, of opposite kinds attract.

The names are usually abbreviated to "north" and "south" poles, which occasionally causes confusion. If the magnetic properties of the Earth came from it being a giant magnet (rather than from electric currents in its interior) then the magnetic pole close to its northern geographic pole would in fact be an "S" pole or "south seeking" pole--since it **attracts** the north-seeking pole of the compass needle!

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

A magnetic storm is marked by the injection of an appreciable number of **ions** from the tail regions of the magnetosphere into the near-Earth magnetosphere, a process accompanied by increased auroral displays. The injected particles cause a world-wide drop in the equatorial magnetic field, taking perhaps 12 hours to reach its greatest intensity, followed by a more gradual recovery.

**Magnetosphere** -- The outermost environment of Earth, dominated by the Earth's magnetic field. The magnetosphere is the site of the radiation belt and many intricate phenomena. See **solar wind**.

**Mass** -- The mass of a body can be loosely defined as the amount of matter it contains. That is expressed in two ways:

1. **inertial mass**, the resistance of the matter to acceleration or deceleration, as given by the factor  $m$  in Newton's 2nd law  $F = ma$
2. **gravitational mass**, the force exerted on the matter by gravity ("weight"), given near the surface of Earth by  $F = mg$ .

According to all experiments, the two are equal, causing all bodies subject to gravity only (near the surface of the Earth) to have the same acceleration  $a = g$ .

**Maxwellian distribution** The distribution of molecular energies (or velocities) in a hot gas, derived by James Clerk Maxwell. At any temperature, a mean energy exists, but collisions between molecules spread out the distribution and a few molecules are always much faster than the average.

**Mean anomaly** An angle used in calculating orbital motion obeying Kepler's laws, increasing by 360 degrees each orbit. The polar angle of an orbiting object around the center of attraction--the "**true anomaly**"--also increases by 360 degrees each orbit. However, while the true anomaly changes unevenly--faster during closest approach--the mean anomaly increases steadily, in proportion to time. The mean anomaly is one of 6 **orbital elements** defining Keplerian motion.

**Metonic Calendar** -- Named for the Athenian astronomer Meton, it is based on the moon, counting each cycle of the phases of the Moon as one month. Days are kept approximately in step with the seasons by including 7 leap years of 13 months in each cycle of 19 years. Used by the Chinese and the

Jews.

**Microwaves** Electromagnetic waves longer than infra-red but shorter than radio, with typical wavelength 0.1-10 centimeters.

**Milankovich theory** -- Theory by which ice ages were caused by slow changes of the motion of the Earth in space, including the coupling between the 26 000 year cycle of the **precession of the equinoxes** and the annual variation of the Earth-Sun distance.

**Momentum** (plural: momenta). The momentum of a moving object is the product (result of multiplication) of its mass and velocity; like velocity, momentum is a vector. The law of conservation of momentum states that when two or more objects interact--a cannon fires a shell, a rocket shoots out a fast jet of hot gas, a bowling ball scatters a group of pins--the total vector sum of their momenta is unchanged. That, too, is an equivalent formulation of Newton's laws.

**Month** A division of the year, corresponding roughly to a period of the Moon. Some calendars start all month at the start of the Moon's period, or close to it.

**Moon** The natural satellite of the Earth; satellites of other planets are also often called "moons" (uncapitalized)

**Multiplet** A closely spaced group of spectral "lines" (wavelengths), suggesting that a single energy level was split into several closely-lying ones, by some additional factor such as electron spin.

**Muslim Calendar** -- Based on a year of 12 months, each corresponding to one cycle of the Moon, but without the **Metonic** correction. Its months migrate through the seasons.

**Naw Ruz** The Iranian name for the new year holiday on the Persian calendar, occurring on the spring equinox.

**Neutron** A particle found in the nuclei of atoms, similar to a **proton** but with no electric charge. Among light nuclei (helium, carbon, nitrogen), the ones that are most stable contain equal numbers of protons and neutrons. In heavier elements, the most stable ones have majority of neutrons, growing with mass. Varieties of nuclei also exist ("isotopes") which have other ratios between their numbers of protons and neutrons, but when the departure from the "most stable ratio" becomes large, neutrons can convert to protons + electrons (or vice versa), producing one form of radioactivity.

**Neutron star** A star (approximately sun-sized or larger), a remnant of a **supernova** explosion, in which gravity has caused all matter to collapse to a giant nucleus, composed only of neutrons. The collapse is also expected to greatly amplify any magnetic field present in the pre-collapse star, as well as speed up enormously any rate of rotation. It is believed that **pulsars**, pulsating radio sources with very precise pulsation periods, are neutron stars of radius about 10 km and rotation period about 1 second. Their magnetic axis spins and beams radio waves, in a way similar to the way a lighthouse beams its light. We detect pulsars when the Earth is in one of the directions swept by the beams.

**Newton** -- Unit of force, the force which, when applied to one kilogram mass, causes an acceleration of 1 meter/sec<sup>2</sup>.

**Newton's laws of motion** -- Three laws which form the foundation of classical mechanics, i.e. of the theory of ordinary motions (not motions on an atomic scale, covered by quantum mechanics, and not at velocities close to that of light, covered by relativity). The laws introduce the concepts of **force** and **mass** and state (in modern terms)

1. In the absence of forces, an object ("body") at rest stays at rest, and an object moving in a straight line with constant velocity persists in doing so.
2. A (small) body subject to a force accelerates; the acceleration is in the direction of the force and proportional to its magnitude, and inversely proportional to the mass of the body:  $F = ma$ .
3. Forces are produced in pairs, in opposite directions and equal magnitudes.

Newton's laws (2) and (3) in **Mach's formulation** reduce to: "When two small bodies act on each other, they accelerate in opposite directions and the ratio of their accelerations is always the same."

**North**. The direction opposite to **south**. At middle latitudes **south** of the equator, the direction to the noontime sun is northwards.

**Nuclear bomb** A device for explosive release of nuclear energy, following fission by fast neutrons.

**Nuclear fireball** A sphere of extremely hot gas (or part of a sphere, for explosions near the ground) formed around the explosion of a nuclear bomb. The heat radiated by the fireball is probably the most damaging effect of the explosion, starting widespread fires and burning anyone caught in the open.

**Nuclear fission** The breaking up of a heavy nucleus in two parts of comparable masses, typically, 1/3 and 2/3 of the original mass, associated with a great release of energy. Since both fragments have a positive electric charge, they repel each other vigorously, causing them to be ejected with great speed in opposite directions. The kinetic energy of that motion, ultimately converted to heat, is the source of the "nuclear energy" of fission.

**Nuclear forces** The short-range forces acting on protons and neutrons in atomic nuclei. Two types actually exist, the "strong force" which holds nuclei together, and the "weak force" which determines the ratio between the numbers of protons and neutrons.

**Nuclear fusion** The process of releasing energy by combining hydrogen atoms to form helium, or more generally, to combine light nuclei into heavier ones. Nuclear fusion appears to be the source of the energy of the Sun and of stars.

**Nuclear power** Power obtained from nuclear fission in nuclear reactors, ultimately converted to electric power.

**Nucleus** (atomic; plural: nuclei). The small concentration of protons and neutrons, positively charged, at the center of atoms. The nuclei of atoms are positively charged and contain by far most of their mass (all but about 0.05% or less).

The existence of the nucleus was **deduced in 1911** by Ernest Rutherford, from experiments on the scattering of **alpha particles** by nuclei.

**Orbit** -- The path of a body in space, generally under the influence of gravity.

**Orbital elements** -- Variables which characterize the motion of an orbiting body. For a planet or satellite in an elliptic orbit, 6 orbital elements exist: the **semi-major axis** gives its size, **eccentricity** its shape and **mean anomaly** its position along the orbit, at the given time. The three other elements are three angles which give the orientation in space of its orbital plane, e.g. that plane's inclination (to the plane of the Earth's equator or the ecliptic, depending on choice of coordinates).

**Orbital period** -- The length of time required for a body to complete one full (closed) orbit.

**Orbital (noun)**. One of the basic modes of electron wave functions in an atom, defining energy levels etc. Earlier, before such electrons were treated as wave phenomena, an older theory viewed them as tiny orbiting spheres and tried to classify atomic energy levels by assuming they represented different classes of orbits of such spheres. Such classes were later replaced by wave modes, but the name "orbitals" stuck to them.

**Ozone** A gas, an alternative form of oxygen in which 3 atoms of oxygen rather than 2 join to form a molecule. Even though ozone forms in the atmosphere only in very small quantities, it has an important impact. **Ozone near the ground** is produced as part of industrial air pollution, and since it is chemically very reactive, it is undesirable--it corrodes masonry, it causes paint to darken and is unhealthy to breathe. **Ozone in the high atmosphere**, around 25-30 km., is formed by solar ultra-violet light. It absorbs such light and prevents it from penetrating to the ground, where it could be harmful to the eyes and to skin.

**Parallax** The angle between the directions in which an object is seen from two different positions. The parallax of an object seen with the left and right eye helps create depth perception. The **stellar parallax** (stellar=of a star) is the angle between the directions a star appears to us, when viewed from opposite sides of the Earth's orbit, half a year apart. Even though that distance is 300 million kilometers, the stars are so much more distant that even for the closest star the parallax is only 3/4 of a second of arc. See **parsec**.

**Parsec** (From PARallax + SECond). A unit of distance between stars. A star would be one parsec from Earth if its (stellar) parallax (see above) were 1 second of arc. One parsec is about 3 1/4 light years.

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

**Pelton turbine** A water turbine invented by Lester Pelton in the 1870s, converting the kinetic energy of a fast jet of water into the rotation of a turbine wheel. The collision between the water jet and cups attached to the moving wheel has some similarities to the encounter between a spacecraft and a moving planet in a "**gravity assist**" or "**planetary swing-by**" maneuver.

**Perigee** -- the point of a satellite's orbit closest to Earth (see **perihelion**, **apogee**).

**Perihelion** -- The point in a planet's orbit when it is closest to the Sun

(Helios is Greek for Sun). See **aphelion**, **perigee**

**Periodic table.** When listing chemical elements in order of the weight of their atoms, it was observed (by Mendeleev ["Mendeleyev"]) that certain sequences of chemical behavior tended to repeat. The reason, we now know, is that chemical properties of an atom depend largely on the number and arrangement of "outermost" (weakest bound) electrons. As atoms get heavier, their number of electrons increases: the ones more tightly bound tend to arrange themselves in closed "shells" dictated by rules of quantum physics, and as each shell is filled, the arrangement of outermost electrons may repeat itself.

**Persian Calendar** A calendar used in Iran and some of its neighbors. It is a solar calendar, counting its years from the same beginning as the Moslem calendar. See **Naw Ruz**.

**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**, increasingly larger for microwaves, infra-red radiation, visible light and ultra-violet light. It is 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 5500 degrees centigrade.

**Planck's constant.** A fundamental constant of nature, denoted by the letter **h** and equal to  $6.626068 \times 10^{-34}$  joule-sec. Introduced by Max Planck in 1900, the constant **h** plays a central role in all quantum phenomena, which dominate physics at the atomic scale.

**Plane of the ecliptic** -- (also called "the ecliptic" for short) The orbital plane of the Earth around the Sun. The line of the **ecliptic** on the celestial sphere is formed by the intersection of the plane of the ecliptic with that sphere. The reason the major planets and Moon appear in the sky close to the ecliptic is that the solar system is flat, and its orbital planes are very close to each other. We observe their motion (very nearly) edge-on.

**Planets** -- Celestial bodies such as the Earth which orbit the Sun (and by extension, similar orbiters around distant stars). Counting from the Sun outwards, planets visible to the eye are Mercury, Venus, (Earth), Mars, Jupiter and Saturn. The telescope also sees the more distant Uranus, Neptune and Pluto, as well as smaller asteroids (most of them inside the Jupiter orbit) and **Kuiper objects** (in the outer solar system). See also **retrograde motion**

**Planets of distant stars** Many distant stars have orbiting planets, most commonly revealed by a subtle oscillation of the position of the main star, as it and the planet revolve around a common center of gravity.

**Planetary swing-by maneuver** -- The encounter between a moving spacecraft and a moving planet or moon, affecting the spacecraft's motion like an elastic collision (in which no energy is lost to heat). Depending on the details of the encounter, the spacecraft can gain or lose appreciable amounts of **energy**, and appreciable changes in the direction of its motion can result.

Swing-by maneuvers with the Moon have been used to reach the L1 **Lagrangian point**; fly-by maneuvers with the planets have played an

essential role in space missions exploring the solar system. Lunar fly-by is similar and is also used.

**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.

**Polar Coordinates** -- An alternative system of marking a point on a plane by its radial distance ( $r$ ) from an "origin" and a polar angle ( $\phi$ ). Polar coordinates in 3-dimensional space use ( $r$ ) and two polar angles ( $\theta, \phi$ ) giving the direction from the origin to the point.

When 3-dimensional polar coordinates overlap a cartesian ( $x, y, z$ ) system,  $\theta$  is the angle between the line to the origin and the  $z$ -axis, while  $\phi$  is the angle (counter-clockwise when viewed from  $+z$ ) between the projection of that line onto the ( $x, y$ ) plane and the  $x$ -axis. Concerning ( $\theta, \phi$ ), see also **latitude and longitude, declination and right ascension, azimuth and elevation**.

**Polaris (Pole Star, North Star)** -- A fairly bright star, the last star in the tail (or handle) of the constellation of the Little Dipper (Ursa Minor). Currently located within a fraction of a degree from the celestial north pole, the point around which the celestial sphere appears to rotate. In the northern hemisphere, the direction towards Polaris is very nearly due north.

**Potential energy** -- Energy stored in the set-up of a mechanical system--e.g. by a weight able to descend (in the presence of gravity), or by a compressed spring.

**Power** -- The rate at which energy is supplied. See **watt**.

**Precession** -- A modern term, derived from the **precession of the equinoxes** and meaning a motion around a cone of the rotation axis of a spinning body.

**Precession of the Equinoxes** -- A slow motion of the axis of the Earth around a cone, one cycle in about 26000 years. As a result, the celestial pole moves around a circle in the sky, and in ancient times, for instance, was quite far from **Polaris**. Discovered by Hipparchus around 130 BC as a slow shift of the **vernal equinox** around the **ecliptic** (i.e. around the **zodiac**).

**Primordial microwaves** A diffuse microwave radiation apparently filling the entire universe, a remnant of gamma rays emitted by the "**primordial fireball**" in the early universe, following the "Big Bang." As the universe expanded, the frequency dropped and is now in the microwave range, but it still follows a black-body spectrum.

**Prominence** A cloud of cooler plasma extending high above the Sun's visible surface, rising above the photosphere into the corona.

**Propeller pitch**--the angle at which the propeller blade (or part of it) "bites" into the air, its [angle of attack](#).

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

**Ptolemy's System** -- The explanation given by ancient Greek astronomers to the motion of planets around the sky, described in a book by the Greek Ptolemy, around 150 AD. It regarded Earth as the center of the universe and assumed the motion of planets was a superposition of circular motions (see **epicycles**).

**Pulsar.** See [neutron star](#)

**[Pythagoras, theorem of](#)** -- A proved assertion in geometry, that in a right-angled triangle which has sides of length (a, b, c), if c is the long side facing the right angle, then  $a^2 + b^2 = c^2$

**[Quantum level](#)** A discrete level set by the laws of quantum physics, limiting the angular momentum of an atom or its energy to certain well-defined values. In-between values are not allowed.

**[Quantum physics](#)** The laws obeyed by matter on the atomic scale, involving [Planck's constant](#) and wave properties of matter.

**[Quantum tunneling.](#)** Atomic particles sometimes face a barrier which, by Newtonian mechanics, would take too much energy to cross, even though its width is limited. By [wave mechanics](#), the particle's wave has a finite (if small) value outside the barrier, too, giving the particle a finite (if small) probability of materializing there, as if it "tunneled" through. Once outside, the particle has enough energy to proceed. In 1928 this effect explained alpha-radioactivity, and it has since then been applied in the quantum physics of solid matter and elsewhere.

**Radiation** --a term used for phenomena that spread radially, especially of two:

- 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 electromagnetic radiation.
- Colloquially, an abbreviation of "**ionizing radiation**" meaning 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 balance.](#)** The condition that when the atmosphere is in equilibrium, incoming radiation must balance outgoing radiation. (Radiation balance also occurs inside stars and planets, but of course, different processes are involved.)

**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.

**Radioisotopes**--Unstable [Isotopes](#) which are [radio-active](#). They may convert spontaneously--after seconds, hours or years, depends on the type of isotope--into other elements; for instance if a neutron in their nucleus converts to a proton, plus and electron which is ejected. The process always lowers the energy of the nucleus.

Elements heavier than lead are often unstable because too many protons in their nuclei repel each other. They expel extra protons as "alpha particles", nuclei of helium--two protons and two neutrons, a very stable combination.

**[Radio waves](#)**--Electromagnetic waves of relatively low frequency.

**Reaction force** -- The added force implied by the lack of motion (equilibrium) when an applied force exists (e.g. gravity).

**Recoil** The motion of a gun in the opposite direction from the shot, a consequence of Newton's 3rd law. Readily calculated by using the conservation of momentum.

**Re-entry (atmospheric re-entry)** -- The return of a spacecraft from orbit to Earth, in which the kinetic energy of the orbital motion is converted into heat. Since that heat is sufficient to melt the spacecraft, if the spacecraft is to land intact, the heat must be safely dissipated. Heat-resistant shields of various types are used, and the reentry is at a shallow angle, to stretch out the process.

**Relativity, principle of.** A fundamental principle formulated by Einstein, that laws of physics remain unchanged when moving to any frame of reference moving at constant velocity. Newtonian mechanics by itself obeys it, but trying to accommodate electricity and magnetism as well forced far-reaching changes in the overall structure of physical laws, including the concept of time.

**Retrograde motion** -- Temporary reversal of the apparent motion of a planet along the ecliptic. Caused because (by Kepler's 3rd law) a planet moves faster the closer it is to the Sun, so that (for instance) Jupiter appears to move backward when the faster-moving Earth overtakes it.

**Right angle** -- The angle formed when two straight lines intersect and the 4 angles at their crossing are all equal. When measured in degrees it equals  $90^\circ$ .

**Right ascension and declination** -- Two angles marking the position of a star on the celestial sphere. Imagine a line from the observer to the star, and draw its projection (like a shadow) onto the celestial equator. Declination  $\delta$  is the angle between the line and its projection ( $\delta = 90^\circ - \theta$ , where  $\theta$  is the angle to the direction to the celestial pole); it is negative south of the equator. RA is the angle between the projection and the direction to the **vernal equinox** or **first point in Aries**.

**Ritz principle** The observation that pairs of frequencies of atomic energy levels often have the same difference, to great precision. That was an early clue to the existence of atomic energy levels. It ultimately allowed representing a great number of spectral lines by a much smaller number of energy levels, also tracing which jumps between levels were allowed and which were not.

**Rocket** -- A device shooting out a fast jet of gas, in order to produce a force in the opposite direction. See **center of gravity**, also **Newton's laws of motion** in Mach's formulation.

**Rosby wave.** A large-scale north-south wave in the overall **westerly global air flow** at middle latitudes. It helps spread the cooling of the atmosphere and thus is one of the drivers of global weather.

**Rotation axis of the Earth** -- The imaginary line around which the Earth turns. Its inclination of about  $23.5^\circ$  to the ecliptic is the reason for the seasons of the year.

**Rydberg constant** A constant appearing in [Balmer's formula](#), first explained by the [Bohr model](#) of the hydrogen atom.

**Saturn V** -- The biggest rocket built to date, weighing 2700 tons fully loaded. It was used to launch NASA's Moon mission and the Skylab space station.

**Second law of thermodynamics** -- A fundamental law of energy exchange, one of whose formulations is "no process is possible whose only net effect is the flow of heat from a cold body to a hot one." A consequence of this is that in any system only part of the heat energy can be converted to other forms; the rest of the heat flows to lower temperature.

**Semimajor axis** -- a property of an ellipse, equal to half its greatest width, as measured along the line connecting its two foci. The semi-major axis of an orbital ellipse is one of the "orbital elements" characterizing it, and is directly related to the energy of the motion.

**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 a magnetic or solid obstacle.

**Sidereal day** The true period of rotation of the Earth, about 4 minutes shorter than 24 hours. The **mean solar day** is the average time from noon to noon, between two southward passages of the Sun in the sky, but during that time the Sun's position relative to the stars changes, too. If we were to measure a day between two southward passages of some star ("sidus"=star), we would get a sidereal day.

**Sodium spectrum** The sodium atom is somewhat similar to that of hydrogen. Its spectrum has similarity to [that of hydrogen](#), but with a more general scheme of energy levels.

**Solar activity** A general term for those processes and changes on the Sun that rise and fall with the sunspot cycle, e.g. flares.

**Solar cycle** (or sunspot 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.

**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 wind** -- A fast outflow of hot gas in all directions from the upper atmosphere of the Sun ("solar corona"), which is too hot to allow the Sun's gravity to hold on to its gas. Its composition matches that of the Sun's atmosphere (mostly hydrogen) and its typical velocity is 400 km/sec, covering the distance from Sun to Earth in 4-5 days. The solar wind confines the Earth's magnetic field inside a cavity known as the **magnetosphere** and supplies energy to phenomena in the magnetosphere such as polar aurora ("northern lights") and magnetic storms.

**Solid fueled rockets** -- Rockets which burn a solid mixture of fuel and

oxidizer, and have no separation between combustion chamber and fuel reservoir. Gunpowder is such a mixture and was the earliest rocket fuel. They are somewhat less efficient than the best liquid fuel rockets, but are preferred for military use because they need no lengthy preparation and are easily stored in ready-to-fly condition. They are also used in auxiliary rockets that help heavily loaded liquid-fuel rockets (Space Shuttle, Delta) lift off and go through the first stage of their flight.

**Solstice** -- The time of the year when the Sun's position in the sky is most distant from the celestial equator. To a good approximation, north of the equator the day (around June 21) and the night (around December 21) are at their longest at the summer and winter solstices, and that is when those seasons are assumed to begin (the dates themselves, however, are known as midsummer day and midwinter day, respectively). Summer north of the equator coincides with winter south of it (and vice versa), and solstice names are also interchanged there.

**South** The direction at middle latitudes in the northern hemisphere, to where the Sun is at noon, when its [elevation](#) above the horizon is largest.

**Space Station** A habitable orbiting structure with a rotating crew and regular resupply.

**Spectral line** A narrow range of spectral color, emitted (or absorbed) by a specific atom (or molecule). The energy of its photon corresponds to the difference between two energy levels of the atom, and such photons are emitted when the atom "falls" from the higher level to the lower one.

**Spectrum** In the original meaning, the spread of colors seen in the rainbow, covering all pure colors the eye can see. **Spectrum of a substance**, e.g. of an atomic element, is the collection of [spectral lines](#) emitted by it.

**Spin of an electron**, intrinsic angular momentum of an electron, affecting energy levels of atoms and such phenomena as the ordering of elements in the periodic table. To explain spin, the electron was originally viewed as a spinning sphere, which also seemed to explain why the electron was magnetized in the same direction. The numbers did not fit, however, and later Dirac explained spin using relativity. Protons and neutrons also have a (much smaller) spin; proton spin in medicine is the basis of magnetic resonance imaging.

**Sputnik ("satellite")** -- The first artificial Earth satellite, orbited by the Soviet Union on October 7, 1957, using Korolev's R-7 rocket.

**Staging of a rocket** -- The placing of smaller rockets on top of larger ones, increasing the lifting ability of the combined set-up.

**Stellar evolution** (stellar=of a star). The different phases in the lifetime of a star, from its formation out of gas and dust, to the time after its nuclear fuel is exhausted. Based on observations of stars at various stages of their evolution, astronomers have developed a general theory of stellar evolution, by which the Sun is a typical "main sequence" star, in the middle of its evolutionary lifespan

**Stratosphere** The layer of the atmosphere above the troposphere. In the [troposphere](#) temperature decreases fairly rapidly with increasing altitude, in the stratosphere it changes only slowly--approximately constant at the lower edge (10-16 kilometers), rising moderately at 25-40 km due to heating by

ultra-violet sunlight, which is absorbed there by [ozone](#). The difference arises because in the troposphere, heat is carried away from the Earth mainly by up-and-down flows associated with [convection](#), in the stratosphere heat is radiated outwards, with little flow motion.

[Sundial](#) -- A device for telling time of day by the shadow which sunlight produces on the instrument. See [gnomon](#).

[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.

[Supernova](#) (More accurately, type II supernova.) When a star burns up all its fuel, it collapses and the released gravitational energy blows off its top layers, creating a supernova explosion. What remains of the star depends on its mass. Low-mass stars crush their atoms and become **white dwarfs**, about as big as Earth. High mass stars collapse into [black holes](#) whose gravity prevents any light from escaping. Stars with masses between those extremes collapse into [neutron stars](#), consisting of extreme dense nuclear matter held together by gravity and nuclear force, with a radius of the order of 10 km.

[Sweepback](#)--the angle by which the wing of an airplane is swept back, measured from the direction perpendicular to the fuselage.

[Synchronous orbit](#) -- The circular orbit above the equator at a distance of 6.6 Earth radii, in which a spacecraft has an orbital period of 24 hours. Such satellites stay above the same spot on Earth and are therefore ideally suited for transmitting communications and broadcasts.

[Synodic period](#). The time it takes for a planet until it returns to the same position relative to the Earth.

[Thermodynamics](#) The branch of physical science dealing with conversion of energy from one form to another, especially involving heat.

[Thrust](#)--the force acting on a rocket or an airplane, produced by the action of its motor and pulling it forward. In an airplane, thrust is one of the four forces sensed by an airplane, the others being [lift](#), [drag](#) and [weight](#)

**Thunderstorm** An atmospheric process involving particularly vigorous [convection](#) of humid, warm air. Such air stores energy not just as heat but also through its humidity, and as it rises and gets rid of its water by producing rain, the latter form of energy gives it extra heating and helps it rise even higher, to the base of the stratosphere, where the thunderstorm flattens out. As the rising air cools, some droplets freeze, and collision of frozen droplets carried in the rising air with larger ones dropping due to gravity leads to [lightning](#).

[Tilt-wing airplane](#). An airplane whose wings are pivoted around an axis perpendicular to the direction of flight, allowing one wing to be swept forward and the other backward. An idea studied by NASA but shelved because it made control of flight too difficult.

[Time--local and universal](#) Most of the world's inhabitants use their own **local time**, adjusted so that noon is approximately the time when the Sun is the farthest from the horizon (for that day).

**Universal time** (UT) is a world-wide measure of time, the same everywhere; a common scheme is based on the time at the meridian of zero longitude in Greenwich, at the edge of London, England (it is also called Greenwich Mean Time or GMT; astronomers may define UT differently). UT is used to give the times of world-wide events--earthquakes, magnetic storms, planetary encounters by spacecraft, etc.

**Time zones** For convenience, [local time](#) in most countries is defined to have the same value in a broad strip, typically 15 degrees wide in longitude (which averages a range of 1 hour in "precisely" defined local time). Some countries define local time to be the same everywhere in the country.

**Trade winds**. Global winds circling the globe at low latitudes, e.g. in the central Atlantic Ocean. Sailing ships used them to travel west, later using the westerlies further poleward for the trip home.

**Transit of Venus** . The passage of Venus in front of the Sun's disk. This rare astronomical event (transits occur in pairs, more than a century apart) was proposed by Edmond Halley as the basis of a method of measuring the [astronomical unit](#).

**Trigonometry** Study of triangles (trigon=triangle), in particular of applications using [trigonometric functions](#) to reconstruct triangles if only some of their sides and/or angles are known. It is the foundation of land surveys.

**Trigonometric functions** Originally, the names given to the 6 possible ratios between pairs of sides in a right-angled triangle (sine, cosine, tangent, cotangent, secant, cosecant). Usually the triangle is drawn with resting on one of its shorter sides, and these functions are viewed as depending on the bottom acute angle (angle smaller than 90 degrees). Later the definitions were extended for any angle, using the [unit circle](#). Though initially introduced as a tool of land-surveying, today trigonometric functions play a key role in many areas of mathematics.

**Trigonometric identities** Relations between trigonometric function which hold for any angle. **For instance**, if  $U^2$  means U squared, for any angle A the identity  $(\sin A)^2 + (\cos A)^2 = 1$  . For other identities, [see here](#)

**Tropic of Cancer** The line of **northern** latitude  $23.5^\circ$ , north of which the Sun is never at zenith on any day of the year. The "tropical zone," where Earth receives the highest rate of solar heating, is between the tropic of cancer and the tropic of Capricorn (below).

**Tropic of Capricorn**. The line of **southern** latitude  $23.5^\circ$ , south of which the Sun is never at zenith.

**Troposphere** The lowest layer of the atmosphere, in which weather processes take place. See [stratosphere](#).

**True anomaly** The polar angle of an object in a Kepler orbit, measured from in the orbital plane from the position at closest approach. See [mean anomaly](#), also [orbital elements](#).

**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.

**Unit Circle** A circle of radius=1 around the origin of (x,y) coordinates, used for extending the definition of [trigonometric functions](#) to angles larger than 90 degrees.

**Unit vector** A vector of unit length. Vectors have both magnitude and direction, but in some calculations it is convenient to separate the two. Denoting vector by an underline, a vector  $\underline{V}$  can be represented by two factors multiplying each other, a unit vector  $\underline{V}_u$  giving just the direction, and a magnitude  $V$ , i.e., the vector is  $\underline{V} = \underline{V}_u V$ .

**Urca process** In the final rapid collapse of a supernova, the energy release causes nuclear reactions. Most of the energy then does not produce heating, but is instead drained away as neutrinos. Heat would have counteracted the star's collapse, but the "Urca process" by which the energy is drained away allows it to proceed very rapidly. It is therefore responsible for the supernova "explosion."

**V2** -- Abbreviation of "Vergeltungswaffe 2" (vengeance weapon 2), a 12-ton German rocket carrying a 1-ton explosive charge, used in World War II, starting in 1944. The V2 had a range of around 200 miles, used a liquid-fuel rocket and was the first large military rocket. [Click here](#) for a calculated example involving the acceleration of the V2.

**Van de Graaff generator** A machine for creating voltages up to several million volts. Electric charge is sprayed onto a rubber band, which carries it into the inside of a metal sphere, insulated from the ground, where it is picked up and added to the charge already on the sphere. The energy invested by the band, overcoming the electrical repulsion of charges already on the sphere provides the energy for creating the high voltage.

**Vector** -- A quantity having both magnitude and direction, e.g. displacement, velocity, acceleration and force. Vectors are added when, for instance, one moves in a frame that itself is moving too (e.g. swims across a flowing river). Vectors are added like arrows, end to end, and the sum (for two) is the vector from the tail of the first vector to the tip of the second.

**Vector resolution**--The representation of a given vector as the sum of vectors in given directions. See [component](#)

**Velocity** -- Rate of position change, a **vector** quantity.

**Velocity, escape** The velocity needed to escape the gravity of a planet or other celestial body. The escape velocity from Earth is 11.3 km/sec.

**Venus transit** See [Transit of Venus](#)

**Vernal equinox** -- The **equinox** which starts spring north of the equator. The term is also used for the point occupied by the Sun at that time, one of the two intersections on the celestial sphere, between the ecliptic and the celestial equator. Also known as **first point in Aries**.

**Watt** -- Unit of **power**, the rate at which energy is supplied. One watt is the power which supplies 1 joule per second, 1 kilowatt = 1000 watts. A grown human climbing stairs (e.g.) supplies about 100 watt; 1 horsepower = 736 watt. Named for James Watt, inventor of the modern steam engine.

**Wave** A disturbance spreading in space, obeying a certain "wave equation." Sound waves, ocean waves and [electromagnetic waves](#) are some of the examples; other, more complicated types of waves can spread in [plasmas](#).

**Wavelength** (Often denoted by  $\lambda$ , the Greek letter lambda.) The distance between two crests of a propagating wave of a single frequency  $\nu$ . If  $v$  is the velocity at which the wave advances,  $v = \lambda \nu$

**Wave number** A term used for the inverse of the wavelength, i.e. for  $1/\lambda$

**Weather** General name for processes in the atmosphere--winds, rain, thunderstorms etc.--driven by the heating of Earth by sunshine. That heat has to be returned to space, and weather processes are the result. See [troposphere](#) and [stratosphere](#).

**Wave mechanics.** The mechanics of atoms and combination of atoms, handling them not as point particles (as in Newtonian mechanics) but as represented by waves in space, obeying quantum rules.

**Weight** -- The force exerted on mass by gravity.

**Weightlessness** (or "zero g") the condition when no force (such as weight) is sensed. Occurs in orbit or free fall, when gravity already produces its full acceleration and can produce no further effect.

**Westerlies.** The global winds at middle latitudes, from west to east. The westerlies are the reason why weather patterns in the US often migrate from west to east. See [jet stream](#).

**Work** -- The overcoming of a resisting force over a distance. The work performed when a force  $F$  overcomes an equal resisting force along a distance  $x$  in the same direction equals  $Fx$ , i.e.  $F$  times  $x$ .

If the force is not in the direction of the motion, only the vector component of  $F$  in that direction enters the calculation.

Energy can be defined as the ability to perform work.

**X-1** -- A rocket-powered research airplane, the first to fly faster than sound, on 14 October 1947.

**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.

**Zeeman effect** The splitting of the frequency of light emitted by atoms, when the emission occurs in a strong magnetic field, into two or more closely spaced frequencies. The Zeeman effect of light from sunspots gave in 1908 the first clue that these regions were intensely magnetized.

**Zenial day** Day of the year when the noontime Sun is exactly overhead. Happens only in the tropics (between the [tropic of cancer](#) and the [tropic of capricorn](#), twice each year.

**Zodiac** -- Twelve constellations dividing the **ecliptic** into approximately equal parts. Each month the Sun is in a different constellation of the zodiac.

Author and Curator: *[Dr. David P. Stern](#)*

Mail to Dr.Stern: [stargaze\("at" symbol\)phy6.org](mailto:stargaze@phy6.org) .

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